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[COMMITTEE PRINT]

GENETIC ENGINEERING, HUMAN GENETICS,
AND CELL BIOLOGY

EVOLUTION OF TECHNOLOGICAL ISSUES

DNA RECOMBINANT MOLECULE RESEARCH

(SUPPLEMENTAL REPORT II)

DOCUMENTS

REPORT

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SUBCOMMITTEE ON SCIENCE, RESEARCH
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OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
NINETY-FOURTH CONGRESS

SECOND SESSION

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, D.C., December 18, 1976.

HON. OLIN E. TEAGUE,
Chairman, Committee on Science and Technology, U.S. House of Representatives, Washington, D.C.

DEAR MR. CHAIRMAN: I am transmitting herewith a report dealing with the current circumstances surrounding research into genetic engineering, human genetics, and cell biology. This report was requested as a supplement to the studies performed in 1972 and 1974 entitled "Genetic Engineering: Evolution of a Technological Issue," including a first Supplemental Report of the same title.

This second supplemental report deals specifically with DNA recombinant molecule research, a field which is now receiving much public attention. The report is especially timely and of particular significance in view of the issues raised by the recent developments in this field, and I commend the report to you and all Members of the Committee. It is my hope that the Committee will consider holding hearings on this important area during the next Congress.

Sincerely,

JAMES W. SYMINGTON, *Chairman,*
Subcommittee on Science, Research and Technology.

(III)

REPORT ON THE PROGRESS OF THE WORK

The work of the Committee has been carried out in accordance with the programme of work approved by the Council at its meeting on 15th November 1961. The Committee has held four meetings, and has received reports from the various working parties. The progress of the work has been satisfactory, and the Committee has been able to complete the work assigned to it. The results of the work are set out in the following sections of the report.

The first section of the report deals with the work of the working parties. The working parties have been set up to study the various aspects of the problem, and to report to the Committee on their findings. The working parties have held a number of meetings, and have produced a number of reports. The Committee has received these reports, and has discussed them at its meetings. The Committee has been able to complete the work assigned to the working parties, and has been able to produce a number of recommendations.

The second section of the report deals with the work of the Committee. The Committee has held four meetings, and has received reports from the various working parties. The Committee has been able to complete the work assigned to it, and has been able to produce a number of recommendations. The Committee has also been able to complete the work assigned to it, and has been able to produce a number of recommendations.

The third section of the report deals with the work of the Council. The Council has held a number of meetings, and has received reports from the various working parties. The Council has been able to complete the work assigned to it, and has been able to produce a number of recommendations. The Council has also been able to complete the work assigned to it, and has been able to produce a number of recommendations.

Approved by the Council on 15th November 1961.
Secretary, Research and Technology.
(Sd/-)

LETTER OF SUBMITTAL

THE LIBRARY OF CONGRESS,
CONGRESSIONAL RESEARCH SERVICE,
Washington, D.C., December 17, 1976

HON. JAMES SYMINGTON,
*Chairman, Subcommittee on Science, Research and Technology, Com-
mittee on Science and Technology, U.S. House of Representa-
tives, Washington, D.C.*

DEAR MR. SYMINGTON: I am pleased to transmit this report entitled "Genetic Engineering, Human Genetics, and Cell Biology: Evolution of Technological Issues-Supplemental Report II" prepared at your request.

The study examines the developments associated with the controversial subject of DNA recombinant molecule research, a rapidly advancing research field in molecular biology supportive of progress in plant and animal genetics. This research field has produced national and international interest as a case history study of the emerging problem of public participation in science policy and the legal, ethical, and moral implications of an expanded role of the public in planning and applying scientific research. The study is intended to supplement earlier committee reports on this subject by providing an analysis of activities, with emphasis on DNA recombinant molecule research, which have taken place since 1974.

The committee print was prepared by Dr. James M. McCullough, our Senior Specialist in Life Sciences, Science Policy Research Division, Congressional Research Service. Dr. McCullough consulted with a number of investigators during the preparation of this report. We would like to acknowledge at this time the very helpful advice and constructive criticism offered by Dr. Joshua Lederberg, Department of Genetics, Stanford Medical School; Dr. Bernard D. Davis, Bacterial Physiology Unit, Harvard University; Dr. Richard Trumbull, Executive Director, American Institute of Biological Sciences; Dr. Robert Acker, Executive Director, American Society For Microbiology, and Dr. Bernard Talbot, Office of the Director, National Institutes of Health, although the final responsibility rests with the author and the Congressional Research Service. Mr. Douglas Paynter, Information Resources Assistant, Library Services Division, Congressional Research Service, provided research assistance, and manuscript preparation was performed by Ms. Sandra Kay Al-Nazer and Ms. Jeannette E. Porter, Editorial Assistants, Science Policy Research Division. This study was coordinated with and reviewed by Mr. Philip B. Yeager, and Dr. Gail M. Pesyna, professional staff members of the Subcommittee on Science, Research, and Technology.

We appreciate this opportunity for the Congressional Research Service to cooperate in this study of a subject of such far reaching and serious social significance.

Sincerely,

LEON M. COLE,
Acting Director

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I. INTRODUCTION

A. PURPOSE

Nobel Laureate James Watson chose the topic of cloning and genetic engineering as the theme of his address to the House Science and Astronautics Committee [now the House Science and Technology Committee] in 1971.¹ His intention was to direct the committee's attention to the capabilities in molecular biology and genetics which those in the forefront of molecular biology research knew were near. Partly as a result of his remarks, the committee directed the preparation of a study which surveyed the status of this research.² The committee's first report confirmed the need for maintaining an awareness of the issues evolving in the technologies of genetic research. A second report³ indicated the accelerating pace of these developments. One of these issues in genetics has now assumed a position of urgent importance throughout the world and is receiving the attention of numerous public policy making groups. Several policies of fundamental importance in the selection, management and application of this new technology are now considered of sufficient urgency that congressional attention seems necessary.

Biomedical research has entered a new era of public concern. The recipients of the results of modern medicine have been accustomed to accepting the benefits of developments in antibiotics, organ transplant, and new therapies and surgical techniques without question for some time. This acceptance of the "benefits" of research without full consideration of the costs has been called into question in increasing numbers of instances within the past decade. With the advent of organ transplantation techniques the realization arose, partially as a result of a sensitivity to the unique position of both the donor and recipient, of the associated moral, legal and ethical implications of such biomedical techniques. The growing awareness of the public to the risks associated with the development of new drugs focused attention on the use of experimental human subjects for evaluating such drugs. The refined techniques for examination and treatment of the developing fetus aroused concern, partially because of its close association with abortion as another public policy issue, and legislators acted to introduce control in this area of research.

Now, scientists have shown that they possess the tools to begin controlled manipulation of the very foundation of life itself. It is pos-

¹ Panel on Science and Technology. Twelfth Meeting. International Science Policy. Proceedings Before the Committee on Science and Astronautics. U.S. House of Representatives. 93d Congress, 1st session. January 26, 27, and 28, 1971: 336-366.

² U.S. Congress. House. Committee on Science and Astronautics. Subcommittee on Science, Research, and Development. Genetic Engineering: Evolution of a Technological Issue. [Washington, U.S. Govt. Print. Off.] 1972. 119 p. (92d Congress, 2d session)

³ U.S. Congress. House. Committee on Science and Astronautics. Subcommittee on Science, Research, and Development. Genetic Engineering: Evolution of a Technological Issue. Supplemental Report I. [Washington, U.S. Govt. Print. Off.] December 1974. 215 p. (93d Congress, 2d session. House).

sible to determine accurately the sex of the developing fetus, to ascertain in utero whether the fetus possesses genetically induced abnormalities of many types, and to provide reasonably accurate guidance to prospective parents about the probabilities of bearing defective children. It is becoming obvious that these capabilities, supported by continuing research, are nearer to general application than had been anticipated only a few years ago.

It is the purpose of this report to provide a current perspective of one of these capabilities in genetics—the capability to effect “genetic engineering.” The popular term “genetic engineering,” while having many interpretations, is gradually being associated more specifically with man’s capability to reconstruct the basic substances determining the heredity of an organism (the DNA). This type of research, known as *DNA recombinant molecule research*, offers the prospect of eventually being able to control or change the genetic information inherited by an organism. The developments in molecular biology or “genetic engineering” are of particular importance because of the rapidity with which these new capabilities are evolving and also because of potential risks being perceived by the public as associated with such research. The progress in medical genetics and related issues in cell fertilization and cell culture techniques as well as the status of fetal research provide a continuum in genetics research which produces related public policy issues. These issues will be examined in detail in a later committee report.

There has been vigorous “public” response to the new developments in genetics. In some instances, the response has been careful and conservative and based upon the best information available. In other instances, questions have been raised about the adequacy of societal involvement in the process of making decisions about the application of such new techniques in the conduct of research. The need for legislation to provide for more adequate public participation and to interpose regulations is growing as an issue of congressional concern.

Although “more public participation” is voiced as a major factor of concern in consideration of issues of the type discussed herein, it should be noted that this factor itself is difficult to define or to secure simply. Public participation has many meanings depending upon a particular situation or problem. It might mean representation as in the political sense; it may refer to specific public interest groups; it may refer to an “adequate representation” of informed, noninvolved (researchers not in the field of interest) individuals or individuals with unique capabilities; or groups representing other fields of expertise such as ethics or law. “Public participation” on scientific issues requires informed participation in order to be meaningful, and an associated implication is that such participation will be of a type that will receive attention. The problem then becomes one of determining when the public participation is adequate for a particular problem and whether the compromises decided upon are truly attentive to societal needs. “Public participation” is an issue that increasingly, as with legal and moral issues, will require careful evaluation. This is one of the reasons that the DNA recombinant issue is of such interest as a case history opportunity to explore participatory decision making at an

early stage of research. There are, of course, many other factors involved in the DNA issue which makes it important in terms of the establishment of new concepts of public policy determination.

This report will be directed at an analysis of developments in genetic engineering, and primarily DNA recombinant molecule research, since 1974 which appear to have a particular significance at this time in terms of issues of immediate potential interest to the Congress. It is impossible in any single paper to provide the detail on these subjects required by investigators in the field, nor would such detail be desirable for the use of congressional policy makers who have limited time to become familiar with issues of concern. Wherever possible, additional citations will be given for additional readings or for further information on summary statements of particular concern. It is hoped that this second supplemental report will be sufficiently detailed to provide the basis for any additional evaluations the committee may desire to initiate. The developments in all of the areas of genetics of potential interest are so rapid that it is almost impossible to insure absolute continuity and it will be necessary for the reader to maintain a sensitivity to these subjects so that new discussions may be fitted into a proper perspective. It is for this reason that this second supplemental report is limited primarily to the new knowledge in genetic engineering. However, comments to the committee about any of the topics in genetics are welcome at any time so that the committee members may be made aware of particular issues of concern which may not have been adequately addressed in this report. The reader also is invited to examine the 1972 and 1974 committee reports on subjects or citations to earlier reference material for recommended background information.⁴

B. BACKGROUND OF THE ISSUES

In the short interval between the publication of the earlier committee reports and this second supplemental report, the advances in genetic research have been remarkable. In some areas, the rate of progress has far exceeded the time estimates provided in the earlier reports. In other areas, while the estimates of potential application still indicate no immediate or near term application to human problems, the applications in plants and animals of agricultural or other commercial importance appear to be even closer.

As noted in the earlier reports, there is a full spectrum of related and overlapping scientific work leading from the fundamental work in molecular biology which lends increasing credence to the predictions of actual "genetic engineering" and to the almost routine use of complex diagnostic techniques in medical genetics.

Historically, and in the perspective of the formal study of man, the developments in genetics have proceeded in an uneven fashion. For example, as noted in a recent article, 1976 marks the tricentennial of the discovery of human sperm.⁵ Most persons are at least vaguely familiar with the developments which led to Anton van Leeuwenhoek's

⁴ Ibid.

⁵ Brody, Jane E. 1976 Marks Tricentennial of the Discovery of Sperm. New York Times, December 1975: 29.

discovery of the microscope. Among his other observations, he reported to the Royal Society in London in 1677 the discovery of human sperm by a medical student who used this new scientific device. As reported in the 1972 committee report, the works of Gregor Mendel on fundamental principles of heredity were not accepted with a full understanding of their significance when reported in 1865. It was not until 1956 that a final accurate determination of the human chromosome number (46) was established and from this point on certain genetically determined diseases could be positively correlated with additions or deletions from this "normal" number.

The most recent discoveries in genetics have been of special interest because there has been an increased awareness of the social as well as the scientific significance of this area of research. The deepest of human emotions can be touched by the birth of a genetically defective child; the guilt of a parent furnished with the knowledge that the defect had been transmitted is particularly acute. The tremendously complex issues of abortion and "right-to-life" are now interwoven with the availability of techniques to detect prenatally a number of dangerous genetic diseases and modern medicine offers abortion of such defective fetuses as an alternative to a life of suffering for both parents and child. Arguments over race and IQ, biased and complex as they may be, are further indications of the implications to society of our increased understandings of the principles of genetics.

When it is realized that it took almost 100 years after the work of Mendel to get an accurate count of the number of chromosomes in man, it is truly amazing to contemplate the developments within the last decade and exciting to view the potential of the near future. At the same time this excitement must be tempered by consideration of several complex issues. The identification in 1953 of the precise molecular structure of DNA, the information bearing substance in the chromosome (which we now know carries the determining hereditary chemicals or genes) by Watson and Crick is one of the epic discoveries in man's scientific endeavor. From their work scientists have moved on to the accumulation of discrete units of knowledge about gene function and structure. There have been developments which are leading to a detailed understanding of gene control. The coding of the biochemical messages from the DNA to the cell's structural components is being deciphered. The biochemistry of the translation of the gene code information to function is being subjected to ever intensified analysis. Chemical start and stop signals are being identified and indeed even synthesized in an operational mode. The association of genetic errors with metabolic diseases and structural abnormalities has been established.

The matching of certain components of the chromosome (DNA or deoxyribonucleic acid) with function in 1961 by Dr. Marshal Nirenberg settled another important debate about the molecular biology of the gene. Years of research by hundreds of researchers can hardly be adequately summarized in a single document or even a series of reports no matter how voluminous. Nevertheless, as will be noted it is becoming increasingly essential that an effort be made to gain sufficient understanding to deal intelligently with these subjects.

The limitations of diet, drugs, or enzyme therapy to correct the effects of genetic defects have led to interest in the possibility of correcting the problem at the level of the gene. The problems with cancers which are suspected of being associated with gene control abnormalities have produced an interest in developing tools to study the molecule at the most basic level. The evidence suggesting that cancer viruses may become a part of normal cellular DNA has focused research attention on the systems of transfer of DNAs between cells. All of these efforts are intimately related to the research in genetic engineering.

Modern human genetics has been described as now providing social choices for our future where previously there were no choices. A significant political issue is to determine whether such choices should be made available and if so how the essential factors can be identified to provide reasonable assurance that the proper choicees are made (and by whom and under what circumstances and constraints).

Platt said:

It is no longer enough to go on working in the labs just to build another brick in the temple of science, hoping it will fit into some great intellectual synthesis in 30 years. Nor is it enough to be politically concerned, working by circulating petitions or trying to influence the government in some 3 month crisis.

Our urgent social problems now are more like war-time problems, such as anti-submarine warfare or the development of atomic energy. These are cases where we must get different experts and inventive minds together to make interdisciplinary operations-analysis and action-oriented designs and pilot studies, but where the time scale is that of a crash program, permitting, say, a few months or a year or two of study before we must come up with some much more effective solutions.⁶

While Platt was not referring only to research in genetics, nor even specifically to the precise problems to be discussed in this report, his concern is still appropriate. It can be interpreted to mean that *science policy* problems require the urgent analysis, not the science research needs. Indeed, in the context of genetic engineering and related genetics problems in some areas, there are those who have examined this problem and ask whether the rush to expand the fields of research should not be preceded by a more complete analysis of the public policy implications of such research. In this regard, Francoeur highlighted some of the observations made by others about new technological developments.⁷ Perhaps there is a need for a mechanism to represent those advocating a selected legal moratorium on some research and application. This approach would be difficult of course. Which areas of research should be identified as "off-bounds"? What kinds of laws need to be formulated, passed, and policed universally without bias? What would really happen in terms of the prevention of harm or prolongation of the achievement of benefits? How could we move into the off-bounds research areas without new legal knowledge to deal with such unknowns? Would such actions drive research underground and out of sight of public policy examination and control?

There are historical precedents for this latter action and even today there is frequent discussion that national actions may simply result on

⁶ Platt, John. The Scientific Urgencies of the Next Ten Years. Michigan Mental Health Research Bulletin. v. 4. 1970: 12.

⁷ Francoeur, Robert T. We Can—We Must: Reflections On the Technological Imperative. Theological Studies. v. 38. September 1972: 428-439.

occasion in the transfer of research with potential commercial value into other nations where prohibitions do not exist. Could such actions result in the need for the establishment of a "deep freeze" information bank with some social judgment process determining when such information could be released for technological application? If so, who decides? What value judgments should be used? There are implications in his thesis which bear further examination, for to some, public control appears to offer a viable and effective solution to the new public policy issues produced by many technological innovations. Controls would establish a public recognition of the scientist's drive to inquire and produce new knowledge. The dissemination of new knowledge by modern communication methods promotes developments on an international level. With controls, there could be a continual testing and evaluation of the implications of the innovations before new steps take society beyond the point of no-return.

Lappé discusses some of these issues more specifically in terms of several of the arguments which evolved in genetics.⁸ Crotty pursues the thesis of public involvement in the scientific decision making process.⁹

He asks the same question being asked in an increasing number of congressional discussions. To what extent are the "people" really sharing in decision making? Is there really a full exchange of information? Are scientists really willing to accept the intercedence of the public in the examination of the worth of their research? Crotty believes that in the field of genetic engineering policy analysis there is a need to differentiate between those developments which might have a genuine and easily identified therapeutic use as contrasted with the research for which there is no immediate therapeutic development. It is his opinion that much of the difficulty in this particular issue arises from the problem of evaluating the worth of the non-therapeutic research.

These few introductory comments are intended to serve as an outline of the questioning which has been associated with the various issues discussed within this report. The issues are complex. The rate of progress is rapid. If developments in this area are not to be treated as was the case in the nuclear energy issue, until after the appearance of the technology and the investments in the program, then the issues must be confronted very soon. It is essential that the true significance of the research, particularly in genetic engineering, be fully appreciated, so that the necessary attention may be focused on policy determination. Oliver Smithies, Professor of Genetics and Medical Genetics at the University of Wisconsin, put this new work in these terms:

In my opinion, the ability to clone DNA fragments from higher organisms represents one of the most significant advances of 20th century biology. The procedures combine the ability to purify genetic material to homogeneity with the ability to replicate the material in virtually unlimited quantities.¹⁰

⁸ Lappe, Marc. Moral Obligations and the Fallacies of Genetic Control. *Theological Studies*. v. 33. September 1972: 411-427.

⁹ Crotty, Nicholas. The Technological Imperative: Reflection on Reflections. *Theological Studies*. v. 33. September 1972: 440-449.

¹⁰ Smithies, Oliver. Letter to Dr. DeWitt Stetten, Jr. Deputy Director for Science. National Institutes of Health. [Letter written in response to a request for evaluation of proposed guidelines for DNA recombinant molecule research.] November 26, 1976.

II. DEVELOPMENTS IN GENETIC ENGINEERING

A. A SUMMARY OF THE STATUS OF DNA RECOMBINANT MOLECULE RESEARCH

1. *Introduction.*—DNA recombinant molecule research is quite diverse and dependent upon a relatively high level of technological capability at the research stage. (The practice of the technology, once protocols are established, requires a lower level of ability. Some commentators have suggested that even undergraduate students could complete the work.) The work is conducted beyond the range of normal visibility, and with the exception of the studies with electron microscopic techniques, dependent upon delicate tests, analysis, and determination of biochemical functions. The investigator tries to isolate and purify extremely small quantities of very complex molecules and is required to utilize exquisite techniques to test the models hypothesized and ascertain the validity of his conceptions.

When an investigator reports the isolation of a particular gene fragment, he is usually dependent upon his experimental methodology to confirm or deny his interpretations. Occasionally, growth or the failure to grow can be utilized as evidence. That is, if a particular molecular fragment is isolated, the determination of the functions produced by this fragment are frequently the first proof that the fragment is indeed present in the system under study. Further proof is obtained by carefully induced reactions involving immunological tests, other biochemical tests or analyses which have evolved for the purpose of characterizing the chemical nature of a molecule, the utilization of theory to construct possible molecular structures, and often the use of other chemical-physical processes including electron microscopy, to support his experimental hypotheses.

This discussion is an oversimplification of the various cross-checking and replication experiments which the thorough scientist conducts to confirm or deny the validity of his results. The important point for purposes of this report is to understand that the geneticist or biochemist/molecular biologist is working on a scale of size frequently demanding the use of techniques to acquire indirect evidence of experimental results. These results must then be evaluated with various other methodologies to support and confirm the interpretation. This type of work is tedious and definitely demanding of a high degree of care and precision to avoid inadvertent contamination and to produce quality data.

An entirely new vocabulary has evolved with this new research. A system of code names for variants of various microorganisms, fragments of microorganisms, viruses of various types, and terminology for the precise enzymes used for synthesis and cutting of large molecules, makes the task of understanding the significance of the scientific reports on developments extremely difficult for the non-specialist. Such

a new language is common to all of the highly specialized fields of endeavor. In space, electronics warfare, psychology and business, the specialist develops and uses a language which permits communication quickly and accurately with his colleagues. It is the new language which is used to describe the research in DNA recombinant molecule research, as well as the complexity of the biochemical reactions involved, which often obscures the significance of these developments from the concerned lay person. Nevertheless, to the credit of the biochemists, geneticists, molecular biologists, microbiologists and others who are conducting this research, a very real effort has been made, from the very beginning of the search for guidelines to control research, to explain to the non-scientific public, the nature and great importance of this new field of investigation.

However, it should be recognized that the scientists who conduct this research are under intense pressure to carry out their chosen tasks. They are research investigators as well as concerned individuals. Their immersion in their work often makes them unaware of the difficulty that lay persons have in understanding the complexities of their work. As an example, several of these investigators, while at a public meeting, had just spent some time discussing the various problems associated with the certification of a newly developed vector. A precise transcript of their discussion would be almost totally unintelligible to the casual observer and yet these scientists had been discussing the research on the very issue of risk about which so much public concern has been expressed. There was little obvious awareness, during the intensity of the discussion, that the lay members of the committee and the observing public were "at sea" with regard to the technical details of the biological processes being examined. This same scientific group, moments later, expressed amusement at the unintelligible "jargon" which lawyers used to discuss patent problems of law associated with these new DNA recombinant developments.

It is obvious that a high degree of public visibility must be given to DNA recombinant molecule work if there is to be informed citizen participation in the determination of policies on this research. This committee report has as one of its objectives, an attempt to provide one more source of information to assist national policy makers to understand the critical nature of the work as well as to provide sufficient information to evaluate the risk/benefit analyses which are being discussed. If this objective is to be met, through the efforts of concerned researchers, the news media, this committee report, or any other medium, it will be necessary for the non-scientist to have at least an introductory understanding of the research. This understanding, as with all new knowledge, requires a careful consideration of the meanings of the terms being used to describe the research for, as with the language of law and politics, misinterpretations easily develop if the meaning of descriptive terms is not understood fully.

2. *Some Terminology of DNA Recombinant Molecule Research:*

(a) *DNA*: The acronym DNA has evolved quite naturally from the precise chemical terminology for the molecules which constitute the inheritable material in the typical cell; this substance is known as deoxyribonucleic acid—DNA. The research of interest in this section is associated with manipulations of this basic molecule which contains the genes that regulate the characteristics and life functions of the

cell, and ultimately the entire organism in the case of a multicellular organism. The discovery of DNA, its chemical nature, and the significance of this molecule in genetics is discussed in more detail within several papers included in the appendix of this report as well as within previous committee reports on the evolution of developments in genetic engineering.¹

(b) *Recombinant Research*: The term "recombinant" refers to the fact that investigators have developed techniques to "recombine" fragments of DNA into new molecules. That is, it is now possible to chemically cut the DNA molecule apart and then to recombine various fragments or portions with some precision, into a new molecule—hence, the term recombinant molecule.

(c) *Host Cell and Biological Containment*: The term host is not new in ordinary vocabulary and in the biological science it has a similar connotation. In the case of DNA recombinant work, the term host is usually used to refer to the cell into which the recombinant molecule is introduced in order to find out if the new molecule can be reproduced or will function. The host cell may be one of the small microscopically sized bacteria or it may be another cell, or in certain types of research it may even be possible to use a totally synthetic environment, the essential chemicals in the right proportions within a test tube. It is more common to find that the host is a microorganism and at least in these early stages of recombinant work, a host has been selected for which a great deal of genetic information is already available.

The selection of the host cell for replicating (cloning or reproducing) the recombinant molecule is quite frequently a relatively "safe" variant of the bacterium known as *Escherichia coli* or *E. coli*. The "normal" strain of *E. coli* is a microorganism that is a common inhabitant of the human intestine; as an inhabitant of this environment the normal bacteria are found in enormously large numbers and perform a number of vital functions within the intestine. It is possible, however, for *E. coli* to produce serious disease in the human being if the blood stream is invaded or if other untoward events contribute to some instability in the normal floral composition of the intestine. Illnesses such as nausea and diarrhea, are quite common results of an upset in the normal intestinal activity of *E. coli*. The K-12 strain of *E. coli* used in the DNA recombinant experiments does not have this degree of pathogenicity—the pathogenic strains such as those which can produce blood infections are biochemically distinct from K-12. It is important to understand that while the DNA recombinant molecule researcher uses *E. coli* as a primary host cell for testing or multiplying the recombinant molecule which has been constructed, it is a laboratory variant of *E. coli* which is the test vehicle; a variant not commonly found in a human intestine. There are many strains of *E. coli* and some variation of strains occur normally within the intestine as a result of environmental changes induced by the use of drugs, changes in diet, or other disturbances in human activity.

It is also important to understand that the investigators using this host cell are concentrating their efforts to develop other forms of *E. coli* which have been deliberately modified to "disable" the cell still further. This is usually done by inducing mutations (by a number of

¹ U.S. Congress. House. Committee on Science and Astronautics. Supplemental Report I. op. cit.

special techniques in microbiology) which provide a cell that has very special requirements for growth and reproduction. The logic of this approach is to produce an organism which meets the needs of the laboratory investigator for a cell which will provide the environment for the multiplication or testing of his newly created recombinant molecule and yet is a host cell which could not survive in a natural environment because of its new and fastidious growth requirements. In other words, the development of such mutants is intended to insure that inadvertent escape of such a host cell containing a recombinant molecule would result either in an inability to reproduce or more likely the death of the cell. This concept is referred to as *biological containment*.

(d) *Recombinant Vectors*: While it is possible, under some chemical conditions, to introduce mixed fragments of DNA directly into a host cell, the preferred method is to incorporate the fragments of DNA into another DNA containing structure which can enter the cell with a higher degree of efficiency and with the assurance that the specific desired recombinant is indeed being incorporated. For this reason, the DNA recombinant molecule researchers have concentrated on using "vectors" to transport the DNA fragments. Again, familiarity with *E. coli* has enabled the investigator to use extranuclear DNA containing structures called plasmids which are found in bacteria. These plasmids have the capacity to be self replicating within the cytoplasm of the cell, contain DNA similar to the more typical DNA of the bacteria, but have the advantage of being smaller units susceptible to ready manipulation. As a result, attention has been concentrated on gaining knowledge about these plasmids so that these structures can be extracted from the bacteria, cut and manipulated to include new fragments of DNA. The newly constructed plasmid then can be introduced into the host cell, again usually *E. coli*, and replication of the plasmid occurs simultaneously with reproduction of the cell. After a period of reproduction of bacterial cells (perhaps a division every 20 minutes) the researcher will now have available for further test and evaluation, a sufficient quantity of the recombinant molecule to permit biochemical analysis and measurement. If the new molecule is present, then the introduced DNA fragment can be identified. Since a major objective of DNA molecular biology research is to find a technique to identify the function of specific fragments (genes) of the total DNA molecule of an organism, this recombinant technique can simplify this difficult task. By careful manipulation of the total DNA molecule of an organism, each fragment can be correlated with function, and it is hoped that eventually the location of each gene/function can be constructed for each chromosome. Because of the commonality of the biochemical nature of all DNA, regardless of the species source, it is now believed that there should be no reason why mammalian chromosomes (including man's) could not be examined fragment by fragment within recombinant molecules multiplied in bacteria or some other host cell. There are some functions which may not be expressed within the capacity of a bacterial host cell and for this reason, other host cells will eventually be included.

The American Society of Biological Chemists held a symposium on plasmids in 1975.² Attempts are being made to gain an understanding of the biological functioning of plasmids from various bacterial strains. This information is critically needed now because of the accelerating emphasis on the use of plasmids as vectors for transferring recombinant DNA molecules into bacterial cells for cloning. The plasmids provide a variety of traits and are found in numerous species. An important characteristic is the plasmid's physical separation from the chromosome as a genetic structure in the bacterial cell and its genetic stability. The availability of a wide variety of plasmids permits the study by both biochemical and physical methods (e.g. electron microscopy) of the relative structure-function relationships among plasmid elements from different bacteria.

Plasmids are known to mediate such properties as antibiotic resistance, pathogenicity for plants and animals, and ability to degrade and utilize many natural and synthetic organic substrates. Some plasmids are potential vectors for transfer of genes between bacteria in different genera. These plasmids are said to be able to cross species' barriers naturally.³ Much less is known about the function of plasmids in higher plants and animals that could be used for effective implants of genes. This area of research will require much more work before the "genetic engineering" of higher organisms can be attempted as with bacteria.

A virus is essentially a unit of DNA (or RNA—ribonucleic acid, with a chemical structure very similar to DNA) with a protein coat. For this reason, the value of viruses as vectors for carrying introduced fragments of DNA from other species is also under examination.⁴ Bacteriophages in particular are in common use. The DNA "phages", or viruses which "infect" bacteria, are relatively small units of DNA and thus the possibility of working with small fragments of DNA increases the sensitivity of the genetic/biochemical analysis which is conducted. Since viruses multiply within the bacterial host and eventually cause "lysing" or death of the host cell, the researcher can readily determine the success of his experiment by observing the growth and development of his bacterial colonies. Further, by careful selection and isolation, the identification of the functions transported by the recombinant molecule, or the hybrid phage, is analogous to the use of plasmids as vectors.

(e) *Molecular Cloning*: A clone is a population of cells derived by asexual reproduction from a single cell. The process of securing an increased quantity of the recombinant molecule by replication in a host cell is referred to as molecular cloning. [Cloning has other biological applications as noted elsewhere.] As discussed by Hamer and Thomas, this process is an important tool for purifying and increasing

² Plasmids. Symposium of the American Society of Biological Chemists. 59th Annual Meeting of the Federation of American Societies for Experimental Biology. Federation Proceedings, v. 35. July 1976: 2024-2043.

³ Saunders, J. R. Aspects of Plasmid Behavior. Report on a NATO Advanced Study Institute On the Biology Of Bacterial Plasmids. Kavouri, Athens. July 5-16, 1976. Nature, v. 262. August 12, 1976: 536.

⁴ Campbell, Allan M. How Viruses Insert Their DNA Into the DNA Of the Host Cell. Scientific American, v. 235. December 1976: 102-113.

the quantity of specific fragments of DNA. The use of new restriction enzymes is under continuing evaluation in order to increase the versatility of the technique.⁵

A recombinant molecule (via phage or plasmid vector) is incorporated into a small number of *E. coli* cells. These hybrid plasmids are replicated by the usual biological processes during the growth and division of the bacterial cell. This precise duplication (cloning) of the recombinant molecule (the new plasmid) results in a "doubling" of the number of cells as well as plasmids each time a cell reproduces. Further doubling and redoubling results in a logarithmic increase in numbers of bacterial cells until the naturally self limiting growth of cells on a single culture plate slows the growth. If desired, the culture of cells containing the recombinant molecule (plasmid) could be redistributed on new growth media and an almost unlimited quantity of cells with the new recombinant molecules could be produced. For industrial purposes, this would be the logical technique. Indeed, in the production of vaccines, this is essentially the process by which large numbers of cells (or viruses) are cultured. Since there is insufficient knowledge at this time to understand all of the potential effects of recombinant molecules in the host cell, particularly in combination and in new relative positions to other genes on the vector (plasmid or phage), the researchers have suggested that for most of these experiments there should be a limitation placed upon the total volume of cells which can be cultured for purposes of limiting the availability (and providing some safety constraints) of the new recombinant molecule [the guidelines set an upper limit of 10 liters with recombinant DNA known to make harmful products].

It can readily be understood, once this concept is grasped, how some valuable product, such as insulin, could be produced by cloning within the bacterial (or other) cell. Fragmentation and processing of the cell contents would permit concentration of the desired new product, and an important substance could be made available. This "biosynthetic" technique could, in many instances, not only provide increased quantities of essential substances but might also provide these substances in a cost effective process. In fact, some of the needed medicinals probably could not be synthesized in any other way at this time.

(f) *Prokaryote-Eukaryote Research*: One of the objectives to be determined in DNA recombinant work, as well as a further examination of the universality of DNA, is whether DNA from a major group of "primitive" cell types, the prokaryotic cell [such as bacteria or other cell types without an organized nucleus with a nuclear membrane surrounding the chromosomes] can be exchanged with the DNA of eukaryotes, those cells with a highly organized nucleus [all of the higher organisms including man]. Such research would involve the isolation of DNA fragments from eukaryotic cells and transfer of these fragments via vectors (plasmids) to the host bacterial cell and then to determine whether the eukaryotic fragment is replicated in the new cell host and, of even greater importance, to determine

⁵ Hamer, Dean H. and Charles A. Thomas, Jr. Molecular Cloning of DNA Fragments Produced by Restriction Endonucleases Sall and BamI. Proceedings of the National Academy of Sciences. v. 73. May 1976: 1537-1541. (See also: Marx, Jean L. Molecular Cloning: Powerful Tool For Studying Genes. Science. v. 191. March 19, 1976: 1160-1162).

if the function regulated by the eukaryotic fragment is performed (such as the synthesis of an enzyme). Struhl isolated a segment of DNA from the eukaryote *Saccharomyces cerevisiae* (baker's yeast) and constructed a recombinant hybrid using bacteriophage lambda DNA as a vector. When this hybrid was incorporated into a strain of *E. coli* biochemical evidence was obtained that the yeast gene was functional within the bacterium.⁶ The interpretation of the results of this experiment is that the transcription necessary for the biochemical synthesis observed was most likely initiated from the segment of yeast (eukaryotic) DNA which had been inserted into the recombinant molecule. This is a significant report of research also as it relates to the arguments concerning the question of evolution of genes from prokaryotes to eukaryotes or vice versa. It is related to studies of the question of the safety of this kind of research because of the arguments that the current DNA recombinant molecule research is creating cell hybrids which could not occur in nature. There is no full agreement that natural exchanges between such groups actually do not occur but one way of testing this theory is to continue research of this type.

The risk/benefit analysis of the new recombinant work does include a consideration of the possible acceleration of evolutionary change in various organisms. Opponents indicate that the usual environmental selection processes are being circumvented as a result of the artificial recombination efforts. For this reason, interest has been increased in the acquisition of more knowledge concerning the possible natural exchange of genetic units between diverse organisms. In a recent report,⁷ the results of a study indicate that trans-species infection might be possible through viral infection. These investigators demonstrated the presence of similar viral genes in both the pig and the rat. Since viruses are known to have the capability to pick up genes from a host and incorporate these host genes in the viral DNA, it has been speculated that natural interspecies viral infection may be a system of gene transfer in evolution. Bacterial viruses (phages) are actually used in recombinant work. In the case of natural exchange via viruses, however, the processes of selection may require millions of years while in recombinant work, only the manpower of the laboratory limits the rate at which such recombinants can be produced. It should be kept in mind, however, that the possibilities for "exchange" in nature occur in the entire vast arena of biological contact. Selection processes while acting over a longer period do result in the formation of "new" recombinants. Some of the work thus far has shown that recombinant DNA is "maladaptive" and fails to survive in nature.

Dr. Terry Rabbits reported at a genetic engineering meeting in Glasgow that he had inserted a specific mammalian gene into bacteria. (His work follows within weeks the announcement of three similar claims from American and European laboratories.) The gene for globin, the major protein in red blood cells was inserted into bacteria.

⁶ Struhl, Kevin *et al.* Functional Genetic Expression of Eukaryotic DNA in *Escherichia coli*. Proceedings of the National Academy of Sciences, v. 73, May 1976: 1471-1475.

⁷ Benveniste, Raoul L. and George J. Todaro. Evolution of Type C. Viral Genes: Preservation of Ancestral Murine Type C Viral Sequences in Pig Cellular DNA. Proceedings of the National Academy of Sciences, v. 72, October 1975: 4090-4094.

The gene was obtained by using a unique technique, part of other developments in biochemistry—he did not dissect out the globin regulating gene by restriction enzyme techniques. Instead a reverse transcriptase enzyme in pure form was used to make a DNA copy of the RNA messenger for this gene—thus getting a “pure” gene which could then be inserted.⁸

DNA recombinant molecule research requires the skills of the microbiologist, biochemist, geneticist, and virologist. A significant discovery which opened this research to rapid development was the isolation and purification of a series of bacterial enzymes. These enzymes, known as restriction enzymes, provide the means to “cut” DNA molecules into fragments by reactions at specific chemical sites within the DNA molecule. The site of cutting can be determined by the enzyme selected to produce the cleavage. Other enzymes, called ligases, can be used to recombine or “anneal” the cut DNA molecule and bind the new fragment into the vector which also has been subjected to a similar biochemical reaction. Then the new fragment, now incorporated in the recombinant molecule can be cloned as described earlier.

(g) *Gene Synthesis*: Interesting variations for securing DNA are becoming available. Recently, Dr. Harr Gobind Khorana and his research team completed nine years of research on the total synthesis of a gene. This synthetic gene has been demonstrated to be functional by transferring the gene into a cell and observing the biochemical evidence of activity. Earlier work on the gene had been completed by 1973 but final synthesis had to await the resolution of the information on the sequence of chemicals necessary to control the initiation and cessation of activity of the synthetic gene. This type of work is very laborious and much more time consuming than the recombinant work which utilizes genes already present in an organism. However, the potential for combining the totally synthetic gene with recombinant techniques may be viewed as a part of the overall development of the capability to control genetic activities. At the very least, the ability to synthesize precisely a gene, thus knowing the exact sequence of elements within the molecule, adds to the available technologies for probing the functions of genes. Some investigators in DNA recombinant work see the synthetic route of inquiry as a desirable approach for determining the structure-function relationships of genes.⁹ The synthesis of a precisely identified gene which might be introduced into an organism is seen as being a lesser degree of potential risk than the potential risk from cutting the same gene out of a living organism and transferring or cloning this gene. In fact, Dr. Ramamoorthy Balagage, one of the team members in this historic synthesis, reportedly noted that this gene synthesis poses no risk because it is a single gene already present in a living system.¹⁰

⁸ Szekely, Maria. Two Approaches to Gene Synthesis. *Nature*, v. 263. September 23, 1976: 277-278 and Genetic Engineers Put Animal Genes into Bacteria. *New Scientist*. March 25, 1976: 659.

⁹ Mariani, K. J. et al. Cloned Synthetic lac Operator DNA Is Biologically Active. *Nature*, v. 263. October 28, 1976: 744-748 and Heynecker, Herbert L. et al. Synthetic lac Operator DNA Is Functional In Vivo. *Nature*, v. 263. October 28, 1976: 748-752.

¹⁰ Synthetic Gene Reported Functional in Living Cell. *Medical Tribune*, v. 17. October 6, 1976: 1, 4. See also: Maugh, Thomas H. II. The Artificial Gene: It's Synthesized and it Works in Cells. *Science*, v. 194. October 1, 1976: 44.

3. *Other Research:* The emphasis at this time, particularly in the development of guidelines for the "regulation" of recombinant molecule research has been on DNA, although the guidelines do provide for RNA-DNA experiments. A reasonable question to ask is whether there is eventually going to be greater concern about RNA research. There is some evidence that the overlaps in this work may already be near. As noted earlier, the gene for globin recombinant work was obtained by using a reverse transcriptase to produce the DNA regulating gene from purified messenger RNA. In other areas, virologists have known for some time that RNA viruses may be concealed after incorporation within the DNA of a cell. As noted by McBride, there is some suspicion that even RNA segments which normally replicate via RNA may be transcribed into an infectious DNA copy.¹¹

According to McBride, the evidence seems to indicate that some RNA's may transcribe the DNA by a means other than normal reverse transcriptase enzyme systems. A number of disease causing viruses such as measles and influenza may have this capacity. It is possible that such RNA produced DNA's may not be recognized in the DNA form and an infectious RNA virus might be transmitted inadvertently. McBride refers to experiments by Dr. Edward Skolnick of the National Cancer Institute which seem to indicate that mouse cell DNA when introduced into the cells of other species resulted in the appearance of RNA viruses. Apparently the mouse cell DNA was harboring an RNA in DNA form. This type of research suggests the presence of a continuum which exists not only between RNA and DNA but also possibly between other genetic fragments which might be exchanged between organisms in nature. Some opponents of DNA recombinant research might conjecture that recombinant work with DNA of poorly defined characteristics could involve a risk of a latent DNA concealed RNA of a dangerous RNA virus disease.

An important problem to be solved if genetic disease is to be examined at the molecular level is physical identification of the location of specific genes as correlated with their function. An unusual technique of value on this problem was initiated when human and plant cells were fused and grown in culture. The research is considered of interest as a part of an overall investigation to determine whether human cells do contain functional units which may have evolved from similar bacterial units. This research also is of importance as it relates to the identification of the functions of various human genes. HeLa cells, cultured human cells of a standard line evolved from cancer tissue, were merged with hybrid tobacco plant cells.¹² Using new techniques, the cells were induced to merge together; only the nucleus of the HeLa cells apparently merged with the intact plant cell. As with other cell hybrids from different species, eventually some of the chromosomes of one of the species are lost during cell division. This is considered an advantage in the research protocol since it is

¹¹ McBride, Gail. Do RNA Viruses Lurk 'Underground' in DNA Form: The Journal of the American Medical Association, v. 235, June 21, 1976: 2695-2698.

¹² Jones, C. Weldon *et al.* Interkingdom Fusion Between Human (HeLa) Cells and Tobacco Hybrid (GGGL) Protoplasts. Science, v. 193, July 30, 1976: 401-403. See also: Sherrill, Robert. Human, Plant Cells Grow Together for First Time. The New York Times, August 3, 1976: 33M; and Plant/Animal Hybrids Create New Era in Biology. New Scientist, July 29, 1976: 211.

hoped that the residual chromosome material will function and thus provide information about the residual fragment. Receptive fusions, with different residual chromosomes thus could permit the gradual mapping of additional chromosomes and perhaps eventual specific gene function or chromosome fractions.

Since the human and tobacco genomes are so different, the genes of human chromosomes can be identified on the residual human chromosomes by biochemical analysis to find the characteristic proteins and enzymes in the plant protoplasm. Similar experiments have been completed in Hungary and Great Britain. It is believed that this research will contribute to an understanding of gene control differences which may exist in plants, as well as animal kingdom cell types, and possibly contribute to the development of hybrid cells of importance in food production.

Other cell fusions can be used for gene mapping. For example, fusion of mouse cells with human cells and observation of losses of chromosomes and associated function may permit residual genomes to be identified as to function. Other cross taxonomic kingdom cell research has been completed between hen's red blood cells and yeast (in England) and carrot cells with HeLa cells in Hungary. There are still many technical difficulties which must be mastered before long term cell replication appears feasible. As with other cell fusion research, it is anticipated that one outcome of this type of research will be a loss of most or all of one set of chromosomes which have been added in the fusion of the two cells. It is anticipated that it will be the animal chromosomes which will eventually disappear. Even if the chromosomes of one of the cell types is lost, thus, permitting study of remaining functions, there is still inadequate information about cytoplasmic factors to be certain that no risk is involved in such experiments. The fusion of plant and animal cells into new hybrids marks an unusual accomplishment in cell research. Although not recombinant DNA research, this basic work in cell physiology is of interest as it permits an analysis of the survivability of DNA from organisms of major cell type differences.

Among other major problems of interest in modern cell physiology and genetics, is the determination of the control systems which turn on and off genetic activity—that is activity relative to synthesis within the cells. As noted earlier in discussions of Khorana's work, it was the task of constructing the "switching" system in the synthetic gene which was an important step toward final synthesis of an operating gene. Gurdon and his group (as well as investigators at the University of Indiana) have been experimenting with whole cell systems in attempts to gain more information about these control systems.¹³ In this latest research, the English investigators injected human HeLa nuclei into frog (*Xenopus*) oocytes (egg cells) and noted that the subsequently formed RNA synthesized HeLa proteins. This work provides a good model for studying control processes within living cells. Gurdon is the same investigator, then at Oxford University, who cloned adult frogs by transferring the nuclei from skin cells to enucleated eggs (see

¹³ Gurdon, J. B. *et al.* Injected Nuclei in Frog Oocytes Provide a Living Cell System for the Study of Transcriptional Control. *Nature*. v. 260. March 11, 1976: 116-120.

the previous committee report for further discussions on this earlier research).¹⁴ One hypothesis is that there is some "substance" in the cytoplasm of the egg which "turns on" the chromosomes in the introduced nucleus and induces renewed synthesis of proteins which had been "switched off." It is the identification of these regulator "substances" that is of interest in this research. Research on this same problem was reported by Dr. Ann Brothers in which a tentative identification has been made of a protein regulator synthesized during egg development.¹⁵

Another important application of recombinant techniques is to use specific viral genomes to aid in the genetic analysis of animal tumor viruses. Miller and Fried¹⁶ indicated their success in beginning the task of locating the DNA regions coding for differences in parent virus strain. Using the standard technique of cutting with restriction enzymes and constructing hybrid viruses, these investigators were able to demonstrate that the hybrid viruses did contain fragments from each of the parent viruses. The follow-on work will be directed at cutting viral DNA in different locations and thus permitting a more precise location of a specific gene as related to a function. Since these are cancer inducing viruses, the work has important implications for the study of cancer induction. Large numbers of the genomes are needed; the technique of cloning associated with DNA recombinant research will permit the manufacture of the needed quantities. However, this is one type of work, that is the use of cancer inducing viruses, which is of particular concern to opponents of DNA recombinant molecule research.

In recognition of the serious concern about the use of viral-DNA recombinant experiments, the NIH has proposed to conduct a risk assessment experiment under the safest conditions available. In essence, the experiment will involve the use of a known rodent cancer virus. The recombinant molecule will then be tested in animal experiments to determine whether the hypothesized survival occurs and whether transmission of cancer takes place. This experiment was proposed in order to collect data to support the theoretical calculations regarding the risks of such experiments. While the expected results would be negative, the experiment is being carefully planned to insure no risk to human beings in the event that the anticipated hypothesis is not supported.¹⁷

B. THE DNA RECOMBINANT MOLECULE ISSUE

As noted earlier, the basic molecular structure in the cell which determines the nature of life is becoming accessible to controlled manipulation. The events which have led to this capability have occurred, not because of some unexpected or explosive breakthrough, but because of the slow incremental increase in knowledge which is characteristic of most basic scientific research. The issue seems to have

¹⁴ U.S. House. Science and Astronautics Committee. Supplemental Report I. op. cit.

¹⁵ Brothers, Ann Janice. Stable Nuclear Activation Dependent On a Protein Synthesized During Oogenesis. *Nature*, v. 260, March 11, 1976: 112-115.

¹⁶ Miller, Lois K. and Mike Fried. Construction of Infectious Polyoma Hybrid Genomes in Vitro. *Nature*, v. 259, February 19, 1976: 598-601.

¹⁷ Cohn, Victor. Risk Seen in Genetics Experiment. *The Washington Post*, September 18, 1976. D1, D3.

evolved suddenly only to those who have not been aware of the developments in this field. These developments in the life sciences are of particular importance as a public policy issue for a number of reasons. However, some preliminary background information is useful at this point in order to place this problem in perspective.

DNA recombinant molecule research deals with the recombination in cell free systems of segments of deoxyribonucleic acid (DNA), the material that determines the hereditary characteristics of all cells. The research has evolved from the efforts of many scientists carrying out investigations in molecular biology and related work in genetics and cell physiology.

Often referred to as "genetic engineering," the ability to modify the genetic material within a cell with some reasonable assurance of outcome results from a number of events. One of the most significant discoveries was the identification and biochemical isolation of a series of enzymes (restriction enzymes) which actually can be used as precision tools for the cutting of the genetic material and the introduction of new genetic material into the original DNA. At the same time, enzymes have been isolated which permit the annealing or joining together of the cut strands after new genetic material is introduced. In other words, the biochemical tools are now available to permit the excision of segments of the genetic material from one organism and the insertion of this new and foreign genetic material into another organism (see appendix 2, for an article by Stanley Cohen which discusses these discoveries in more detail).

Although the bulk of the basic research associated with the development of this technique has been completed with microorganisms (and most frequently with *Escherichia coli* [*E. coli*]), there is hope for the eventual insertion of any animal gene into plants or any plant gene into animals. For example, it has been demonstrated that genes from yeast, a eukaryote (an organism higher on the evolutionary scale than bacteria which are prokaryotes) can successfully survive when inserted into bacteria. The biochemical function of the yeast genes may be expressed in the bacterial activity. Other examples will be cited later and some of the exquisite techniques actually involve intermediate vectors such as modified viruses for transferring genes from one cell to another in a precise fashion. Whatever the specific technique or organism involved, the procedure is exciting from a basic research standpoint because it can function as a powerful tool for the elucidation of the genetic structure and gene function of many organisms and because it also offers the possibility of "installing" valuable new functions within organisms which lack such functions. As in all aspects of man's activities, however, the benefits cannot be achieved without consideration of potential risk.

When the capability to cut and recombine genes with reasonable reliability became available, a number of scientists recommended that this type of research be examined to determine whether control over the research should be instituted because of potential risks to health. As a result of these early recommendations and subsequent efforts by a large number of scientists, guidelines for the conduct of DNA recombinant research were developed. The effort to develop these guidelines is an interesting case history study of this unique field of research also discussed in more detail later within this paper.

The DNA recombinant molecule research issue is of public policy interest for a number of reasons. First of all, the potential benefits which have been postulated appear to be enormous. The technique offers the promise of the diagnosis of genetic disease in many forms, the capability to create new and more efficient forms of plant life, and the opportunity to manufacture many valuable biochemical substances by cost effective methods. Potential applications to problems of food and nutrition, waste disposal, medicine, and industry are abundant. In contrast, the unknown dangers of producing some combination of genetic characteristics in an organism which might inadvertently escape into the environment and produce human cancer or other novel infection, increase antibiotic resistance in pathogenic organisms, permit the survival of pathogens in environments not normally amenable to survival, or upset natural evolutionary processes, and similar dangers all have been cited in opposition to continuation of this research.

From a public policy perspective, the attention given to this area of research by the research scientists themselves was a unique experience. DNA recombinant molecule research also has focused attention on a broader science policy issue that has been evolving for more than a decade. This is the issue of how to evaluate the effect on society of the results of new research. The task of integrating the contrasting perspectives in an examination of scientific issues of national importance is assuming great significance. In the case of the DNA issue, the research is moving so fast that it is difficult to maintain an awareness of the status of development. The rewards and thus incentives for success in research in this area are extremely high for commercial developers and researchers alike. The risks in some instances can be partially defined but in most cases are highly speculative. Since most of the research is being supported by Federal funds, there is a considerable political challenge to maintain an awareness sufficient to exercise control over policy. At the same time, there has always been considerable resistance, from the basic research community, against any infringement upon the historic rights of academic freedom and the search for basic knowledge.

C. CHRONOLOGY OF RECENT DEVELOPMENTS ASSOCIATED WITH THE GUIDELINES

1. *Background.*—It was during the 1973 Gordon Conference on Nucleic Acids (held June 11–15, 1973, New Hampton, New Hampshire) that a group of scientists indicated publicly their concern about the potential hazards from the rapidly expanding research with DNA recombinant molecules. Following these expressions of concern to the National Academy of Sciences, an international meeting sponsored by an Academy committee was held at Asilomar, California on February 24–27, 1975. At the same time, the Director of the National Institutes of Health had appointed a special advisory committee on DNA recombinant research. During the period of planning for this meeting, the British government, through its medical council, also initiated a review program to develop recommendations with regard to the conduct of DNA recombinant research in England. These initial developments are discussed in more detail in the supplemental committee report cited earlier.¹⁸

¹⁸ U.S. Congress, House, Committee on Science and Technology, 1974 Report. op. cit.

2. *The Asilomar Conference.*—The Asilomar Conference on Recombinant DNA Molecules in February 1975 was sponsored by the National Academy of Sciences with financial support from the National Cancer Institute and the National Science Foundation. Attendance was limited to invitation only. There were 155 participants, 83 from the United States representing research, governmental, and industrial institutions, 51 representatives from foreign nations, and 21 lay and news media representatives. The names of the attendees are provided in appendix 3.¹⁹

The conference proceedings were not published although tape recordings of the sessions were collected for further research purposes. Five subjects were placed upon the formal agenda for discussion. These were: Ecology of plasmids and enteric bacteria; molecular biology of prokaryote plasmids and their use for molecular cloning; synthetic recombinants involving animal virus DNAs; synthetic recombinants involving eukaryote DNAs; and ethical and legal concerns arising from work on synthetic recombinant DNAs.²⁰ A summary statement of the guidelines developed from this conference is provided in appendix 4.

These guidelines had a particular importance for they were accepted generally by the research community and served as the foundation for the work of the more formal group established by the Director of the National Institutes of Health to develop guidelines to govern NIH-sponsored research in this area. Of further significance with regard to these guidelines is that they were developed as a result of the initiative of the research community and were accepted on a voluntary basis because of a concern for potential hazards which were hypothesized for this research. Although there were strong feelings at this conference about the imposition of "regulations," there also was a very strong feeling about the social obligations of the investigators to provide a maximum of protection against any possible untoward event. From this debate, the Asilomar guidelines evolved.

3. *The NIH Recombinant DNA Molecule Program Advisory Committee.*—On October 7, 1974, an NIH Recombinant DNA Molecule Program Advisory Committee was established to provide advice to the Director of NIH (and the Secretary of HEW and the Assistant Secretary for Health). The committee was asked to consider a program for developing procedures to minimize potential dangers and to develop guidelines to be followed by investigators in this field of research. Thus, both safety requirements and research protocols are areas of responsibility.

The first meeting of the DNA Recombinant Molecule Advisory committee was held in San Francisco immediately after the Asilomar Conference in 1975. The NIH committee recognized the value of the work of the participants at the Asilomar conference and recommended interim adoption of the Asilomar guidelines until the NIH committee could develop more detailed guidelines. In examining the research work since 1974 and the efforts to get approval of certain types of

¹⁹ U.S. Department of Health, Education, and Welfare. Public Health Service. National Institutes of Health. Recombinant DNA Research. v. 1. Documents Relating to NIH Guidelines for Research Involving Recombinant DNA Molecules. February 1975–June 1976. August 1976. p. 46.

²⁰ Ibid.

vectors and hosts for DNA recombinant work, it is important to note that the researchers were passing through a stage of evolving guidelines. These changing requirements induced frustration on the part of some investigators for it meant that while the requirements of existing guidelines were being satisfied, approval of biological research systems often was being considered in an atmosphere of debate on new qualification requirements. This "ad hoc" approach became more critical as the members of the NIH DNA committee became more sensitive to the legal and social implications of their task. (See appendix 5 for a list of the committee members as of April 1976. Dr. Leroy Walters, Director of the Kennedy Institute, Center for Bioethics, recently accepted appointment as a member).

The second meeting of the NIH DNA Recombinant committee, on May 12-13, 1975, dealt with the task of developing more specific recommendations as an evolution from the Asilomar guidelines. This task was initiated by a subcommittee chaired by Dr. David Hogness, Stanford University and produced a proposal which was referred to during subsequent discussions as the "Hogness" paper. Emphasis in the "Hogness" paper was placed upon more detailed descriptions of the concept of biological containment and also was directed toward the specification of the criteria to be used in selecting physical containment facilities for the conduct of experiments with a higher degree of risk.

The third meeting of the NIH committee was held in Woods Hole, Massachusetts in July 1975. At this meeting, the "Hogness" paper was revised and a significant level of controversy about the guidelines began to emerge.

As anticipated, the debate was polarized around the issues of the degree of biological and physical containment being proposed for certain types of research. Some critics believed that the guidelines were too strict and would seriously handicap or even prevent desirable research while others believed that the Woods Hole version was too lax and might induce an unsuspecting or poorly qualified researcher to conduct research under conditions which would inadequately insure safety in the event of an accident.²¹

For example, a group of 48 scientists who attended the Cold Spring Harbor bacteriophage meeting sent a letter to Dr. Dewitt Stetten, Chairman of the DNA committee, in which they expressed their concern about the Woods Hole guidelines. In their letter, they specifically listed examples of containment which were believed to provide an inadequate degree of safety. The petitioners, including Dr. Richard N. Goldstein of Harvard Medical School, also expressed their belief that the NIH committee should include broader representation from other fields of expertise and specifically should include scientists not directly involved in cloning experiments.²²

Because of the rather significant controversy generated by the Woods Hole guidelines, Dr. Stetten decided to circulate the Woods Hole draft also within the scientific community in order to secure a wider peer review. The detailed comments which he received indicated

²¹ Wade, Nicholas. Recombinant DNA: NIH Group Stirs Storm by Drafting Laxer Rules, *Science* v. 190. November 21, 1975: 767-769.

²² DNA Committee Has Its Critics. *Nature* v. 257. October 23, 1975: 637.

a need for further significant revision. Accordingly, Dr. Elizabeth M. Kutter, Evergreen State College, Olympia, Washington, was asked to chair another subcommittee and prepare a revised version of the guidelines. The "Kutter" version was considered at a fourth public meeting of the NIH DNA committee in La Jolla, California on December 4-5, 1975. At this meeting, a side-by-side comparison was made of the "Hogness", "Woods Hole" and "Kutter" versions of the guidelines in which each section was compared (similar to a legislative bill analysis) and differences were examined by the committee members. The laborious and often argumentative discussion of these three versions resulted in the preparation of a revised document which was then presented to the Director of the National Institutes of Health (Dr. Donald S. Fredrickson) for his consideration and approval. The "La Jolla" document, now referred to as the "NIH Proposed Guidelines For Research Involving Recombinant DNA Molecules", represented the results of long hours of vigorous debate not only during committee meetings but involving long telephone conferences among committee members, interface during the public meetings between committee members and researchers attending as observers, examination of letters of comment from various groups, contributions by interested foreign nation representatives, an increasing acknowledgement of the need for public participation in the resolution of those points affecting the prohibition of certain types of research and the establishment of safety procedures, and for the approval of vector and host cell systems.

Following a public meeting on the guidelines held by the Director of NIH, the DNA Recombinant Molecule committee was asked by the Director to consider the new comments received and to recommend any further change to the guidelines. At a meeting held April 1-2, 1976, the DNA committee reviewed the comments received by the Director and provided him with a rationale for acceptance or rejection of proposals for change. At the same meeting, a viral vector developed by Dr. Philip Leder was approved.

At their most recent public meeting on September 13-14, 1976, the Recombinant DNA Molecule Program Advisory Committee continued their examination of the published guidelines with the intention of providing further change as necessary. This meeting also provided an opportunity for the committee to consider the research needs for a highly secure research facility, proposals for a program to construct and distribute cloned segments of mammalian DNA, NIH patent policies on developments in DNA recombinant molecule research, experiments to assess the biohazards which had been postulated for DNA recombinant molecules and requests for certification for a mutant host for cloning and a viral vector.

A mutant strain of *E. coli* host with two specific plasmids developed by Dr. Roy Curtiss, University of Alabama, was approved for use in DNA recombinant research. A second viral vector developed by Dr. Philip Leder (NIH) as well as vectors developed by F. Blattner and others at the University of Wisconsin were approved contingent upon the completion of several additional tests. Thus additional formal steps of compliance with guidelines have been taken. Copies of the minutes of all meetings held by the Advisory committee

are available from Dr. William Gartland, Executive Secretary, Recombinant DNA Molecule Program Advisory Committee, NIGMS, NIH, PHS, Room 4A52, Bldg. #31, Bethesda, Md. 20014.

4. *NIH Advisory Committee Actions on the DNA Recombinant Guidelines.*—When the DNA Recombinant Advisory committee had completed their deliberations at La Jolla, the proposed guidelines were forwarded to the Director of NIH for his consideration and possible adoption. Despite the fact that all meetings of the DNA Recombinant Advisory committee had been public, Dr. Fredrickson decided that further public scrutiny of the proposed guidelines would be appropriate prior to adoption. The Director convened a public meeting of his NIH Advisory Committee (a special Advisory Committee to the Director, see appendix 6) for the purpose of discussing the guidelines and to invite public comment. This meeting was held on February 9–10, 1976. The Director broadened the participation in his Advisory Committee meeting to add additional scientific and lay representatives including former members and individuals knowledgeable in the fields of ethics and socioeconomics as well as biological research. The transcript of that meeting and the list of invited participants have been published.²³

After review of the comments submitted during and following this meeting, the Director asked his DNA Recombinant Advisory committee to evaluate a number of the comments for possible incorporation into the proposed guidelines and to justify the exclusion of recommendations considered inappropriate. Since a great deal of concern had been expressed at his Advisory Committee meeting about the imposition of the guidelines on non-NIH investigators, the Director also held an interagency meeting with representatives of other Federal agencies to discuss the proposed DNA guidelines. The concern expressed about the problem of gaining compliance with the guidelines by private researchers also led the Director to hold a meeting with selected industry representatives. The list of the invited participants at this industry meeting is provided in appendix 7. Finally, the Director personally provided special briefings to selected House and Senate committee staff members on the actions being contemplated for dissemination of the guidelines.

The guidelines were then published in the Federal Register on July 7, 1976 after final consideration of all of the comments received (see appendix 8). A number of policy considerations were taken into account prior to publication. In his preface, the Director noted that he had been particularly concerned with the process of implementing the guidelines. He stated that the guidelines are not regulations and thus do not have the same force as law except that control could be exercised through the funding process controlled by NIH. He expressed his belief that administration should remain as flexible as possible since frequent adjustments in requirements were anticipated.

In publishing the guidelines in the Register, the Director invited further comments thus leaving the door open to further public debate on the applicability of any particular specification.

²³ U.S. Department of Health, Education, and Welfare. Recombinant DNA Research, v. 1. op. cit., pp. 140–349.

The Director of NIH has attempted to determine a method of resolving the applicability of the guidelines to investigators not funded with NIH money. For example, the National Science Foundation, the Energy Research and Development Administration and the Department of Agriculture all appeared to have potential interests in DNA recombinant molecule research. As noted, the Director of NIH held meetings with the Federal agencies which might be involved and it was decided to attempt to secure voluntary compliance from these Federal agencies and from industry. By September 22, 1976, the National Science Foundation, the Energy Research and Development Administration and the Department of Defense had indicated that they would comply in research funded by their agencies.²⁴ The Department of Defense indicated that although no research of this type was currently being funded, the Department would comply if such research was initiated. Although the Department of Agriculture had not indicated that they would comply, the absence of this agreement was noted as being due to the administrative review process as it might affect various research programs and not any basic disagreement with the intent of the guidelines. The Director of NIH indicated that he anticipated that the USDA also would indicate compliance with the guidelines in the near future.

At the Senate hearings held in September,²⁵ the President of the Pharmaceutical Manufacturers Association indicated that the drug industry endorsed the spirit and intent of the guidelines and that with some minor modifications should and would accept the guidelines. At this same hearing, the subcommittee chairman introduced into the record a copy of a letter to the President of the United States in which he and Senator Jacob K. Javits indicated their concern with the issue of DNA recombinant research.

D. GUIDELINES FOR RECOMBINANT DNA RESEARCH

1. *Introduction.*—The earlier committee reports, particularly Supplement I²⁶, provide additional background information concerning the unique actions of the research scientists who directed public attention to the new developments in DNA Recombinant research. As a result of these actions and the work discussed in this report, most of the public attention on the DNA recombinant molecule issue has been focused on the guidelines. The general public interest in the recombinant research itself has been somewhat more superficial even though it is believed, in the opinion of many observers, to be one of the greatest achievements in modern science; even more significant perhaps than the development of nuclear power. However, the guidelines have received the publicity because they are the first effort to control this research and, no matter whether the interest is to delay or prohibit such research or to accelerate developments, it has been quite natural that the debate in this area of genetic research should become polarized

²⁴ U.S. Senate, Labor and Public Welfare Committee. Subcommittee on Health. Hearings on the Guidelines for DNA Recombinant Molecule Research. Testimony by Dr. Donald Frederickson. September 22, 1976. Unpublished.

²⁵ Ibid. Statement of C. Joseph Stetler, President of the Pharmaceutical Manufacturers Association.

²⁶ U.S. Congress. Committee on Science and Astronautics. 1974 Report—Supplement J. op. cit.

around the DNA recombinant molecule guidelines. The debates about the content of the guidelines have pitted friendly rivals against each other in the research field; aroused communities to a fever pitch about the control of research within universities; resulted in the fear that this important area of research might be driven to other lands if restrictions become too prohibitive; produced concern within the minds of environmentalists about a potential new source of pollution in the biosphere; and engaged the attention of ethicists, lawyers, theologians, and practically every other public interest group which can be identified. Since this is not the first effort by a Federal agency to control research in some way, an initial reaction might be to ask why so much furor has evolved over the proposals. The answer to this question involves a number of factors.

First of all, the proposals known as the Recombinant DNA Research Guidelines are guidelines and not Federal regulations being promulgated with the force of law. Second, these proposals for regulation are unique in that they were stimulated by the very research scientists who are conducting the research. Third, the "enforcement" procedure proposed in the guidelines will depend upon the approval by the peer review hierarchy which has evolved within the National Institutes of Health for review and approval of research funded under the usual contracts and grants procedures (since the National Institutes of Health has been funding the bulk of the government research in this area, control of the money also provides control over the research). Fourth, there is concern that commercial firms may not choose to comply with the guidelines and, since there is no prospective procedure for licensing, inspection, fines or other penalties for noncompliance, the guidelines may not really be effective with industry.

Other factors which make the guidelines of interest depend upon the perspective from which they are viewed. Some researchers consider the guidelines as an unnecessarily restrictive control over independent research; others are concerned that foreign nations may develop less restrictive guidelines or none at all and the benefits of the research will be lost to American industry. Others think that the guidelines should never have been written since they imply an approval of a type of research which is viewed as too dangerous to be conducted at all.²⁷ Those who are interested in a continuing participation of the public in the development of policies of such significance question the manner in which the guidelines were developed by researchers who are involved in the research, the limited analysis of risks and benefits, and whether the guidelines detract from consideration of alternatives to DNA research.²⁸

The guidelines are an extremely interesting series of requirements for they reveal much of the status of the research and introduce new concepts regarding safety systems for research with potentially dangerous organisms. For these reasons alone, aside from the public policy implication of the guidelines, some time should be taken to examine the objectives established at this point. It should be kept in mind that **although the guidelines have been published and are now being**

²⁷ Chargoff, Erwin. On the Dangers of Genetic Meddling, *Science*, vol. 192, June 4, 1976: 938, 940.

²⁸ Simring, Francine Robinson. Recombinant DNA Risks and Benefits. *Science*. vol. 192. June 4, 1976: 940.

utilized, the NIH committees have a continuing task of evaluation and modification as experience dictates. Further, as will be discussed later, the Director has published a Draft Environmental Impact Statement which provides another route of participation by all interested parties for input and modification of the guidelines.

2. *Summary Comments On The Guidelines.*—The Department of Health, Education, and Welfare Guidelines For the Conduct of Recombinant DNA Research were formally published in the Federal Register on July 7, 1976.²⁹ These guidelines, the results of the efforts of the many individuals described in an earlier section of this report, were published with a preamble from the Director of NIH which indicated:

On Wednesday, June 23, 1976, the Director, National Institutes of Health, with the concurrence of the Secretary of Health, Education, and Welfare, and the Assistant Secretary for Health, issued guidelines that will govern the conduct of NIH supported research on recombinant DNA molecules. The NIH is also undertaking an environmental impact assessment of these guidelines for recombinant DNA research in accordance with the National Environmental Policy Act of 1969.

. . . The NIH recognizes a special obligation to disseminate information on these guidelines as widely as possible. . . . Accordingly, the Guidelines will be sent to all of the approximately 25,000 NIH grantees and contractors. The Guidelines will be sent to medical and scientific journals, and editors of these journals will be asked to request that investigators include a description of the physical and biological containment procedures used in any recombinant research they report on. International health and scientific organizations will also receive copies of the guidelines for their review.

. . . It must be clearly understood by the reader that the material that follows is not proposed rulemaking in the technical sense, but is a document on which early public comment and participation is invited.³⁰

The guidelines provide a summary of the chronology of the work conducted to prepare them as well as a summary of the science policy considerations and the considerations within NIH for further implementation of the guidelines outside the NIH.

There are three major provisions within the guidelines. They are quite comprehensive and are included as appendix 4 for further information.

The guidelines develop and expand the concepts proposed at the Asilomar Conference for the establishment of physical and biological containment criteria graded as to degree of safety dependent upon the risk assessed for a particular type of experiment.

(a) *Physical Containment*: Physical containment laboratories are described in four degrees of safety code numbered P1, P2, P3, and P4.

P1 facilities are described as minimal facilities involving laboratories with no special engineering design. This is the type of laboratory commonly used for microbiological work with no or only minimal hazard.³¹ (It is of interest to recall, however, that a great deal of work with important pathogens had been performed in the past at levels now defined as P1-P2 levels of containment.)

²⁹ U.S. Department of Health, Education, and Welfare. National Institutes of Health. Recombinant DNA Research Guidelines. Federal Register. vol. 41. July 7, 1976: 27902-27943.

³⁰ Ibid., p. 27002.

³¹ Ibid., p. 27912.

The P2 level of confinement is similar to the P1 laboratory with the added requirements for an autoclave (a device for steam sterilizing culture media, glassware, etc.) within the building and the laboratory may have a biological safety cabinet depending upon the experimental work. Access to the laboratory may be somewhat more restricted than with the P1 laboratory. The guidelines prescribe the laboratory practices which should be followed as a minimum with such experiments as are authorized to be conducted in P2 facilities.³²

P3 laboratories are described as providing a moderate level of safety. These laboratories must have special engineering design features and physical containment facilities. The laboratory is separated from general public access with controlled access facilities such as air-locks, separate corridors or other design features as necessary. Biological safety cabinets must be provided within the controlled laboratory area and an autoclave also must be available within the building and preferably within the controlled access laboratory. Ventilation systems or air flow control must be designed to prohibit recirculation of exhaust air without treatment and a positive air pressure is maintained within the laboratory with all exhaust going outside the building. Again, minimum laboratory practices are described as are the types of DNA recombinant experiments which can be conducted within such a laboratory.³³

P4 facilities are intended to provide the highest degree of safety possible within available biohazard technologies. These facilities are designed to permit work designed to contain microorganisms that are extremely hazardous to man or may cause serious epidemic disease. The laboratory is either a separate building or a tightly controlled area within a building which is completely isolated from other areas within the building. Again, special safety cabinets must be used, engineering design features are developed to prevent the escape of microorganisms to the environment, air flow is controlled, personnel access and cleanliness is tightly controlled, and other safety features are prescribed. Operational procedures for work within such laboratories are described.³⁴

(b) *Biological Containment*: The principle of biological containment is unique in these guidelines and a great deal of time is devoted to describing this idea. Basically, the idea of containment evolved from the work with *Escherichia coli* which suggested that it would be possible to "construct" a variant of this bacterium which would be so fastidious in its growth requirements that the probability of its surviving outside of the precisely controlled laboratory culture conditions would be very slight.

The levels of biological containment are designated EK1 through EK3 (the acronym EK derives from the K-12 variant of *Escherichia coli* used in many experiments) with the highest level of biological containment being an EK3 variant. The knowledge already gained from working with some variants of these microorganisms and with plasmid vectors of a particular strain supported this idea of a "weakened" strain suitable for experimental work. Furthermore, knowledge

³² Ibid., p. 27913.

³³ Ibid., p. 27913.

³⁴ Ibid., pp. 27913, 27914.

had been acquired about the survivability outside the laboratory of *E. coli* host with plasmid or bacteriophage variants which also had certain propagation restrictions so that the combination of the restricted growth characteristics of the host cell (*E. coli*) and the plasmid or phage vector produced a degree of safety described as being suitable for use with the permissible experiments. Specific data on the survival probabilities permitted for various host vector systems are described (the testing of proposed host-vector systems is being continuously monitored and changes to the guidelines are already evolving).³⁵ The availability of a suitable mutant of *E. coli* (or an alternative organism) is absolutely essential to the concept of biological containment. Despite the fact that many are opposed to the use of this microorganism, it is the organism which has played the major role in DNA recombinant work thus far and is not likely to be either supplanted or prohibited without a great deal more discussion. Thus, Dr. Roy Curtiss' (University of Alabama) development of a mutant of *E. coli* and NIH Committee approval of this weakened mutant is a significant achievement.³⁶

What he did was to manipulate the test strain until he had a mutant variety which is dependent upon an external source of an amino acid needed to construct its cell wall, made it sensitive to temperatures, reduced its capabilities to incorporate DNA within its chromosomes, and reduced its ability to exchange genetic material with other bacteria. This mutant is believed to have a very low probability of survival under non-laboratory conditions. Each time Curtiss thought he had solved the problem, the microorganism demonstrated an ability to use alternative mechanisms for development. Further selective mutation finally permitted Curtiss to demonstrate to the NIH-DNA Recombinant Committee that the mutant form was satisfactory for use in the "EK2" experiments permitted by the guidelines. Similar effort is expended in attempts to construct weakened plasmids or phages (viruses).

It is desirable in considering biological containment to insure that the combined host-vector does not survive, that is, that the vector does not transmit the required growth characteristics in some way to the host, or that the vector cannot survive if it should escape in the host even though the host might not survive. For this reason vectors are either selected for their specificity of host or vector mutations may be selected to provide the desired characteristics of limited infectivity. A complication of this construction of safe biological host-vector system is that the host and the vector must still be able to grow and reproduce under conditions which assure a reasonably high degree of productivity within the bounds of the experimental control. If the mutants selected are so weakened that reasonable productivity during cloning cannot be accomplished then one of the advantages of the DNA recombinant system is eliminated. Thus, the skills of the microbiologist or virologist must be devoted to the solution of several simultaneous problems.

³⁵ Ibid., 27914-27917.

³⁶ Leeper, E. M. Self Destructing *E. coli* Developed at Alabama, Bioscience v. 26, April 1976: 243.

Alternatives which might alleviate some of the difficulty in using biological containment as a safety factor would be to develop host-vector systems that do not rely on bacteria, some strains of which are pathogenic. Unfortunately, *E. coli* is the organism about which the largest quantity of information is currently available. The development of a similar data base on another microorganism might mean a significant delay of research. Work is proceeding on *Bacillus subtilis* as a potential alternative host cell.

The guidelines then list the various combinations of physical and biological containment which are required as a minimum for the conduct of various combinations of permissible experiments such as those involving DNA from plants, birds, cold blooded vertebrates, primates, and others. In certain instances, the host-vector systems are not yet available to permit some of these experiments to be conducted.³⁷

Table I is a summary of the combinations of physical and biological containment required for various experiments.

TABLE I.—*Guidelines in detail*

The guidelines define four levels of physical containment, designated, in order of increasing stringency, P1 to P4, and three levels of biological containment, EK1 to EK3, and assign experiments to them on the basis of potential risk. The following is a summary of containment levels specified for various sources of DNA:

(a) Shotgun experiments using *E. coli* as the host:

Non-embryonic primate tissue-----	P3+EK3 or P4+EK2.
Embryonic primate tissue or germ line cells--	P3+EK2.
Other mammals -----	P3+EK2.
Birds -----	P3+EK2.
Cold blooded vertebrates:	
Nonembryonic -----	P2+EK2.
Embryonic or germ line-----	P2+EK1.
If vertebrate produces a toxin-----	P3+EK2.
Other cold blooded animals and lower eukaryotes.	P2+EK1.
If class 2 pathogen, ¹ produces a toxin, or carries a pathogen.	P3+EK2.
Plants -----	P2+EK1.
Prokaryotes that exchange genes with <i>E. coli</i> :	
Class 1 agents (nonpathogens)-----	P1+EK1.
Low risk pathogens (for example, enterobacteria).	P2+EK1.
Moderate risk pathogens (for example, <i>S. typhi</i>).	P2+EK2.
Higher risk pathogens-----	Banned.
Prokaryotes that do not exchange genes with <i>E. coli</i> :	
Class 1 agents-----	P2+EK2 or P3+EK1.
Class 2 agents (moderate risk pathogens)	P2+EK2.
Higher pathogens-----	Banned.

In all above cases, if DNA is at least 99 percent pure before cloning and contains no harmful genes, either physical or biological containment levels can be reduced one step.

¹ Classes for pathogenic agents as defined by the Center for Disease Control.

³⁷ Ibid., pp. 27917-27920.

TABLE I.—*Guidelines in detail*—Continued(b) Cloning plasmid, bacteriophage and other virus genes in *E. coli*:

Animal viruses-----	P4+EK2 or P3+EK3.
If clones free from harmful regions-----	P3+EK2.
Plant viruses-----	P3+EK1 or P2+EK2.
99 percent pure organelle DNA, Primates-----	P3+EK1 or P2+EK2.
Other eukaryotes-----	P2+EK1.
Impure organelle DNA: shotgun conditions apply.	
Plasmid or phage DNA from hosts that exchange genes with <i>E. coli</i> :	
If plasmid or phage genome does not contain harmful genes or if DNA segment 99 percent pure and characterised.	P1+EK1.
Otherwise, shotgun conditions apply.	
Plasmids with phage from hosts which do not exchange genes with <i>E. coli</i> .	
Shotgun conditions apply, unless minimal risk that recombinant will increase pathogenicity or ecological potential of the host, then.	P2+EK2 or P3+EK1.

NB. cDNA's synthesised *in vitro* from cellular or viral RNA's are included in above categories.

(c) Animal virus vectors:

Defective polyoma virus:	
DNA from nonpathogen-----	P3.
DNA from Class 2 agent-----	P4.
If cloned recombinant contains no harmful genes and host range of polyoma unaltered, reduce to.	P3.
Defective SV40+DNA from nonpathogens---	P4.
If inserted DNA is 99 percent pure segment of prokaryotic DNA lacking toxigenic genes, or a segment of eukaryotic DNA whose function has been established and which has previously been cloned in a prokaryotic host-vector system, and if infectivity of SV40 in human cells unaltered.	P3.
Defective SV40 lacking substantial section of the late region+DNA from nonpathogens, if no helper used and no virus particles produced.	P3.
Defective SV40+DNA from nonpathogen can be used to transform established lines of nonpermissive cells under P3 provided no infection particles produced. Rescue of SV40 from such cells requires.	P4.

(d) Plant host-vector systems:

P2 conditions can be approximated by insect-free greenhouses, sterilization of plant pots, soil and runoff water, and use of standard microbiological practice.	
P3 conditions require use of growth chambers under negative pressure and routine fumigation for insect control.	
Otherwise, similar conditions to those prescribed for animal systems apply.	

NOTE.—Norman, Colin. Genetic Manipulation: Guidelines Issued. Nature. v. 262. July 1, 1976: 3.

The guidelines explicitly prohibit certain types of experiments:

(i) Cloning of recombinant DNAs derived from the pathogenic organisms in Classes 3, 4, and 5 of "Classification of Etiologic Agents on the Basis of Hazard" (see appendix 9) or oncogenic viruses classified by NCI as moderate risk, or cells known to be infected with such agents, regardless of the host-vector systems used.

(ii) Deliberate formation of recombinant DNAs containing genes for the biosynthesis of potent toxins (e.g. botulinum or diphtheria toxins; venoms from insects, snakes, etc.).

(iii) Deliberate creation from plant pathogens of recombinant DNAs that are likely to increase virulence or host range.

(iv) Deliberate release into the environment of any organism containing a recombinant DNA molecule.

(v) Transfer of a drug resistance trait to microorganisms that are not known to acquire it naturally if such acquisition could compromise the use of a drug to control disease agents in human or veterinary medicine or agriculture.

In addition, at this time large-scale experiments (e.g., more than ten liters of culture) with recombinant DNAs known to make harmful products are not to be carried out. [Approval of larger scale experiments of obvious societal benefit may be possible if approved by the DNA Molecule Program Advisory Committee of NIH.]³⁸

The guidelines also list the responsibilities of the individual investigator and the institution involved in a particular experiment. Additional responsibilities are assigned to the NIH Initial Review Groups to include requirements to insure evaluations of proposals involving DNA recombinant research. The responsibilities of the DNA Recombinant Molecule Program Advisory Committee are described (including responsibilities for approving proposed new host-vector systems), and the responsibilities of all NIH staff include special criteria to insure adequate review for safety of DNA recombinant molecule research.³⁹

E. THE DNA RECOMBINANT MOLECULAR ENVIRONMENTAL IMPACT STATEMENT

During the considerations of the guidelines, the Director of NIH was urged to promulgate an Environmental Impact Statement. Subsequent to the issuance of the guidelines, the Director determined that it would be advantageous to the public and in compliance with the National Environmental Policy Act (NEPA) of 1969 to issue such a statement. The Draft Environmental Impact Statement was issued in the Federal Register on September 9, 1976⁴⁰ (see appendix 10). This statement provides a description of the recombinant DNA research; events leading to the development of the guidelines, a description of the issues associated with DNA recombinant research, a discussion of the guidelines and other proposed action; and an assessment of the possible environmental impact of such guidelines. The issuance of the Draft Environmental Impact Statement *after* the publication

³⁸ Ibid., pp. 27914-27915.

³⁹ Ibid., pp. 27920-27921.

⁴⁰ Recombinant DNA Research Guidelines. Draft Environmental Impact Statement. Federal Register, vol. 41, September 9, 1976: 38426-38483.

action on the guidelines has been criticized because the NEPA is intended to secure public reaction before the actions contemplated are actually implemented. In the Draft Environmental Statement, the Director justifies this unusual action by pointing out that it was his position that the public interest would be best served by immediate issuance of the guidelines. His opinion was that the likelihood of the escape of potentially dangerous organisms was greater in the absence of guidelines and that prompt issuance of guidelines was necessary to gain cooperation of scientists not controlled by NIH funds as well as that of researchers in other nations.

The possibility that NEPA procedures, particularly the Environmental Impact Statement, would be the appropriate procedure for assessing biological technologies, and more specifically the DNA recombinant issue was considered earlier by Parenteau and Catz.⁴¹

These authors point out:

At present, no mechanism exists for systematically disseminating information on this important research effort to the public; public debate of these issues [biomedical technologies] requires finding some such mechanism.

... One solution to the information gap problem lies in requiring Federal agencies responsible for funding these research programs to prepare and disseminate detailed statements explaining the nature of the work and the costs and benefits that are likely to result.

... As we stand on the verge of such breakthroughs (genetic, invitro fertilization, etc.) in biological research, it becomes necessary to examine the degree to which society can and should control that research.

... It would seem that biological technologies, with their great potential for direct impact of mankind's physical, intellectual, and psychological characteristics fall squarely within the policy declarations of NEPA.

... Where a technology is rapidly taking shape and will be ready for application within a short time, NIH ought to make a serious effort to explain, in as great detail as data will permit, the environmental effects of its application.

... The need for relying on NEPA procedures in this area is underscored, however, by the alternative of leaving the process entirely in the hands of the scientific community without public participation or scrutiny. That alternative is unacceptable.⁴²

This discussion, encouraging the use of the Environmental Impact Statement (EIS) for assessing biomedical technologies, succinctly summarizes the larger issue of public participation in the decision making process for technologies having obvious societal impacts. Apparently, the Director of NIH reached the same conclusion about the use of an EIS, although the timing of the publication may not have been fully acceptable.

F. RISKS AND BENEFITS OF DNA RECOMBINANT MOLECULE RESEARCH

1. *Benefits.*—The benefits postulated most frequently, if the research with DNA recombinant molecules is successful, can be classified in three broad categories.

First, and of fundamental importance to all genetics research, the technique is considered important as a fine tool for the examination and identification of gene function. The number of genes per chromosome for the higher organisms is so large that, with procedures other

⁴¹ Parenteau, Patrick A. and Robert S. Catz. Public Assessment of Biological Technologies: Can NEPA Answer the Challenge? Georgetown Law Journal. vol. 64. February 1975: 679-695.

⁴² Ibid., pp. 680, 682, 684, 695.

than recombinant molecule research, it has been almost impossible to do more than correlate function with a particular chromosome. It has (except in a few rare instances) been very difficult to construct maps of the human chromosome to ascertain the point (gene) which regulates a particular biochemical activity. The deciphering of the meaning of duplicate gene sequences on a chromosome, the location of activation or repression sections (or stop and start sections of chromosomes), the determination of interactions of adjacent genes, the effect of relocation or displacement of normally adjacent sections, and many other positional factors are of the utmost interest. As pointed out by Lane, the raw materials for experiments to gain information on the control of gene expression might be provided by cloning DNA recombinant molecules.⁴³

It will only be possible to correct by genetic engineering a particular gene controlled deficiency when knowledge of the gene or combination of genes, or positional relationships of genes within chromosome pairs or even between pairs of chromosomes, is known. Current information is far from sufficient to accomplish this objective. DNA recombinant research is identified as an important method for carefully isolating many of these individual factors and then relating these factors to function. Even with this research technique, the task will be laborious and detailed for the DNA of a mammalian cell adds up to be the equivalent of several million genes. It is the knowledge that the task will require a great deal of time and effort which adds to the sense of urgency about continuing research.

The attempts to determine this type of information have been initiated primarily with microorganisms and viruses because these contain some of the simplest organized chromosome structure, that is small numbers of genes or information units. Work on the exchange of DNA between species, genera, and even different kingdoms, has been pursued in order to test the thesis of the common nature of DNA to all living organisms. An alternative but closely allied technique is direct transfer of DNA by cell fusion or other procedures for incorporation of DNA fragments.

In order to have confidence in the information being derived from recombinant research, the investigator must be sure that the genes introduced into the host system are the structures of interest and that these genes actually are producing the function being observed. For this reason, the techniques for assuring a reasonable supply of purified segments of DNA are important. Cloning facilitates the collection of this material.

The research with recombinant molecules as well as with cell fusion and other methods for introducing exotic DNA into cells also provides an opportunity to explore some of the interactions involving extra nuclear structures such as the plasmids in bacteria and the cytoplasmic activities of interest in the cells of higher organisms. There is considerable interest in all of the mechanisms of gene translation, the actions of messenger RNA, and protein production. Much of this activity occurs outside the nucleus and therefore is of interest in the total study of genetic function.

⁴³ Lane, Charles. Rabbit Hemoglobin From Frog Eggs. *Scientific American*. v. 235. August 1976: 71.

On an even more fundamental level, recombinant research adds to the knowledge concerning the evolution of different species. These investigations permit exploration of theories concerning the genetic mechanisms of natural selection and provide an opportunity to test some of the theories concerning mutation and selection at the molecular level. It is apparent already that there are many sections of chromosomes of distantly related species based on current classical taxonomic methods, which are very similar if not precisely identical.

A second classification of benefits from recombinant research falls into the more easily identifiable area of potential therapeutic benefits. These are the benefits most frequently identified by the lay person as being directly related to this research. Although there is considerable doubt at this point as to whether such an achievement is really possible, the brightest vision is the dream of being able to insert the correct gene to replace or override the influence of a defective gene or combination of genes which is producing a serious structural or metabolic defect. It is hoped that some day the recombinant techniques will produce the knowledge to permit the isolation of a defective gene controlling a particular defect and permit the introduction and incorporation of a correct gene. Thus, the gene therapy would be permanent and no drug or other lifetime care would be required. If defects can be detected during early development, and provided our knowledge of growth and development at the earliest stages is adequate, such "genetic engineering" techniques would enable mankind to prevent the suffering and sorrow now borne by the thousands of children with genetically induced birth defects.

If the answers to the questions about the disruptive activities associated with cancer can be secured as a result of contributions from recombinant research, then the diseases may possibly be attacked at the most fundamental level. In some instances, the association of viruses with cancer leads to the suspicion that viral transport of DNA and other incorporation of new or foreign DNA may induce cancer. In other instances, the basic assumption is that, in some way, the control system of the cell may be disrupted, thus leading to the uncontrolled growth known as cancer. Another theory suggests that genomes (genes) with the potential for initiating malignant activity may be resident in the cells of cancer prone individuals and exposure to appropriate environmental stresses induces tumorigenic or malignant activity. Investigations at the molecular level should aid in evaluating many of these hypotheses and ultimately may permit genetic intervention to prohibit the start of the cancer cycle.

A final example in this group, but not the last which could be discussed in a more comprehensive report, is that these research techniques offer the opportunity to biosynthesize an enormous variety of proteins of extremely great value in therapeutic medicine. Enzymes, blood components, and a host of other important human proteins seem to be the promise at the end of this research (see the paper by Lederberg in appendix 11 for further discussion on this point).

The third broad category of benefits relates to the opportunities hypothesized for the improvement of plant and animal species, not only in agriculture but in other important applications.

It has been estimated, for example, that it may be possible some day to produce more plants with the genetic capability to convert atmospheric nitrogen into the nitrate form necessary for plant synthesis of protein. This capability now exists in some plants as a result of symbiotic relationships between certain plants and bacteria. It has been speculated, and indeed this speculation may be near fruition, that it may be possible to induce genetically this nitrogen fixation capability in plants, such as corn, where such a capability does not now exist. The implications, in terms of reduced energy demands for the production of artificial fertilizers containing nitrogen, are indeed important in today's energy deficient environment and are also relevant to the need for increased production of food.

The opportunity to improve the efficiency of biosynthetic production of enzymes and other chemicals of industrial importance by genetically engineering improved characteristics in microorganisms used in fermentation and other processes appears to be an obviously important commercial opportunity. Processes involving the production of alcohol from grain, or modification of metabolic routes to provide such capabilities for other plant products, stretch the imagination in terms of potential bioenergy conversion systems.

The mechanisms of photosynthesis, while already one of the more efficient processes in nature, if significantly improved in efficiency might help to alleviate food shortages. Indeed, the potential exists to permit the construction of specific organisms with unusual characteristics for improvements in the photosynthetic process and also changes in metabolic functions related to the synthesis of all of the essential amino acids within one plant food source.

Only the imagination of the investigator seems to limit the potential applications in agriculture and industry. At the same time, an acceleration in the improvement of characteristics of agriculturally important animals is being hypothesized.

The use of microorganisms to aid in the conversion of wastes into useful products or to "clean-up" hazardous spills of chemicals is being examined. If the characteristics of an oil consuming microorganism could be improved, perhaps such an organism could be used to convert fuels into innocuous breakdown products and thus the pollution danger to water and land ecosystems from such spills could be significantly reduced. In other problems, sludges or industrial wastes might be treated with specially constructed microorganisms to permit conversion either to useful products, even with some side benefits in the form of useful energy, or at least a chemical reduction to products which could be safely returned to the environment.

While it is true, that many of these benefits could be obtained through normal genetic hybridization procedures, the scope of modification and the rate at which such modifications could be accelerated is said to be orders of magnitude greater if the recombinant work can be developed to the point where such capabilities can be applied. In most instances, excluding a few near term developments of potential commercial value with microorganisms, a great deal of work must be done at the basic research level to determine whether many of these potential benefits are actually feasible. Much of the information made

available from traditional hybridization experiments can be utilized. However, the DNA recombinations being produced or contemplated will result in many rearrangements and gene combinations which do not occur at all naturally or, if they have occurred, do so with such a low order of frequency that it is almost impossible to detect such unusual variants.

2. *Risks*.—The discussions of risks almost invariably take the form of concern about catastrophic epidemics or the creation of new and uncontrollable harmful organisms. For purposes of systematizing these discussions, the risk estimates may also be classified into three general categories.

At the basic research level, opponents enter a philosophical level of debate and challenge the ability of investigators to ever quantify the benefits or the risks in a fashion to permit evaluation and intelligent decision making. The fear has been expressed that DNA recombinant research may somehow adversely affect the diversity of natural gene pools. (See the papers by George Wald, Marc Ptashne and Robert Sinsheimer in appendixes 12 and 13.)

There are frequent and detailed analogies drawn between the dilemmas confronted in the current nuclear power debates and the basic research proposals in the field of DNA recombinant research. Statements, occasionally in the form of demands, have been made that a full moratorium on all DNA recombinant research should be instituted until all of the social, legal, and moral implications of this research have been thoroughly examined. Chargaff, for example, discussed the "awesome irreversibility of what is being contemplated."⁴⁴ He continued his discussion by expressing concern about the fact that there is no way of really knowing what is happening in changing the orientation of genes within new organisms and that we might be producing an irreversible attack on the biosphere. Haring asks whether mankind is to be allowed to try, by direct genetic manipulation, to improve the human species beyond the requirements for therapy? He questions whether man can be trusted to approach such important research frontiers in the right spirit. He expresses the fear that the altruistic aims of DNA recombinant molecular research may fall under the heartless rules of the marketplace.⁴⁵

In general, many of these objectives would have to be countered by proving the negative, an impossible task. The issues are very important as they expose basic concerns about the ethics of science generally. As pointed out by Sinsheimer, risks must be assessed in terms of probability calculations which are virtually impossible to measure.⁴⁶ It was this general issue of ethics in science and the problem of resolving philosophical conflicts between science and non-scientists that was the topic of a conference held in June 1976 at the very time that the Director of the National Institutes of Health was requiring a continuing examination of public reactions to proposals for guidelines to control DNA recombinant research.⁴⁷ The coincidence between this

⁴⁴ Chargaff, Erwin. On the dangers of genetic meddling. *Science*. vol. 192. June 4, 1976: 938, 940.

⁴⁵ Haring, Bernard. *Ethics of Manipulation*. New York. Seabury Press. 1975: 159-211.

⁴⁶ Sinsheimer, Robert. Troubled Dawn For Genetic Engineering. *New Scientist*. October 16, 1975: 148-151.

⁴⁷ Steinfels, Peter. Biomedical Research and the Public. A Report From the Airlie House Conference. *Hastings Report*. June 1976: 21-25.

increasing expression of concern about ethical issues in science and the controversy over the ability to carry out basic manipulations of basic life processes is most remarkable. It provides an ideal opportunity to introduce the evolving methodologies of ethicists in an examination of the most important developments of life sciences from the perspective of public participation in the science policy making process. The DNA recombinant molecule issue does indeed provide a unique opportunity to study a case history during its evolution rather than after the fact.

While it is more difficult to criticize the value of DNA recombinant work from the perspective of potential therapeutic applications, even here there are strong opposing opinions. Part of this concern is directed toward the fact that much of the research involves the use of *E. coli*, a microorganism which is a common inhabitant of the human intestine. Since this is an organism already adapted to the human environment, the concern is that accidents might result in easy entry and infection of human beings.⁴⁸

If the host with the recombinant molecule carried all or part of an oncogenic virus, for example, or now had an unexpected resistance to drug therapy, or could produce some new and unexpected toxin, then human beings might be exposed to a disease which could reach epidemic proportions. The arguments about probabilities of escape, probabilities of survival if escape does occur, and probabilities that such an escaped host would indeed be pathogenic are described as impossible to calculate and therefore meaningless in terms of evaluating potential risk. The position is that the opportunity for risk exists and therefore the research should not be conducted. For example, the Boston Area Recombinant DNA Group has presented a recommendation that a safer host be developed and *E. coli* be abandoned within two years for use in this research. The counterargument is that delay would occur until the required information about alternate hosts was made available. Another concern is about the need for haste to continue this research. What difference does it really make if it takes five years longer to develop a process or technique if, in waiting, a higher degree of safety is assured. The proposal is made that the risk at this point is too great to justify hurried continuation in the face of so many unknowns.

Those opposed to DNA recombinant research also suggest that the successes in drug therapy, improvements in diagnosis, the new knowledge of dietary therapy, and the evolution of a greater understanding and control of environmental factors may provide just as much of an opportunity to cope with genetically induced disease without gambling on the poorly defined risks associated with recombinant research. The dangers of producing some uncontrollable combination of genes with unknown pathogenic characteristics is considered by some individuals to be too great at this time.

With regard to the third group of benefits, opponents point to the great successes already achieved in the more classic types of plant and animal hybridization experiments.

⁴⁸ Anderson, E. S. Viability of and Transfer of a Plasmid From *E. coli* in the Human Intestine. *Nature*, v. 255. June 5, 1975: 502-504.

Some of the potential dangers of using recombinant techniques in plant hybridization are discussed in more detail by Doy. He indicated that genetic engineering with plants cells should be discussed as thoroughly as the present discussions are beginning with animal cells. Specifically, he noted:

The possibilities of this field are going to attract a lot of workers because of the science, but also because of the possibility of grants, fame, and fortune and realistically, I think in some quarters, because of the possibility of creating agents of biological warfare. I find among many scientists, and plant biologists in particular, either a lack of understanding or a reluctance to acknowledge the possibilities of accidental disaster or deliberate evil. Scientists working with transgenesis in animal systems and viruses have recently clearly recognized the possible dangers . . . I shall not reiterate the arguments, but I would urge that plant biologists participate in the proposed discussions [on DNA guidelines]. The potential dangers of the human and animal work appeal to the emotions and therefore have an immediate impact, especially in the media. To my knowledge the analogous possibilities in plant biology have not been discussed. I do not think that ideas can be suppressed, nor do I think that possibilities for understanding and good should be foregone because of possibilities for evil which might then go on in secret [Note: the plant sciences are represented on the NIH DNA Recombinant Molecule Advisory Committee].⁴⁹

The use of in-vitro fertilization techniques with reimplantation in host mothers is viewed as a safer method for improving the production of animals of agricultural importance which has not yet been fully exploited. While acknowledging the possible value of securing improved scavengers or organisms capable of currently unavailable bioenergy conversions or waste processing, the counterargument is that too little is known about ecosystem interactions to be able to predict the potential effects of such organisms if released into the environment. Experiences with other accidentally introduced organisms (such as American chestnut blight) which have proved catastrophic are cited as supporting this fear. Again, however, the ability to select naturally occurring hybrids suggests that there is no need to rush into the unknown dangers of recombinant research.⁵⁰

During a symposium at the University of California, Berkeley, April 1976, a number of the unusual events which might ensue following supposedly beneficial genetic engineering were discussed. Dr. Ananda Chakrabarty, a microbiologist at General Electric Laboratories, Schenectady, New York, reportedly pointed out that while it had been possible to manipulate *E. coli* to produce a strain which can convert cellulose into assimilable sugars and fatty acids, this might not be as valuable a metabolic capability as first perceived. For example, while it might appear that the ability to convert cellulose (such as wood) into soluble products would be a valuable capability in the human gut, as is now the case with ruminating animals, the establishment of such organisms in human beings might result in the production of fatty acids and sugars faster than the intestine could absorb them and lead to dietary problems, and possibly even harmful toxins. Chakrabarty also described the GE lab's success in constructing

⁴⁹ Doy, Colin H. Asexual Approaches, Including Transgenesis and Somatic Cell Hybridization to the Modification of Plant Genotypes and Phenotypes. In: Genetic Improvement of Seed Protectins. Proceedings of a Workshop. National Academy of Sciences. Washington 1976: 341-357.

⁵⁰ Canadian Scientist Isolates Pollutant-Gobbling Bacteria. InterCom. vol. 4. August 1976: 5.

a bacterium which could metabolize crude oil. He indicated, however, that it might be possible for pathogens in the environment to capture these new gene combinations and permit the pathogen to multiply in a crude oil spill to the point where an epidemic of disease might be possible. These examples are illustrative of the type of concerns being expressed by many researchers about the need for total ecological information before such research results in the release of genetically engineered organisms into an environment.⁵¹

3. *General Comments.*—Other comments which emerge in the risk/benefit debate associated with the justification of the continuation of DNA recombinant research examine more specific as well as broader issues on general research and development. There are questions as to the wisdom of diverting research funds at this time to an expansion of recombinant research when other areas of lower risk require funding. There are assertions of the increasing need for a fuller social participation in decision making for research which will ultimately impact on all of society.

Others have been quoted as saying that scientific investigation must never be permanently halted in the face of hazard—only ignorance, not knowledge, is the real danger to mankind.⁵² McDougall points out that genetic engineering has been going on for many years.⁵³ He suggests that the real concern stems from the suspicion that there will be an abuse of power and that there has been undue emphasis on potential hazards.

Davis has asked opponents of the research on recombinant molecules to consider that *E. coli* is already exposed to free human DNA which has been released from broken cells in the gut and that natural recombination may very well have been going on continuously.⁵⁴ Under these conditions, one would expect that random recombinations between free DNA and bacterial DNA would have occurred given the number of opportunities available and the time period of association of the two organisms. Thus, there probably already has been some testing of these combinations by natural selection and, if this is true, then experimental recombinants would probably not produce any new unusual combinations. His second point is that since natural evolution tends to emphasize selection of the combination providing a competitive advantage, deliberate recombinants would have a lower probability of survival. He concludes by asking whether the risk of working with recombinant molecules is really so much greater than the historical risk of dealing with many of the known pathogens to warrant prohibition or severe restrictions on recombinant research.

There is a general recognition by both sides of the controversy that the success of either biological or physical containment control systems imposed for research on recombinant molecule will be dependent to a high degree on compliance with any guidelines and on the capability of the investigator. Investigators involved in the development of these techniques at this time tend to be the elite among the total scien-

⁵¹ Genetic Engineering: Two-edged Sword. Chemical Week, May 12, 1976: 65–66.

⁵² McWethy, Jack. Science's Newest Magic, A Blessing or a Curse. U.S. News and World Report, vol. 81, July 12, 1976: 34–35.

⁵³ McDougall, Kenneth J. Genetic Engineering: Hazard or Blessing? Intellect, vol. 104, April 1976: 528–530.

⁵⁴ Davis, Bernard D. Evolution, Epidemiology, and Recombinant DNA. Science, vol. 193, August 6, 1976: 442.

tific (and semiscientific) community which may eventually enter this field. While not discussed intensively in the debates over this research, there appears to be in the background of many of the discussions, a concern that "sloppy" technique or a casual approach to research may increase the risk to a higher degree than has been estimated on the basis of research accomplished thus far. There is no question that accidents will occur.

Recent instances confirm that the biohazards of controlling dangerous microbiological research exist even under the best of conditions and even when the danger is evident. For example, a research worker at the Microbiological Research Establishment, Porton Down, Salisbury, England was reported to have been infected with viral hemorrhagic fever as a result of accidental penetration of the protective gloves being used in the highest level of biological security for such experimentation. This accident occurred at a laboratory reported as providing facilities unrivaled in Western Europe for safe handling of the most dangerous viruses known.⁵⁵ (Similar exposures have been reported in a rare accident during research work with Lassa Fever, another dangerous disease.) In the case of viral hemorrhagic fever, no known cure is available. Yet, such research must continue if the vaccines are to be developed. This is not to say that such risks must be assumed for dangerous work with recombinant DNA research, it simply illustrates that viruses develop normally in nature and can be coped with under existing experimental situations albeit with some degree of risk. This is, however, the type of situation envisioned by some critics as a potential hazard in working with recombinant molecules involving the transfer of genes with unknown biological activity.

Studies have been made to determine the extent of accidental infection even within such highly secure and tightly controlled facilities as the former biological warfare research laboratory at Ft. Detrick, Maryland. These studies have shown that while the incidence of infection leading to either morbidity or mortality has been relatively low, it has occurred frequently enough to demonstrate that the best of systems is not one hundred percent fail-safe. In these instances, a large proportion of the infections were the result of human failure to comply with safety requirements. None of the infections resulted in epidemics in the surrounding communities.

Irwin and Stoner have indicated that there is a need for continuous evaluation of laboratory procedures to insure that all safety conditions are being followed.⁵⁶ They propose a need for a continuous review of the biohazard control literature to aid in identifying weaknesses in control systems; consultation with special authorities on biohazard control; the need for an independent active surveillance program involving engineers, microbiologists, and other specialists; the need for regular on-site inspections to check physical conditions; the availability of safety cabinets; special instrumentation of safety cabinets to insure appropriate operation at all times; regular evaluation of labora-

⁵⁵ Lawrence, Eleanor, Porton Lab Will Study Fever Virus. *Nature*, v. 255, May 15, 1975: 185. (See: Morbidity and Mortality Weekly Report, Center for Disease Control, Atlanta, U.S. Department of Health, Education and Welfare, Public Health Service, v. 25, December 23, 1975: 378, 383 for a report of the accident with African hemorrhagic fever).

⁵⁶ Irwin, John and Gerald D. Stoner. A Facet of the Biohazard Control Program: Agent Registration, Risk Assessment and Computerization of Data. *American Journal of Public Health*, v. 66, April 1976: 372-374.

tory researchers and technicians to determine the adequacy of practices; and the use of written reports of evaluation to insure a legal record of investigations. As may be appreciated, such a description hints strongly that legislation and government regulation may be required which might lead to inspection and certification of laboratories in a fashion now being proposed for certification of clinical laboratories. The Center for Disease Control, Atlanta, already has some responsibilities in this area. Legislators have suggested publicly that legislation may be required to insure public safety, particularly for commercial recombinant research where compliance with the NIH guidelines is only voluntary. A key question about such legislation is whether it would be flexible enough so that it does not impose an unacceptable degree of restriction on all research, academic and industrial.

Dr. Roy Curtiss III, Professor of Microbiology at the University of Alabama and the designer of the first host-plasmid variant of *E. coli* to be approved by the NIH DNA Recombinant Advisory Committee as EK2 has provided a detailed analysis of the potential hazards associated with DNA recombinant work. As a trained microbiologist, who obviously is supportive of the DNA recombinant work, he is quite frank about the need to provide a high degree of assurance for the safety of such work. Perhaps it is his realization that inexperience and careless personnel can so easily lead to accidents that prompts his attention to this problem. In a recent review, he summarized the potential biohazards and identified the need for personnel training, the types of facilities required, and the requirements for emergency or accident contingency plans. He also provides information on the probabilities for escape and survival of recombinant molecules and the need for additional information before deliberate introduction into the environment in any form is accomplished. As he points out in his analysis, even the best of guidelines and safety procedures will be meaningless if there is noncompliance with recommended procedures. He notes that it is his belief that any release of DNA in one country would essentially mean release throughout the world (assuming survival). He suggests the need for some international authority to regulate beneficial uses of recombinant molecules.⁵⁷

The NIH DNA Recombinant Molecule Advisory Committee has not ignored many of these well justified expressions of concern. As a part of continuous revision of the guidelines, several tasks are of immediate concern.

The NIH has a special task to provide continuing information about the conditions necessary to ensure safety of the physical facilities described in the guidelines for experiments of varying degree of risk.

The DNA Recombinant Molecule Advisory Committee is meeting regularly to consider comments from all sources to determine the need for revision of the guidelines as new information is made available. The development of weakened hosts and vectors is being closely monitored and the test protocols for approval of such hosts and vectors is in a dynamic state of development with the best available information being used to ensure that all potential hazards are being considered.

⁵⁷ Curtiss, Roy III. Genetic Manipulation of Microorganisms: Potential Risks and Benefits, Annual Review of Microbiology. v. 30. 1976: 507-533.

Because so much of the information about both risk and benefit is very speculative, there is a continuing feeling of uncertainty which can only be resolved by regular reevaluation. To this end, the Director of the National Institutes of Health has indicated every intention to provide for public participation and contribution to all of the processes leading to the guidelines under his control.

As noted by a number of investigators, and a point which was addressed specifically by the American Society for Microbiology in its considerations of the DNA recombinant research issue, the task of coping with the fears raised by speculation about the potential of an epidemic from some recombinant molecule will require greater participation by epidemiologists. There is a great deal of experience from the laboratory study of extremely virulent pathogens. Microbiologists and virologists have learned to work with a high degree of safety with such organisms. Epidemiologists have a familiarity with the factors determining the spread of disease. Thus, there are data available, both from history and from theoretical risk models, to support a more precise examination of this concern and perhaps clarify the actual extent of the risk.

III. CONGRESSIONAL AND FEDERAL AGENCY REACTIONS RELATED TO DNA RECOMBINANT RESEARCH

A. HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY

The House Committee on Science and Technology, Subcommittee on Science, Research, and Technology has been evaluating the impending developments in the various genetic technologies for a number of years. The committee's interest became formalized in 1971 during an annual conference on research and development. As a result, a program of monitoring the developments to follow the progress of DNA research was initiated. Although no formal hearings have been held specifically on DNA recombinant research to date, the committee has published two separate reports on the progress of this technology so that the Members might be kept aware of the issues. These reports have served as useful reference documents not only for the committee members but also for other Members of both Houses. This report has been prepared to provide the committee and other Members with a summary analysis of the current status of the work in DNA recombinant work specifically so that the need for further action can be determined.

B. SENATE COMMITTEE ON LABOR AND PUBLIC WELFARE

The Subcommittee on Health, Senate Committee on Labor and Public Welfare held two hearings during the 94th Congress which were focused directly on the DNA recombinant molecule issue. The first hearing was held immediately following the Asilomar conference. Questions emphasized in this hearing and considered by witnesses as being of primary interest included:

What is the nature of this research which so disturbed the investigators that they felt compelled to stop it for a time?

Is there a safety threat to the general population?

What are the implications of the research for society as a whole?

How could nonscientists participate in the process; even if that were desirable, what should be done now in terms of public policy in this area?

Was it proper for scientists alone to decide to stop and then resume the research?

What are the potential dangers of Federal intervention?¹

These questions were not answered fully during this brief hearing and it was announced that the issue would be the subject of a continuing dialogue.

A second hearing was held by the subcommittee on September 21, 1976. These hearings were much more comprehensive with the theme

¹ U.S. Congress. Senate. Committee on Labor and Public Welfare. Subcommittee on Health. Genetic Engineering. 1975. Examination of the Relationship of a Free Society and its Scientific Community. 94th Congress, 1st session. April 22, 1975. Washington, U.S. Govt. Print. Off. 1975. 35 p.

being the NIH Guidelines on Recombinant DNA Research. Witnesses included representatives from the DHEW, the EPA, the Pharmaceutical Manufacturers Association, and the Environmental Defense Fund. The General Electric Company was invited to send a representative because of their known involvement in the DNA research but refused the invitation. Researchers testified from several of the major universities (Dr. David Baltimore, MIT; Dr. Norton Zinder, Rockefeller University; Dr. Robert Sinsheimer, Cal Tech; and Dr. Halsted Holman, Stanford). These witnesses represented the contrasting range of views concerning the acceptability of the guidelines and the need for the research. The views expressed by some of these witnesses have already been cited in other sections of this report with the exception of the statement by Dr. Wilson K. Talley, Assistant Administrator for Research and Development. His comments are of interest for they indicate the concerns which led to the establishment of a Federal interagency coordination committee on DNA to determine the applicability of the guidelines to all Federal agencies. During his testimony, Dr. Talley said:

Because the NIH guidelines only apply to research conducted or sponsored by NIH, universal protection against the potential hazards of this research can only be accomplished if the guidelines are extended to cover recombinant research performed by other Federal agencies and the private sector. I strongly support the extension of the coverage of the guidelines to all recombinant DNA research performed in the U.S. To this end, EPA will actively participate on the interagency committee on DNA research which has been established by the President.²

[Note: While Dr. Talley, has referred to this interagency committee as being established by the President, the formation is not quite that formal. The committee is one formed by the Secretary of HEW with the President's approval and is chaired by the Director of the National Institutes of Health. Senators Kennedy and Javits had forwarded a letter to the President on July 19, 1976 in which they had expressed their concern about the need for implementation of the NIH guidelines at all levels of responsibility. In their letter, the Senators urged the President to explore all executive means for extending the guidelines and if legislation was considered necessary, to make proposals to the Congress. The interagency committee is one of the mechanisms adopted by the Secretary of HEW to explore the problem of implementing the guidelines among all Federal agencies.]

Again the Subcommittee on Health indicated that this topic was considered to be of sufficient concern to warrant further evaluation and as indicated by the Chairman, he would consider legislative action in the event that industry does not voluntarily comply with the guidelines.

C. NATIONAL SCIENCE FOUNDATION

The National Science Foundation is funding a very unusual project which eventually may be viewed as a model method for studying evolving social problems. Under the Directorate for Science Education of the NSF, there is a special project on Ethical and Human Values in Science and Technology. As one part of this program, the Massa-

² U.S. Congress. Senate. Committee on Labor and Public Welfare. Hearings. September 21, 1976. op. cit.

Massachusetts Institute of Technology has accepted a task, funded by NSF, to prepare an oral and documentary history of all activities associated with the DNA recombinant molecule issue. Personal interviews are being taped with all individuals who have significant contributions to make in the debate. The proceedings of the various conferences and meetings in this country, and wherever possible in other nations, are being recorded. An archive of official documents, articles, and other printed material pertinent to any aspect of the controversy is being constructed to supplement the taped interviews. This project, under the direction of Dr. Charles Weiner, Department of History, MIT, is being identified with increasing interest and enthusiasm by researchers around the country. The project materials will be available to historians or other researchers desiring to study the evolution of this issue and for this reason will be a unique record of an exceedingly complex social policy issue.

D. OTHER FEDERAL ACTIVITIES

The Director of the National Institutes of Health has been holding interagency meetings with other executive agencies to determine the best course of action to follow with regard to adherence of these agencies with the NIH guidelines. As indicated earlier, most of these agencies have indicated their intention to comply. Total agreement has not been reached on this problem however, and the interagency meetings are continuing in an attempt to resolve this problem.

This interagency committee also is examining legislation to determine whether there is authority already in existence to permit regulation of all DNA recombinant research—whether Federal, State or local government, university, or private. The laws under which the FDA, OSHA, EPA, the Center for Disease Control and others operate are being studied to ascertain whether these agencies, collectively or individually, already have the responsibility to permit regulation if necessary. There are many difficulties involved, such as the need for additional State-Federal agreements for OSHA regulation of universities, and if it appears necessary, one of the tasks of the interagency committee is to recommend such additional legislation as might be necessary.

Among other ideas tentatively explored has been the potential need for a Biohazards Commission of some type to oversee DNA recombinant research as well as possibly other biological hazardous experimentation. In the Office of Technology Assessment, the Advisory Panel on Decision Making on R&D Policies and Priorities, has initiated a case study of the manner in which decisions are made regarding the funding of research and development. Dr. Robert F. Rushmer, Professor of Bioengineering and Social Management of Technology, University of Washington, a member of this panel, has initiated an analysis of the DNA recombinant molecule issue as a prototype for developing mechanisms for presenting points and counterpoints about evolving technologies.³ It is his intention to develop this analysis into a case study for presentation to OTA.

³ Letter to the Advisory Committee on Recombinant DNA Molecule Program, September 3, 1976.

As an example of the type of legislative action related to problems in genetics which was initiated during the 94th Congress, one bill is of particular interest. S. 2515, introduced by Senator Kennedy for himself and Senators Javits and Schweiker, contained a provision of direct relevance to the DNA recombinant issue. The primary purpose of the bill was to amend the Public Health Service Act to establish a President's Commission For the Protection of Human Subjects involved in biomedical and behavior research. Section 483 of the bill would have required the Commission also to:

... conduct an investigation and study of past, present and projected research in the modification of any living organism or virus by the inspection of recombinant DNA molecules. The Commission shall consider the ethical, social, and legal implications of such research, and evaluate the potential hazards posed by such research both to research personnel, the human subjects of such research, and to the public at large. The Commission shall, if appropriate, develop guidelines on how such research should be carried out in order to protect human health.

The legislation passed the Senate but not the House.

IV. NON-FEDERAL REACTION TO DNA RECOMBINANT RESEARCH AND THE GUIDELINES

A. INTRODUCTION

The debate concerning the NIH guidelines and the issue of DNA recombinant research is not limited to the Federal hierarchy alone nor to those institutions participating in the Federal decision-making process. This is a truly national debate, indeed, it is even international in scope.

As may be noted in the selected examples in the following paragraphs, the issue has rapidly expanded down to the level of local government. There are active discussions going on ranging in size and intensity from small student/faculty discussion groups up to the level of serious consideration at the State level of the need for controls through legislation or other regulation. A few of the more prominent instances have been selected and summarized in order to convey the extent to which this issue occupies attention throughout the Nation and the World.

B. UNIVERSITY OF MICHIGAN

University of Michigan faculty members attended the Asilomar Conference and have assisted on the NIH Recombinant Molecule Advisory Committee. The University, following the suggestions of several faculty members, initiated a parallel local study and discussion of the research on recombinant DNA in early 1975. The University committee has utilized the same process of evaluation being followed at the Federal level. The committee members represent university programs in health and human values, law and psychiatry, philosophy, medicine, genetics, history, biochemistry, physics and mental health, English, literature, social work and social psychology. Deans of the Schools of the University were consulted and the news media was contacted to insure public awareness. The faculty was informed of the deliberations, university opponents of the research programs were offered opportunities to discuss their views, critics from other universities or institutions were invited to submit their views, the literature was examined—both scientific and ethical literature—and the occupational and safety aspects of the issue were considered.

The University of Michigan report on a "Policy for the Molecular Genetics and Oncology Program" essentially adopted the NIH guidelines with the recommendation that the research be allowed to continue. It was recommended that: the NIH guidelines should be the code of practice for all work on the campus regardless of the source of funds; only research up to and including work at the P3 level of containment should be permitted (P4 work would have to be completed outside the University campus unless separate and specific ap-

proval was provided by an appropriate University decision-making authority); the University should establish a Biological Research Review Committee to maintain continuous surveillance of activities associated with such research; the Review Committee should set up a procedure for reporting accidents and maintaining records of such events; appropriate training for all personnel be instituted; procedures for continuous monitoring be established; and that the University Senate Assembly Committee on Research Policies regularly review all practices to determine whether any new policies or changes needed to be instituted.

The University committee also considered the potential liabilities which might be associated with formal approval of research which might involve injury. The legal liabilities were considered by the University counsel from the standpoint of negligence and strict liability, workmen's compensation, nuisance statutes, State occupational health and safety legislation, Federal statutes, immunity against claims, and insurance requirements. The University committee determined on the basis of this legal analysis that there were no exceptional legal inhibitions to be anticipated with the possible exception of the need for strict adherence to safety regulations and included in their recommendation that DNA recombinant research be permitted to continue.

Nevertheless, there was not unanimity in the committee's decision. A dissension was filed by Dr. Shaw Livermore, Jr. of the University's Department of History. Dr. Livermore's disagreement was not with regard to the considerations given to the containment and other safety considerations. Like several other objections which have been voiced nationally, he said:

I do not believe that the University of Michigan should encourage research in DNA recombinant technology . . . I believe that the limitations of our social capacities for directing such a capability to fulfilling human purposes will bring with it a train of awesome and possibly disastrous consequences . . . Neither do I share a generalized fear of science and technology . . . What I am intent upon is the particular nature of DNA recombinant research . . . The claims of free inquiry and individual initiative are among the most zealously guarded in a free society and they should remain so . . . I do not sense that we are presently at such a crisis [. . . all temporarily-safe means to relieve human distress are justifiable] or are so powerless, that we must suspend judgment to grasp at each prospect of temporary alleviation.¹

After the publication of the University committee's report, a formal critique of the report was prepared by a group of faculty members and presented to the Regents of the University on April 15, 1976. The committee responded to the critique in a detailed comment which left the impression that the criticisms were for the most part unfounded. The arguments and counterarguments were similar to the objections and counterobjections being voiced about the National Institutes of Health guidelines. As at Harvard University, examination of the DNA research issue was coupled with the need to upgrade university facilities to provide appropriate containment and security to meet the requirements of the guidelines.

It should not be surmised from the preceding summary that the only considerations on this topic in Michigan were at the University

¹ Statement of Dissent. Shaw Livermore, Jr. Report of the University Committee to Recommend Policy for the Molecular Genetics and Oncology Program. (Committee B). The University of Michigan. March 1976.

level. The Washtenaw County Democratic Party provided a copy of a resolution they initiated which recommended that DNA recombinant molecule research be restricted by law to a limited number of facilities equipped to prevent inadvertent escape of test organisms until further data on the magnitude of the risk are available. Three institutions in Washtenaw County, Michigan were identified as carrying out DNA recombinant work: The University of Michigan, Eastern Michigan University and the Parke-Davis Research Laboratories. In their letter to the Chairman of the Science and Technology Committee, the suggestion was made that other researchers could make arrangements to conduct research at these limited number of facilities until such time as more information on the risks could be developed.²

C. HARVARD UNIVERSITY-CAMBRIDGE

Perhaps the most highly publicized disagreement regarding the conduct of DNA recombinant research occurred at Cambridge, Massachusetts. In this university setting, the Cambridge City Council challenged the right of Harvard University to conduct potentially dangerous research within the City. As in the case at the University of Michigan, Harvard University needed to upgrade some of its laboratory space in order to meet the more demanding requirements specified in the NIH guidelines. The controversy about the research drew the attention of proponents and opponents of DNA recombinant research from all over the Nation.

One of the reasons that the Harvard controversy received so much high level attention is that Harvard and MIT are already among the relatively few institutions having researchers highly capable of conducting such research. The issue had also been discussed during a public symposium at Massachusetts Institute of Technology and earlier events, not only in research in molecular biology but also in the social impact of medical genetics, had made members of the faculties of these universities particularly sensitive to the public policy implications of their research.

The issues discussed at the public hearings held by the Cambridge City Council were no different from those summarized within this report or discussed at other symposia. However, here the problem was immediate and local. Harvard and MIT have members of their faculty who present both opposition and support of the research. The City Council position was one of concern about the potential risk to the public. The result of the hearings was to establish a temporary moratorium on the conduct of the "higher risk" types of such research. In the meantime, Harvard University is completing the planned renovation of the laboratories which led to the focus of attention on this issue.

D. NEW YORK STATE

The first State level action on the DNA research issue has been initiated by the State Attorney General's Office in New York. Hearings were held in October 1976 to consider the need for action to control DNA recombinant research. The options considered during the

² Washtenaw County Democratic Party letter to the Chairman, Committee on Science and Technology. May 26, 1976.

October 21 hearings ranged from witnesses calling for a complete moratorium to a requirement for adherence to the NIH guidelines as suitably modified to meet any additional State regulations. The State hearing provided another forum for a discussion of the main grounds of debate which had been covered by essentially the same witnesses at the University of Michigan, the Harvard-Cambridge hearings, and during the various stages of development of the NIH guidelines. There has evolved a well identified core of proponents and objectors in this area and public hearings tend to provide an opportunity for further discussion of the same issues. No definite action has been taken as yet but it is significant that a State judicial body has now entered the national arena of debate on this issue.³

E. SAN DIEGO, CALIF., CITY COUNCIL

The San Diego City Department of Environmental Quality has been holding a series of semi-formal meetings for the past several months to examine the different points of view regarding the conduct of DNA recombinant molecule research at the University of California San Diego campus. These meetings are not being held in response to any particular public pressure but to insure that the city government and the university officials have examined the issue sufficiently to avoid such conflict as has evolved in other localities. It is anticipated that after one or two additional meetings the informal hearing group, a so-called "Quality of Life Group" will prepare a report for the Mayor of San Diego and the City Council which will provide some perspective for the local government to determine whether any action is needed. Since the City has no jurisdiction over university activities, any formal disagreements or representations for change or control will probably have to flow through the State government to university officials. It is unlikely that serious misunderstandings will occur since the University is represented on the working group by Dr. Clifford Grobstein, Vice Chancellor for University Relations and William Davis, staff member from the City Council's Department of Environmental Quality participates in the public meetings. At this time (December 1976) it is anticipated that it will probably be February 1977 before the report to the Mayor will be available.

F. INDUSTRY RESEARCH

Perhaps the area of primary concern regarding DNA recombinant research is that segment of the industrial research community which is already conducting such research. As practical applications of the technique come near, there will certainly be an expansion of effort in the non-Federal sector, including primarily commercial research efforts.

The Director of the National Institutes of Health was aware during the early stages of guideline development that one of the critical factors in the success of a voluntary compliance with the guidelines

³ Wade, Nicholas. Recombinant DNA: New York State Ponders Action to Control Research. *Science*. v. 194. November 12, 1976: 905-706.

would be industry acceptance. It was for this reason that he held a meeting with some 30 industrial representatives (see appendix 7) to determine their reactions to the proposed guidelines. During this meeting, it was evident that some research was already underway. General Electric, for example, had been reporting on its work with waste converting microorganisms primarily for purposes of developing bioconversion energy systems. Miles Laboratories indicated an interest in biosynthesis of enzymes. In general, the industries seemed to be somewhat hesitant to commit themselves with regard to the guidelines since it was believed that the guidelines might eventually assume the status of regulatory law and this would place an entirely different perspective on their views about the details in the guidelines. There is no comprehensive compilation of the extent and nature of DNA work which is being conducted in industry either in this country or throughout the world, although it appears that at least seven companies are doing some recombinant work. These are, in addition to Lilly, GE, and Miles, Abbott Laboratories, W. R. Grace & Co., Merck, and Upjohn.⁴ It is obvious that knowledge of the precise nature of any research being conducted would have great value in the competitive industries and just as with other proprietary work, there evidently is concern about maintaining industrial security. However, it is this very tendency for secrecy which produces a counter concern that potentially risky research might be attempted if no control or guidance is exercised.

Although Pharmaceutical Manufacturers Association President, Joseph Stetler implied during congressional hearings that the drug industry endorsed the guidelines and probably would not object to some monitoring,⁵ it does not appear that this spirit is general through all industries. (Stetler added Upjohn to the known list of other companies presently conducting DNA recombinant research.) Stetler indicated during his testimony that the only problems he anticipated had to do with the protection of trade secrets and the provision restricting volumes to ten liters. This latter provision would not be acceptable in any commercial applications.

PMA also indicated their support for the use of normal patent application procedures to protect developments which emerge during DNA recombinant research.

More recently, a news report was interpreted by some individuals as meaning that there was more resistance to the guidelines on the part of drug and chemical executives than might be inferred from the earlier testimony of Mr. Stetler. The Department of Commerce held a meeting with representatives of 17 companies to discuss the compliance procedures needed in order that commercial development might proceed safely in this area of research. During this meeting, the representatives of these industries apparently indicated that there would be a number of changes required before the guidelines would be acceptable as regulations. According to reports available, the industrial representatives would accept a system which would require them to register to conduct such research but would not force them to

⁴ Industry Wary About Genetic Guidelines. Chemical and Engineering News. June 7, 1976: 7.

⁵ U.S. Congress, Senate, Committee on Labor and Public Welfare. Subcommittee on Health. Hearings. September 21, 1976. op. cit.

comply with the guidelines, even though the implication was that there would be voluntary compliance.⁶ In general, however, there is no specific information to indicate that any basic changes in industry attitude have occurred. Again, a primary concern seemed to be the need to protect trade secrets until patent rights had been established.

G. GENERAL

The listing of the preceding specific examples of State or local government examination of the DNA recombinant molecule issue or industry reactions should by no means be interpreted to mean that these are the only discussions which are occurring. The Biological Safety Committee at Yale University, New Haven Connecticut has attempted, through public discussions which have included the city government, to keep their community apprised of activities at that university. In fact, Dr. Frank H. Ruddle, Chairman of the Yale Biological Safety Committee has already made a proposal to the NIH with regard to the possibility of establishing a national repository for DNA material which would provide some support to all investigators and thus prevent unnecessary duplication of effort. Such a national repository for DNA material would be similar in concept to the American Type Culture collection. Princeton University has completed a study recommending approval for research on recombinant DNA.

Other individuals and groups have expressed concern or support for this area of research from all over the Nation and from many diverse sections of our society.

The New York Academy of Sciences has sponsored one major symposium which included a discussion of this issue. The National Academy of Sciences has endorsed the guidelines. The Environmental Defense Fund and the Natural Resources Defense Council have petitioned the Department of Health, Education, and Welfare to apply the guidelines to all investigators regardless of source of funding. The petition, incidentally, cites as legal justification for HEW action of this sort the authority of NIH to regulate the spread of communicable diseases. The Federation of American Scientists has polled its membership to determine opinions regarding the research.

The American Association for the Advancement of Sciences, as a part of its expanding role in increasing public understanding of public policy issues will probably continue to play an important role in providing a public forum for the discussion of this issue. The American Institute of Biological Sciences regularly provides discussions on this subject for its membership. The American Society for Microbiology established an ad hoc committee to study the NIH guidelines. Their recommendations essentially endorsed the guidelines with several recommendations to strengthen containment criteria and to protect susceptible researchers. The ASM committee also indicated a need for increased ASM responsibilities in the area of education for DNA recombinant molecule researchers. The National Academy of Sciences is planning a special workshop in their Academy Forum Series (March 1977) to consider research on recombinant DNA.

⁶ Cohn, Victor. Drug Industry Seeks to Alter U.S. Rules on Genetic Studies. The Washington Post. November 20, 1976: A3.

A special congressional staff briefing on the need for legislation to control recombinant DNA research was held on December 14, 1976 under the sponsorship of the Environmental Study Conference [an informal congressional group supported by Members of both Houses] and the Scientists' Institute for Public Information.

Although the proliferation of interest in this issue has not been totally unexpected, there is some concern about the potential for the evolution of ordinances or regulations on a local basis. Since the research transcends local boundaries, there is a strong interest in the development of standard guidelines. In the discussions held thus far, the NIH guidelines have occupied a central focus of attention. There probably would be no objection by NIH if State or local regulations evolved which utilized these guidelines as the core for any locally enforced regulations. The evolution of a maze of regulations would, on the other hand, contribute to great confusion as to requirements and undoubtedly interfere with effective control over research which crosses not only State but international boundaries. Evidence for this same interest in other Nations is available not only from the statements made by foreign participants at U.S. meetings but also in the debates which are producing regulations in these other Nations.

V. INTERNATIONAL REACTIONS TO THE DNA RECOMBINANT MOLECULE RESEARCH ISSUE

A. INTRODUCTION

A number of nations have already taken formal action to regulate or consider regulation of DNA recombinant research. The U.S. Department of Health, Education, and Welfare is making a direct effort to maintain open lines of communication with these nations so that their views regarding the NIH guidelines may be considered as well as to determine any new data which might require evaluation in the United States. This cooperation was evidenced from the first Asilomar meeting on and including the meetings of the NIH DNA Advisory Committee meetings which have been attended by foreign representatives, principally the United Kingdom, West Germany, and the U.S.S.R.

B. UNITED KINGDOM

Toward the end of 1971, the British Association for the Advancement of Science expanded its efforts to make the public aware of the developments and consequences of science. In this objective at least, the BAAS was attempting, in the same way as the American Association for the Advancement of Science, to be more responsive to the need for greater interaction between society and the scientific community. Among the several areas of long range interest selected for special study by a working group of the BAAS was a thorough examination of the scientific, social, ethical and legal issues associated with advances in genetics and biology.¹ By the end of 1974, the working group had completed a series of papers on topics in this subject area and a report had been published in the form of a book.² The efforts of the working group are of interest not only because of the perspectives about the evolving issues in genetics which are presented but also because this group attempted to provide for an examination of these issues by a broad spectrum of representatives of different segments of society: the press, the Parliament, many fields of medicine and biomedical research, law, and sociology. This working group effort provided a natural background for the more intense examination of the DNA recombinant molecule issue which began to evolve during this period.

In another related action within the United Kingdom, a working party was set up by the Secretary of State for Social Services to

¹ Social Concern and Biological Advances. Report of a Study Group. British Association Publication 7412. British Association For the Advancement of Science. London. September 1974. 16 p.

² Jones, Alun and Walter F. Bodmer. Our Future Inheritance: Choice or Chance? A Study by a British Association Working Party. Oxford University Press. 1974. 141 p.

determine whether there was a need for taking special measures to control laboratory studies with pathogens. This action was initiated following an accidental release of smallpox virus from a laboratory in London. The time span of this study overlapped the DNA recombinant issue. Therefore, their report included a recommendation that a "Dangerous Pathogens Advisory Group" be constituted to provide advice on control measures for DNA recombinant research.³

The first comprehensive assessment of DNA recombinant molecule research was initiated following the publication in the journal *Nature* of the request by Paul Berg and others for a moratorium on certain forms of this research. Upon review of this statement, the Advisory Board to the Research Councils established another Working Party:

To assess the potential benefits and potential hazards of techniques which allow the experimental manipulation of the genetic composition of micro-organism; and to report to the Advisory Board for the Research Council.⁴

The "Ashby" Report provided a number of recommendations which focused on the need for safety in handling and work with DNA recombinant molecules. A central theme in this report, as in many reports in other nations, dealt with the potential danger of accidental dissemination of DNA recombinants with unpredictable and potentially dangerous characteristics. The general reaction to the report appeared to be quite favorable. For example, Bernard Dixon reported:

Lord Ashby's report is notable, therefore, in examining a potential hazard of unique seriousness—and one which has been brought into the arena of public debate by a group of scientists anxious about the repercussions of their own work. It is also unprecedented in the clarity and simplicity of its prose. The committee felt, quite rightly, that the subject should be made accessible to people not familiar with increasingly opaque jargon of microbial genetics. One cannot but applaud the motives of both the researchers and the Ashby panel in stimulating public awareness and discussion in this way.⁵

Dixon was not entirely satisfied with the report, however, and pointed out that the Ashby report identified research indicating that the K-12 *E. coli* could serve in the human intestine⁶ but at the same time suggested that the likelihood of such an event was extremely remote. The Ashby report was criticized further by Dixon for not calling for a complete stop to all research until the necessary safety systems had been developed.

The next phase of the British examination of this issue was completed by a "Working Party" assigned the task to:

(a) draft a central code of practice and to make recommendations for the establishment of a central advisory service for laboratories using the techniques available for such genetic manipulation, and for the provision of necessary training facilities;

(b) to consider the practical aspects of applying in appropriate cases the controls advocated by the Working Party on the Laboratory Use of Dangerous Pathogens.⁷

³ Department of Health and Social Security. Report of the Working Party on the Laboratory Use of Dangerous Pathogens. [Sir George Godber, Chairman. London. Her Majesty's Stationery Office. May 1975. 40 p.]

⁴ Secretary of State for Education and Science. Report of the Working Party on the Experimental Manipulation of the Genetic Composition of Micro-Organisms. [Lord Ashby Chairman]. January 1975. London. Her Majesty's Stationery Office. 23 p.

⁵ Dixon, Bernard. Not Good Enough. *New Scientist*. January 23, 1975. 186.

⁶ Anderson, E. S. op. cit.

⁷ Secretary of State for Education and Service. Report of the Working Party on the Practice of Genetic Manipulation. [Professor Sir Robert William, Chairman]. August 1976. London. Her Majesty's Stationery Office. 31 p.

A summary of the recommendations provided within this report was prepared by the editors of *Nature*:

The working party divides experiments into four categories (depending on their hazards) and provides a code of practice to cover each category . . . Researchers will submit details of their experiments to a Genetic Manipulation Advisory Group (GMAG) which will vet and categorize the work. They can then decide voluntarily whether or not to abide by the advice of the GMAG and to follow the code of practice.

But at the same time, details of the experiments will have to be submitted to the Health and Safety Commission (HSC) which has turned its eye specifically to all forms of genetic manipulation of microorganisms, including those which preceded the advent of the new technology for recombinant DNA. The HSC will, through its inspectors, police the work using the existing (and very wide ranging) Health and Safety at Work Act, which it administers. The great advantage of this Act is that it applies to all employers, in industry, public laboratories and universities. This has allowed the working party to avoid the problem being faced in the United States, where guidelines control only research sponsored by the National Institutes of Health (NIH) and leave industrial and defense-related work largely untouched.⁸

The British Health and Safety Commission did not take long to promulgate a proposed document for regulations for "Compulsory Notification of Proposed Experiments in the Genetic Manipulation of Micro-organisms."⁹

Although the request for comments on this document had a closing date of November 1, 1976, this date was extended to permit additional comments to be submitted. Reports in the literature indicate that the scientific community is quite disturbed by the stringency of the proposals in the HSC draft regulations and by the sweeping scope of the research encompassed by the regulations.

As the HSC regulations are under evaluation and consideration for revision prior to promulgation, the British Genetic Manipulation Advisory Group has initiated its examination of the problem. Sir Gordon Wolstenholme, Chairman of the Group has already met with the Director of the U.S. National Institutes of Health to consider the practicality of the guidelines which are evolving.¹⁰

Britain's Institute of Biology had already endorsed the guidelines developed at the Asilomar Conference. This organization as well as the British Society for General Microbiology, the Association of University Teachers, and the Association of Scientific, Technical, and Managerial Staffs are all directly affected by the proposals of the Health and Safety Commission.

C. CANADA

The Medical Research Council of Canada established an ad hoc committee:

to make recommendations to the Council regarding the safeguards to be required in MRC supported research on recombinant DNA molecules and certain animal viruses and cells.¹¹

⁸ Genetic Guidelines: Handle With Care. *Nature*. V. 263. September 2, 1976: 1. See also: Lawrence, Eleanor. Genetic Manipulation: Guidelines Out. *Nature*. v. 263. September 2, 1976: 4-5.

⁹ Health and Safety Commission. Consultative Document. Compulsory Notification of Proposed Experiments in the Genetic Manipulation of Micro-Organisms. London, August 1976. 6 p.

¹⁰ Britain and U.S. Discuss Genetic Engineering. *New Scientist*. November 18, 1976: 372.

¹¹ Draft Report to the Medical Research Council From Its Ad Hoc Committee on Guidelines for Handling Recombinant DNA Molecules and Certain Animal Viruses and Cells. March 1976. 72 p.

The Committee submitted its report to the Canadian MRC and a copy was provided to the Director of the U.S. National Institutes of Health for his comments. The report provides recommendations for mechanisms and procedures for monitoring of MRC supported research. As in the U.S. guidelines, it was suggested that the proposed MRC guidelines also be adopted for non-MRC funded research. Safety procedures and containment levels are described for varying degrees of hazardous work with viruses, cells, and recombinant DNA molecules.

D. AUSTRALIA

There is no formal government policy in this area; nor is there likely to be. The number of Australian scientists likely to do work in this field is strictly limited and well known to the scientific community.

The Australian Academy of Sciences has convened a "Standing Committee on Recombinant DNA Molecules." On behalf of the committee, Professor G. L. Ada of the Australian National University has prepared a report, titled "Guidelines for Both Physical and Biological Containment Procedures for Work Involving Recombinant Nucleic Acid Molecules."

Basically the document sets up and describes five "risk" categories and prescribes appropriate "containment measures" to be followed in each case. These categories are as follows: (a) minimal risk experiments; (b) low risk experiments; (c) moderate risk experiments; (d) high risk experiments; and (e) experiments to be deferred.

A final category includes:

Technically feasible experiments which present such serious dangers that their performance should not be undertaken at this time with currently available vector-host systems and presently available containment capability. These include the cloning of recombinant nucleic acids from highly pathogenic organisms (i.e. class 3 and 4 aetiological agents as classified by HEW), nucleic acids containing toxin genes and large scale experiments (more than ten liters of culture) using recombinant nucleic acids that are able to make products potentially harmful to man, animals or plants.

High risk experiments are described as those in which:

The Potential for Ecological Disruption or Pathogenicity of the Modified Organism Could be Severe, and Thereby Pose a Serious Biohazard Both Within and Outside the Laboratory.

Containment procedures for "high risk experiments" include "isolation from other areas by air locks and a negative pressure environment, clothing changes and showers for entering personnel and laboratories fitted with treatment systems to inactivate or remove biological agents that may be contaminants in exhaust air and liquid and solid wastes. The handling of agents should be confined to biological safety cabinets from which the exhaust air is incinerated." Containment procedures also prescribe use of "rigorously tested vectors and hosts whose growth can be confined to the laboratory."

Risk descriptions and containment levels for other categories are appropriately scaled down from high risk category.

The Standing Committee of the Academy requests scientists working on or proposing work in this area to study guidelines and then fill in a questionnaire. The committee will assess the degree of hazard in

submitted proposals and will recommend appropriate containment procedures. The Department of Health expects to be able to monitor proposed studies through the need for financing of proposed projects, the vast majority of which comes from government sources in one form or another.¹²

E. U.S.S.R.

There is no evidence available at this time that there are any restrictions on DNA recombinant research in the Soviet Union. This nation has had representatives in attendance at meetings in the United States, for example, at the Asilomar Conference which developed the initial guidelines, and at the public meeting of the NIH DNA Recombinant Advisory Committee. Some indication of the Soviet attitude about this research can be found in a recent paper prepared by I.T. Frolov. In addition to discussing the usual examples cited with regard to the benefits and risks of this research, including "a big danger in the case of their use for military purposes as well as in the hands of various kinds of ill-intentioned persons" Frolov notes: "... voices are being raised with increasing frequency concerning the need for democratic (sic) control over scientific research in fields abutting on the vial interests and man and mankind."¹³ It has also been learned informally that the Soviets have requested a culture of the viral vector being proposed for approval in DNA recombinant research at the U.S. National Institutes of Health.

In another report, Academician Vladimir Engelhardt who attended the Asilomar Conference is quoted as saying:

Soviet biologists . . . believe the ethical side of the problem has probably been exaggerated. At the moment, molecular biologists are happy if they can transfer just one gene. . . . The possibility of manipulating the huge number of separate genes that would be necessary if one was meddling with man's characteristics, is such a complex problem that it clearly lies in the distant future . . . when such genetic engineering becomes possible, society will be mature enough to overcome the possible dangers.¹⁴

F. FRANCE

The principal site of controversy over recombinant DNA work in this country has been at the Pasteur Institute. Genetic experiments of this type had been temporarily halted awaiting the guidelines from Asilomar. Following the publication of these guidelines, the French government formed two committees: one to examine the ethics of the research, the other to develop safety limits to control the research. At the time of this report, no definitive guidelines had been made available to the U.S. government, but the controversy at the Pasteur Institute is very similar to the debates occurring at Harvard, University of Michigan and other campuses in the United States.

¹² Source. Informal Document Provided by the Office of the Executive Secretary, NIH Recombinant Molecule Advisory Group. HEW. March 1976.

¹³ Frolov, I.T. Research on Man, Genetic Engineering. *Voprosy Filosofii*. no. 7, 1975: 83-95. no. 8, 1975: 121-138. (U.S. Joint Publications Research Service. JPRS 66307. December 5, 1975.)

¹⁴ A Unique Plan for Soviet Molecular Biology. *New Scientist*. January 8, 1976: 53.

G. OTHER NATIONS AND INTERNATIONAL ORGANIZATIONS

Committees to examine the DNA recombinant research problem and develop national positions regarding this research have been established in Sweden, (Swedish Medical Research Council); Japan, the Netherlands (Royal Academy of Science Advisory Committee), and West Germany. While other nations have entered into discussions at international conferences on genetics and cell physiology, there is at present no indication that procedures as detailed as those described for the United States, the United Kingdom, or Canada have been completed.

The European Science Foundation has recommended adoption of the guidelines proposed by the United Kingdom. Apparently, the ESF prefers the British approach because of the greater emphasis on physical containment rather than biological containment and the fact that the British approach would apply to all laboratories and not just government funded research. One important factor considered by ESF in its evaluations was the need for all nations to establish essentially similar control levels in order to prevent the movement of research from one country to another in search of the least stringent conditions.¹⁵

At the 16th General Assembly of the International Council of Scientific Unions meeting in Washington, D.C. in October 1976, the Council approved the formation of a Committee on Genetic Experimentation to monitor, assist, and advise on recombinant DNA research.¹⁶

The European Molecular Biology Organization has established a standing committee on Recombinant DNA to provide advice and assistance to any members engaged in genetic engineering research. Although the EMBO standing committee has no regulatory or legislative responsibilities, it is prepared to provide help on scientific and technical aspects of recombinant research. EMBO also has noted that a collection of bacteria, plasmids, and bacteriophages best suited for recombinant work should be established within Europe or elsewhere within the framework of EMBO. The EMBO advisory committee on DNA recombinant research also has advised the Director of NIH of their full support of the need to carry out experiments specifically designed to provide information to permit assessment of the hazards being postulated for this type of research. EMBO has been represented at several of the meetings held by NIH and at Asilomar and exchanges communications with the Director of NIH with regard to the guidelines which are evolving in the United States.

The World Health Organization has been urged to coordinate recombinant DNA studies. In the September WHO Chronicle, however, the position of WHO was stated as follows:

While WHO has a clear duty to act as a worldwide coordinator and promoter of international collaboration in this field [Safety of research on DNA recombinants], it should not itself set up guidelines but should ensure that Member States are kept fully informed of guidelines promulgated within countries chiefly with such research.

¹⁵ Kenward, Michael. Europe Urged to Adopt UK's Genetic Rules. Science and Government Report. v. VI. December 1, 1976: 3-4.

¹⁶ ICSU Acts on DNA, Taiwan, Space Issues. Chemical and Engineering News. October 25, 1976: 8.

. . . In view of the potential benefits of research on DNA recombinants, it is suggested that an expert group should meet within the next 12-15 months for a detailed examination of certain promising technical areas.

. . . The potential benefits of research on DNA recombinants in relation to agriculture are emphasized. The nutritional implications are enormous, and the possibility of obtaining new energy sources from plants should also be borne in mind.¹⁷

In summary, the DNA recombinant issue is receiving world wide examination in actions ranging from the specific recommendations to utilize the resources of the Occupational Safety and Health legislation in the United Kingdom to control all research wherever performed to an attitude of little or no immediate concern about the issue at this time. In all instances, it appears that lines of communication have been established among the various governmental groups and the efforts of the U.S. National Institutes of Health are receiving careful and regular scrutiny.

¹⁷ Towards More Effective Biomedical Research. WHO Chronicle. v. 30. September 1976 : 377.

VI. CONCLUDING REMARKS

A. GENERAL

In her introductory remarks in a recent paper, Barbara Gardner provides a good summary of the DNA recombinant research dilemma:

There is a growing realization in modern society that science and technology alone cannot solve the problems of contemporary life. Indeed, technology has in some cases given rise to problems . . . The rapid developments in the field of genetic research present perhaps the foremost area for social concern about the possible application of basic research. Future discoveries and refinements of current procedures will force society to confront squarely and resolve the question of the role of science and technology in modern life. The necessity for political, legal and ethical decisions will arise in genetics more than in other areas of scientific research because of the far reaching impact genetics has on humanity. Genetic research involves the fundamental elements of what it means to be human and alive. The imminent technological capability to alter or manipulate human nature and the human organism is the central concern . . .

. . . A leading commentator has postulated that there are four types of perception with regard to scientific research [citation given in the Gardner article]. When the consequences of any line of research are unknown, the possible outcome may be viewed with extreme optimism, moderate optimism, moderate pessimism, or radical pessimism. The extreme optimist sees the pursuit of scientific research as an intrinsic good which even the greatest possible dangers should not deter. The moderate optimist believes that more benefit than harm generally results from scientific research and therefore that research should proceed when the consequences are unknown. The moderate pessimist asserts that, based upon historical evidence, harm is as likely to result from research as benefit. Finally, the radical pessimist holds that despite the benefits scientific research has produced, its products are intrinsically harmful to modern society.

. . . In no other field of scientific research will the perception that society ultimately adopts prove as important as in genetic research.¹

As is evident in any examination of the debates on the DNA recombinant issue, there is a spectrum of perceptions present. One significant aspect of the debate is the fact that these various perceptions are being vocalized early in the research stage and thus the debate can be effectively engaged before full blown technology emerges. It is in the action-reaction part of the issue where there is a particular concern.

For example, in a recent commentary on public issues over the past 20 years, the *New Scientist* noted:

Cell biology, in the form of recombinant DNA research, is another controversial public concern, currently the subject for *unprecedented* [emphasis added] moves in Britain to establish legal constraints on scientific work.²

The implications of this comment vis-a-vis an unprecedented constraint over scientific work is evident also in the remarks of Dr. Stanley N. Cohen when he testified before the Senate Subcommittee on Health. Dr. Cohen pointed out:

While it is essential for the public to be assured that experiments seeking basic knowledge are carried out safely, I believe that it would be contrary to the

¹ Gardner, Barbara Jeremiah. The Potential for Genetic Engineering: A Proposal for International Legal Control. *Virginia Journal of International Law*, v. 16. Winter 1976: 1-2.

² Twenty Years On. *New Scientist*. November 25, 1976: 427.

public interest if the initiative of the scientific community in raising issues of experimental safety should lead to a decision by the public to *direct* [emphasis added] the scientific course of such investigations.³

Dr. Richard Roblin voiced a similar concern:

. . . I hope that this move toward self-regulation on the part of the scientific community will be given a chance to demonstrate its effectiveness before other forms of social control are applied.⁴

In contrast with this concern about certain basic scientific rights of free inquiry, Sinsheimer believes that we may be at a point in scientific achievement beyond which we should not proceed. He perceives long range philosophical issues in the DNA recombinant debate which he believes have not been adequately addressed.⁵

Dr. Susan Wright (University of Michigan), an outspoken critic of the process by which the NIH guidelines evolved, recently summarized her concern about reaching public policy decisions on difficult issues generally:

Advocates of the present policy [on DNA recombinant research] maintain that the public has participated in its formation. Let it be clear that expression of views to decision makers is a quite different matter from participation in decisions. Through the mechanism of a technical committee, decision-making power has been concentrated in the hands of front-rank researchers, all of whom are committed to biological research in general and many, to recombinant research in particular. There has been no representation from those most immediately at risk—technicians and maintenance personnel, for example; no representation from public interest and environmental organizations; no representation from the public at large.

It is questionable whether self-regulation of this type can be relied upon as a means of making public policy . . . Scientists must recognize that in a democratic society, they do not have special rights to self-government for an activity which carries serious implications for the whole society. . . . Unfortunately, procedures for making policy decision on hazardous areas of science and technology have not yet been developed.

Accountable commissions at the local and national levels established to formulate policy for all work that poses biological hazards might afford one path. Such bodies would require access to the widest possible range of technical perspectives from both advocates and critics. But their memberships should reflect the fact that their decisions would be on matters of public policy.⁶

Whether one agrees with the NIH guidelines or not, there is evidence that there was a deliberate effort to provide for participation by the public at large and by public interest groups. The persistence of this concern by the advocates of a need for even more public participation indicates that further efforts may need to be made. (For examples of the spread of participation thus far, see the several lists of participants in the appendices.)

It is difficult to resolve this complex issue into a minimum of factors for easy evaluation. Fundamentally, however, there appear to be several basic issues. One, there is a strong criticism that the decision to continue the research was made essentially on the basis of a determination that the research could be conducted at an "acceptable" level of

³ U.S. Congress. Senate. Genetic Engineering. 1975. Hearings. op. cit. p. 10-11.

⁴ Roblin, Richard. Ethical and Social Aspects of Experimental Gene Manipulation. Federation Proceedings, v. 34. May 1975: 1424.

⁵ U.S. Congress. Senate. Recombinant DNA Research and the NIH Guidelines. September 21, 1976. op. cit. (See also Appendix 13 for an editorial by Sinsheimer on this theme.)

⁶ Wright, Susan. Doubts Over Genetic Engineering Controls. New Scientist. December 2, 1976: 520-521.

safety rather than examining the issue from the perspective of whether the research should be conducted at all. In this respect, the DNA recombinant molecule issue is being likened to the nuclear energy problem. Some would prefer that the research had never continued to the technology. Two, there is an even more fundamental question which many wish would receive more attention. This is the issue of society interacting with science and the determination of the basic social responsibilities for the decision making process. The scientist is beginning to acknowledge the right of society to participate in the evaluation of the scope and rate of investment of resources in research but still wants to retain certain basic rights of freedom of inquiry. There is a nucleus of resistance to total scientific freedom as the ability to tamper with the most fundamental processes of life challenges the ability of society to perceive the implications of this capability. Perhaps this is fundamentally a fear reaction. The ethicists are finding this aspect of the issue a fertile field for investigation. Third, if the research is to continue, there is concern being implied that the investigator is not to be trusted.

This is the basis of the evolution of guidelines and the gradual emergence of stronger criteria such as monitoring, licensing, inspection, education, and training of investigators in this field. The British approach, through their Occupational Health and Safety Act, presumes a need for such regulation. Accidents recorded in history support the need for control, particularly as the research becomes more widespread and involves individuals without as high a level of competence or experience as the early cautious investigators. Related to this need is the fact that this research is not limited geographically or by national scientific capability. Experience in other fields of research have demonstrated that reasonably standard controls, if established, will be required, otherwise the research effort will move to the area of least resistance. In fact, Gardner emphasized this point specifically:

Genetic research has reached a crucial stage in its development. International society is now challenged to assert reasonable and carefully considered control over the direction of man's evolution. Such control is essential in order to prevent an irrational reaction to unexpected future events or an uninformed public perception of scientific manipulation of human evolution.⁷

In a very thought provoking lecture, Dr. Arthur Kornberg considered this new social evaluation of biomedical research which is occurring and which has lent strength to the current controversies confronting the DNA recombinant molecule research. He summarized his concern in one sentence when he said: "Strong social, economic and political pressures now threaten acquisition of basic knowledge." Kornberg certainly does not challenge, in his article, the serious evaluation of the commitment of resources to basic research, but he asks that the impact be carefully considered in terms of the rewards which may be lost if basic research is actively inhibited.⁸

⁷ Gardner, Barbara Jeremiah. *op. cit.* p. 428.

⁸ Kornberg, Arthur. Research, *The Lifeline of Medicine*. The New England Journal of Medicine, v. 294. May 27, 1976: 1212-1216.

Perutz pointed out in a review article:

Molecular biology is sometimes said to be of little medical significance because it has not cured anyone yet. A hundred years ago the same might have been said of histology. At that time cellular anatomy and pathology began to improve our understanding of many diseases; today, molecular anatomy and pathology give us much deeper insights . . .

What has molecular biology contributed to this work [studies of proteolytic enzymes and their inhibitors, haemoglobin diseases, etc.]? It has supplied the basic concepts of microbial genetics, mutagenesis, repair and feed-back control; it has supplied the techniques of transferring genetic material from one strain of bacteria to another. . . . These concepts and techniques were developed by scientists who set out to interpret fundamental biological processes in physical and chemical terms.

. . . . Although we know more now than when we started, molecular biology is still too young a science for it to be clear exactly where it will pay off, whence we may do best if we spread our efforts over a wide field.

. . . . There is a unity of life at the molecular level which implies that anything found to be true in *E. coli* may also hold in man. . . .

. . . . In the future, the most important contribution of molecular biology to medical practice may well be genetic engineering, but early hopes that eukaryotic genes could be transcribed and translated in prokaryotes have not yet materialized [note, this has now been accomplished]. Instead, workers may try to see if cultures of animal viruses carrying human genes could be used for the manufacture of therapeutically important human proteins.⁹

The guidelines are out and the limitations on certain types of DNA recombinant research are now proscribed more specifically. The continuation of DNA recombinant research and the rapid progress in exploring new areas of research with this tool are evidenced in the many papers cited within this report and in the selected bibliography. In fact, the interest is so intense now that a new journal, "Gene," will be devoted to publication of research in this area. In her report of the Biochemical Society's 9th Harden Conference "The Role of Recombinant DNA in Molecular Biology," September 20-24, 1976, Eleanor Lawrence provides ample illustration of how the researchers have continued their efforts to solve the mysteries of DNA regulated activities.¹⁰ She identifies research from all over the world. West Germany, Switzerland, the Netherlands, England, the United States, and Scotland, for example, all had scientists in attendance who reported on their efforts involving plasmid and viral vectors and the intricate techniques of recombinant DNA molecular research. This is not to say that the practical benefits are immediate nor that there has been any change in the status of firm knowledge about the risks.

B. MOVING ON

It is just as difficult to identify majority opinions regarding the nearness of application of genetic engineering techniques in human beings as it is to secure a resolution of the public policy issues concerning the risks of the experiments. In an editorial in *Lancet*, it was noted that:

. . . . Application of gene cloning to "genetic engineering"—in the sense of deliberate manipulation of the genetic constitution of an organism with a view to altering its characteristics—is a very distant prospect.

⁹ Perutz, M.F. Fundamental Research in Molecular Biology: Relevance to Medicine. *Nature*, v. 262. August 5, 1976: 449-453.

¹⁰ Lawrence, Eleanor. Nuts and Bolts of Genetic Engineering. *Nature*, v. 263. October 28, 1976: 726-727.

... Before any serious steps can be taken in this direction, at least three major problems must be resolved. Firstly, the gene or genes to be cloned have to be isolated from the parent organism in pure form. It is no accident that all the successful experiments to date have involved the gene coding for rabbit globin. ... No other mammalian gene, or its corresponding messenger R.N.A. template, has yet been isolated with comparable purity. ... Secondly, a suitable vector must be found to carry the gene from donor to recipient species, since native D.N.A. does not readily gain access to an intact cell. ... Thirdly, there are the fundamental questions of whether a gene inserted into the cells of a given organism will function at all and, if so, whether its expression will be subject to normal controls at a cellular level. ... At present this whole area is a closed book. ...¹¹

The Medical Tribune is more optimistic:

Clearly, it is now possible to make any double-stranded DNA once its purified RNA has been prepared. It should then be relatively simple with the use of available techniques to synthesize large quantities of particular genes. The ultimate direction taken by these advances in molecular biology remains uncertain.¹²

However, as noted in the earlier discussions on benefits, potential applications are much closer in other areas such as biosynthesis of pharmaceuticals and the construction of "scavenger" bacteria. In these instances, the technology for producing the "genetically engineered" organisms is not the immediate obstacle. It is concern that insufficient information is available to predict that there will be no adverse environmental hazards which seems to have temporarily slowed progress in this area.

The NIH guidelines (as well as the regulations/guidelines of other nations) are a fact. These guidelines are obviously a dynamic compromise between those who would hold up all DNA recombinant research until all of the pertinent public policy or safety questions are answered and those who would like to continue to enjoy the freedom to exercise their own prerogatives about the nature and direction of their work. Since the Director of the National Institutes of Health has clearly indicated that the NIH guidelines are subject to revision, there still exists a continuing opportunity for inputs into the process of evaluating these standards.

Several questions still seem to be relevant to this continuing evaluation. The guidelines are voluntary. The British approach suggests that alternative methods might be utilized to insure enforcement. In the United States as in the British Isles, the Occupational Safety and Health Act requires the conduct of work under safe conditions. Further, some laboratories are already subject to inspection and certification by the Center for Disease Control and proposals to expand clinical laboratories legislation will project this authority into other laboratories.

Although the NIH guidelines provide for a system of peer review extending from responsibilities of the individual investigator through his university and to the NIH, there is really no central control over all DNA recombinant research. The publication of a Draft Environmental Impact Statement to secure public reaction to the NIH guidelines provides an opportunity for ideas to be considered concerning the need for national biohazards control or some other licensing or registration system to be considered. Proposals for registration and

¹¹ Gene Cloning: One Milestone on a Very Long Road. *The Lancet*. April 24, 1976: 893.

¹² Advances in Molecular Biology. *The Medical Tribune and Medical News*. February 4, 1976: 11.

certification of all laboratories and personnel undertaking DNA recombinant research have been discussed.

As noted by the testimony of Dr. Talley from the Environmental Protection Agency, there is little information available from the standpoint of potential ecosystem hazard. This aspect of the DNA recombinant issue could profitably be examined in more detail and the necessary programs to acquire the needed information properly implemented. The current plans of the National Institutes of Health to begin an assessment of the hazards to acquire data to validate (or invalidate) the probability calculations of risk are being supported on a much smaller scale of investment than the investments to continue the DNA recombinant research. The original charge to the DNA recombinant molecule committee was to:

Evaluate . . . the potential biological and ecological hazards of DNA recombinants of various types, for developing procedures which will minimize the spread of such molecules within the human and other populations, and for devising guidelines to be followed by investigators working with potentially hazardous recombinants.¹³

The last charge seems to have received the highest priority. Critics of the pace of reactivation of DNA recombinant research efforts have said that the first two charges should have been thoroughly developed before the guidelines were approved. As a matter of fact, however, since adherence to any guidelines at this point is voluntary (except as governed by the peer review process during NIH funding), the Asilomar guidelines were actually the first step toward lifting the moratorium on certain types of research and the NIH guidelines simply are more specific and in some instances more restrictive as they apply to NIH funded research.

It is difficult to determine the best course among the many actions being proposed. The majority opinion seems to be to get on with the work. Grobstein has said:

Questions dictated by anxiety about the future are often vague and difficult both to phrase and to answer. They are, nonetheless, dangerous to ignore. . . . both the risks and the benefits are hard to quantitate, and neither may bear equally on all groups. Discussion of what can be done to reduce uncertainty may not yield universal assurance but it can lessen purely imagined fears. Such fears, otherwise, may come to dominate public reaction and become major determinants in new policy decisions.

It is important, therefore, to broaden and transform the restricted context of the Asilomar conference and the resulting NIH guidelines. The approach should now be dominated not by fears but by fundamental and positive objectives: (i) to continue expansion of the understanding of genetic phenomena; (ii) to minimize foreseeable hazard, whether to health, essential human relations, or biotic environment; (iii) to consider the priorities to be assigned to realization of positive social benefits from growing genetic engineering capability; (iv) to give "due process" to deeply held values whose accommodations may require time and special attention; and (v) to provide opportunity for "informed consent" or other reaction from the several publics that may otherwise see themselves involuntarily placed at risk.¹⁴

¹³ U.S. Department of Health, Education, and Welfare. Public Health Service. National Institutes of Health. NIH Public Advisory Groups: Authority, Structure, Functions, Members. July 1, 1976: 4.

¹⁴ Grobstein, Clifford. Recombinant DNA Research: Beyond the NIH Guidelines. *Science*, v. 194. December 10, 1976: 1133-1135.

Others have identified objectives in the form of questions. For example, can an agency that supports research also effectively regulate that research? Is the focus of attention on this issue accurate—the narrow view is concern about accidents—the longer range view deals with question of the potential impact of crossing species barriers? Is it necessary at this time to continue using *E. coli*? How much effort should be devoted to making available alternative and more acceptable test organisms? Shouldn't the potential risks of genetic engineering be postponed by delaying research in this field until the ethical and social problems of more immediately available biomedical application of other techniques in genetics are resolved. The list of questions is almost endless and includes critical legal issues associated with patent policies for discoveries in this field of research. This is an area under special study at this time by the Director of NIH.

Since the momentum of research on DNA recombinant molecules is increasing, it now appears that the basic science policy actions to be taken are those which will provide the most appropriate solution to these questions and similar objectives. The interface between legislation and research will determine which direction these actions will take.

APPENDIXES

APPENDIX I

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APPENDIX 2

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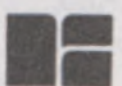
**SCIENTIFIC
AMERICAN OFFPRINTS****THE MANIPULATION OF GENES**

by Stanley N. Cohen

**SCIENTIFIC
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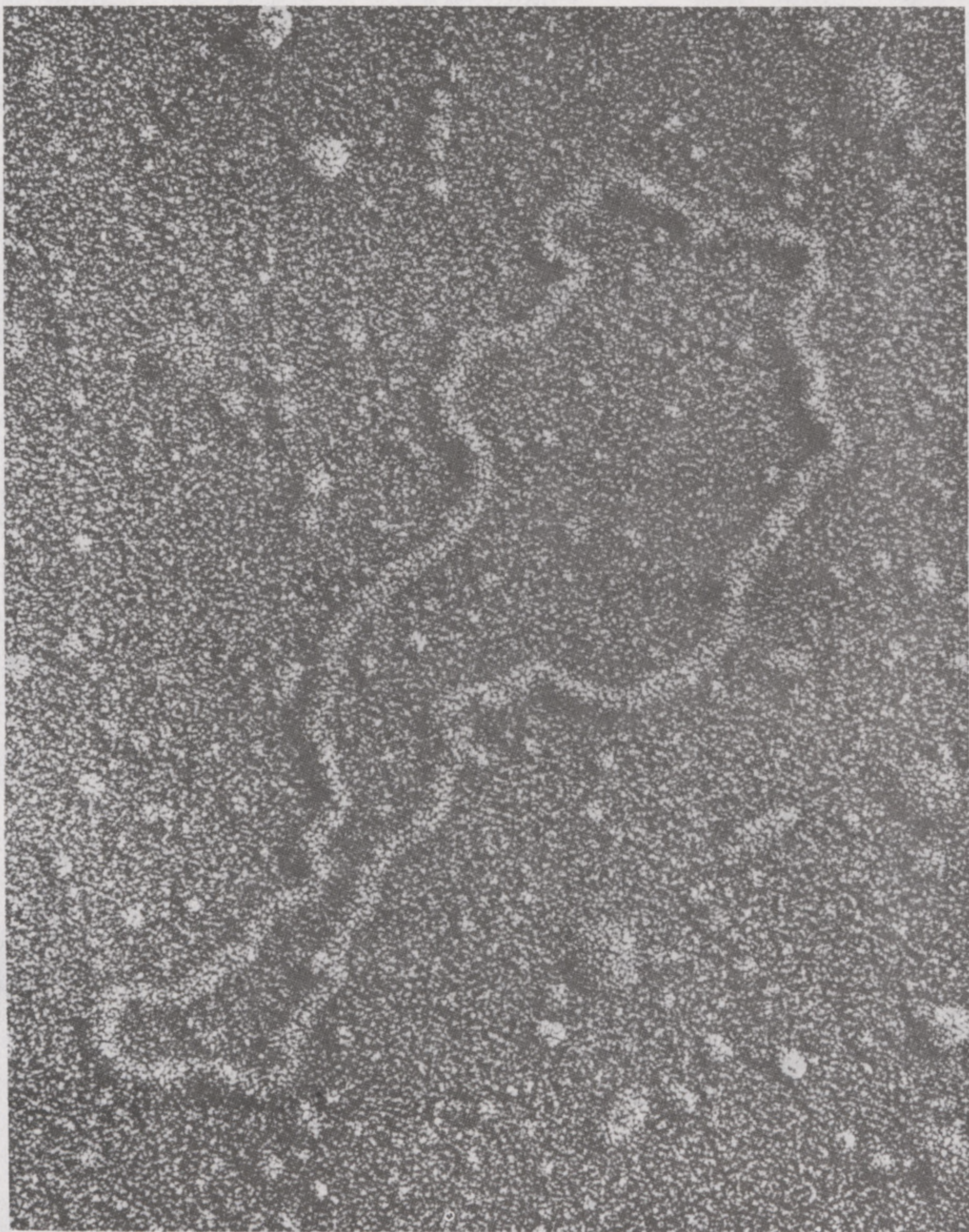
JULY 1975

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PLASMID *pSC101* is shadowed with platinum-palladium and enlarged 230,000 diameters in an electron micrograph made by the author. A plasmid is a molecule of DNA that exists apart from the chromosome in a bacterium and replicates on its own, often carrying the genes for some supplementary activity such as resistance to antibiotics. This plasmid, a small one made by shearing a larger plasmid native to the bacterium *Escherichia coli*, is a circular, or

closed-loop, molecule of DNA about three micrometers in circumference that carries the genetic information for replicating itself in *E. coli* and for conferring resistance to the antibiotic tetracycline. It was the "vehicle" for the first gene-manipulation experiments by the author and his colleagues. Foreign DNA was spliced to it and the plasmid was introduced into *E. coli*, where it replicated and expressed both its own and the foreign DNA's genetic information.

THE MANIPULATION OF GENES

Techniques for cleaving DNA and splicing it into a carrier molecule make it possible to transfer genetic information from one organism to an unrelated one. There the DNA replicates and expresses itself

by Stanley N. Cohen

Mythology is full of hybrid creatures such as the Sphinx, the Minotaur and the Chimera, but the real world is not; it is populated by organisms that have been shaped not by the union of characteristics derived from very dissimilar organisms but by evolution within species that retain their basic identity generation after generation. This is because there are natural barriers that normally prevent the exchange of genetic information between unrelated organisms. The barriers are still poorly understood, but they are of fundamental biological importance.

The basic unit of biological relatedness is the species, and in organisms that reproduce sexually species are defined by the ability of their members to breed with one another. Species are determined and defined by the genes they carry, so that in organisms that reproduce asexually the concept of species depends on nature's ability to prevent the biologically significant exchange of genetic material—the nucleic acid DNA—between unrelated groups.

The persistence of genetic uniqueness is perhaps most remarkable in simple organisms such as bacteria. Even when they occupy the same habitat most bacterial species do not exchange genetic information. Even rather similar species of bacteria do not ordinarily exchange the genes on their chromosomes, the structures that carry most of their genetic information. There are exceptions, however. There are bits of DNA, called plasmids, that exist apart from the chromosomes in some bacteria. Sometimes a plasmid can pick up a short segment of DNA from the chromosome of its own cell and transfer it to the cell of a related bacterial species, and sometimes the plasmid and the segment of chromosomal DNA can become integrated into the chromosome of the recipient cell. This

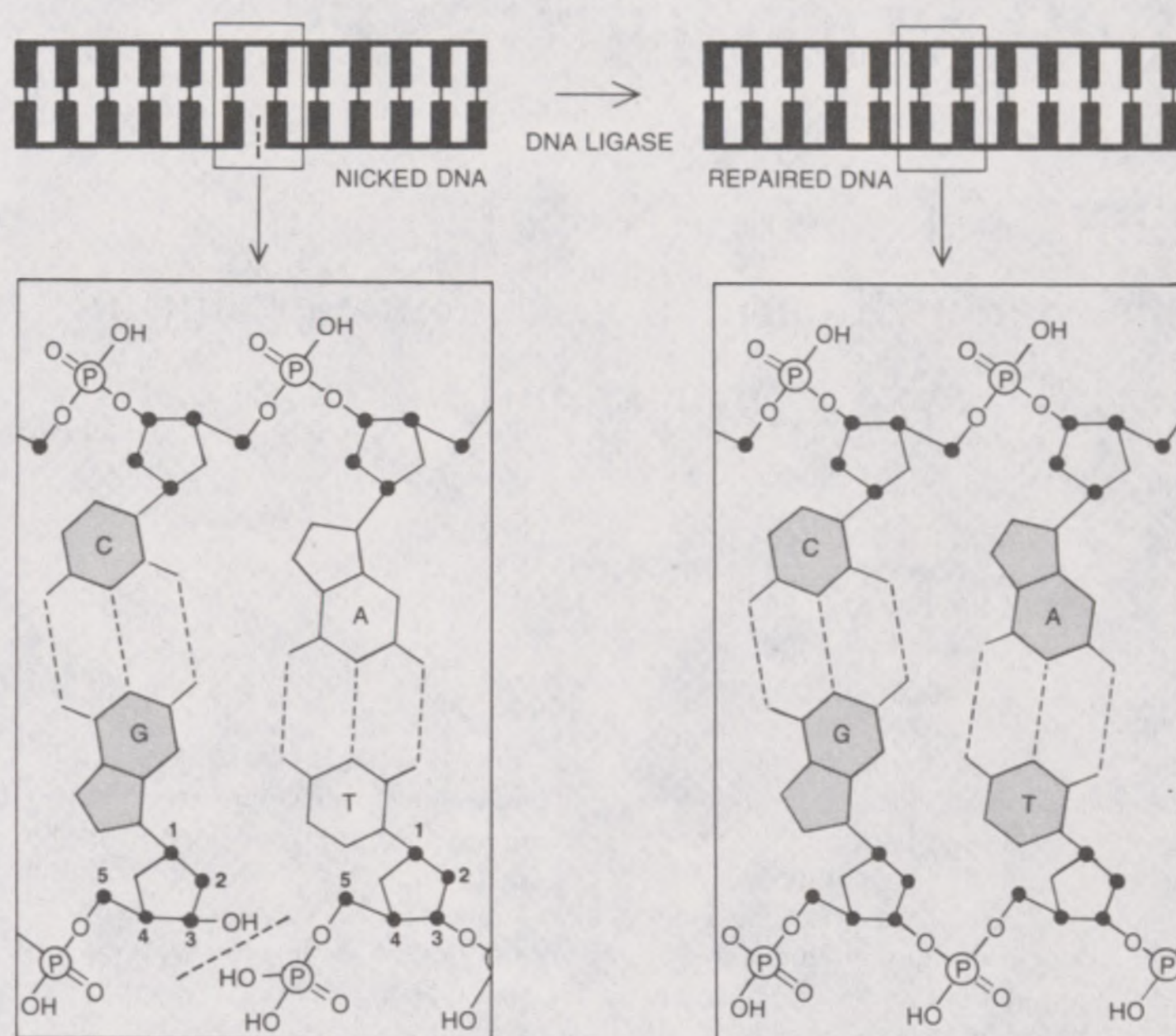
transfer of genes between species by extrachromosomal elements has surely played some role in bacterial evolution, but apparently it has not been widespread in nature. Otherwise the characteristics of the common bacterial species would not have remained so largely intact over the huge number of bacterial generations that have existed during the era of modern bacteriology.

In 1973 Annie C. Y. Chang and I at the Stanford University School of Medicine and Herbert W. Boyer and Robert B. Helling at the University of California School of Medicine at San Francisco reported the construction in a test tube of biologically functional DNA molecules that combined genetic information from two different sources. We made the molecules by splicing together segments of two different plasmids found in the colon bacillus *Escherichia coli* and then inserting the composite DNA into *E. coli* cells, where it replicated itself and expressed the genetic information of both parent plasmids. Soon afterward we introduced plasmid genes from an unrelated bacterial species, *Staphylococcus aureus*, into *E. coli*, where they too expressed the biological properties they had displayed in their original host; then, applying the same procedures with John F. Morrow of Stanford and Howard M. Goodman in San Francisco, we were able to insert into *E. coli* some genes from an animal: the toad *Xenopus laevis*.

We called our composite molecules DNA chimeras because they were conceptually similar to the mythological Chimera (a creature with the head of a lion, the body of a goat and the tail of a serpent) and were the molecular counterparts of hybrid plant chimeras produced by agricultural grafting. The procedure we described has since been used and extended by workers in several laboratories. It has been called plasmid en-

gineering, because it utilizes plasmids to introduce the foreign genes, and molecular cloning, because it provides a way to propagate a clone, or line of genetically alike organisms, all containing identical composite DNA molecules. Because of the method's potential for creating a wide variety of novel genetic combinations in microorganisms it is also known as genetic engineering and genetic manipulation. The procedure actually consists of several distinct biochemical and biological manipulations that were made possible by a series of independent discoveries made in rapid succession in the late 1960's and early 1970's. There are four essential elements: a method of breaking and joining DNA molecules derived from different sources; a suitable gene carrier that can replicate both itself and a foreign DNA segment linked to it; a means of introducing the composite DNA molecule, or chimera, into a functional bacterial cell, and a method of selecting from a large population of cells a clone of recipient cells that has acquired the molecular chimera.

In 1967 DNA ligases—enzymes that can repair breaks in DNA and under certain conditions can join together the loose ends of DNA strands—were discovered almost simultaneously in five laboratories. A DNA strand is a chain of nucleotides, each consisting of a deoxyribose sugar ring, a phosphate group and one of four organic bases: adenine, thymine, guanine and cytosine. The sugars and phosphates form the backbone of the strand, from which the bases project. The individual nucleotide building blocks are connected by phosphodiester bonds between the carbon atom at position No. 3 on one sugar and the carbon atom at position No. 5 on the adjacent sugar. Double-strand DNA, the form found in most organisms, consists of two



DNA LIGASE is an enzyme that repairs "nicks," or breaks in one strand of a double-strand molecule of DNA (*top*). A strand of DNA is a chain of nucleotides (*bottom*), each consisting of a deoxyribose sugar and a phosphate group and one of four organic bases: adenine (A), thymine (T), guanine (G) and cytosine (C). The sugars and phosphates constitute the backbone of the strand, and paired bases, linked by hydrogen bonds (*broken black lines*), connect two strands. The ligase catalyzes synthesis of a bond at the site of the break (*broken colored line*) between the phosphate of one nucleotide and the sugar of the next nucleotide.

chains of nucleotides linked by hydrogen bonds between their projecting bases. The bases are complementary: adenine (A) is always opposite thymine (T), and guanine (G) is always opposite cytosine (C). The function of the ligase is to repair "nicks," or breaks in single DNA strands, by synthesizing a phosphodiester bond between adjoining nucleotides [*see illustration above*].

In 1970 a group working in the laboratory of H. Gobind Khorana, who was then at the University of Wisconsin, found that the ligase produced by the bacterial virus T4 could sometimes catalyze the end-to-end linkage of completely separated double-strand DNA segments. The reaction required that the ends of two segments be able to find each other; such positioning of two DNA molecules was a matter of chance, and so the reaction was inefficient. It was clear that efficient joining of DNA molecules required a mechanism for holding the two DNA ends together so that the ligase could act.

An ingenious way of accomplishing this was developed and tested independently in two laboratories at Stanford: by Peter Lobban and A. Dale Kaiser and

by David Jackson, Robert Symons and Paul Berg. Earlier work by others had shown that the ends of the DNA molecules of certain bacterial viruses can be joined by base-pairing between complementary sequences of nucleotides that are naturally present on single-strand segments projecting from the ends of those molecules: A's pair with T's, G's pair with C's and the molecules are held together by hydrogen bonds that form between the pairs. The principle of linking DNA molecules by means of the single-strand projections had been exploited in Khorana's laboratory for joining short synthetic sequences of nucleotides into longer segments of DNA.

The Stanford groups knew too that an enzyme, terminal transferase, would catalyze the stepwise addition, specifically at what are called the 3' ends of single strands of DNA, of a series of identical nucleotides. If the enzyme worked also with double-strand DNA, then a block of identical nucleotides could be added to one population of DNA molecules and a block of the complementary nucleotides could be added to another population from another source. Molecules of the two populations could then be annealed

by hydrogen bonding and sealed together by DNA ligase. The method was potentially capable of joining any two species of DNA. While Lobban and Kaiser tested the terminal-transferase procedure with the DNA of the bacterial virus P22, Jackson, Symons and Berg applied the procedure to link the DNA of the animal virus SV40 to bacterial-virus DNA.

The SV40 and bacterial-virus DNA molecules Berg's group worked with are closed loops, and the loops had first to be cleaved to provide linear molecules with free ends for further processing and linkage [*see illustration on opposite page*]. (As it happened, the particular enzyme chosen to cleave the loops was the *Eco* RI endonuclease, which was later to be used in a different procedure for making the first biologically functional gene combinations. At the time, however, the enzyme's special property of producing complementary single-strand ends all by itself had not yet been discovered.)

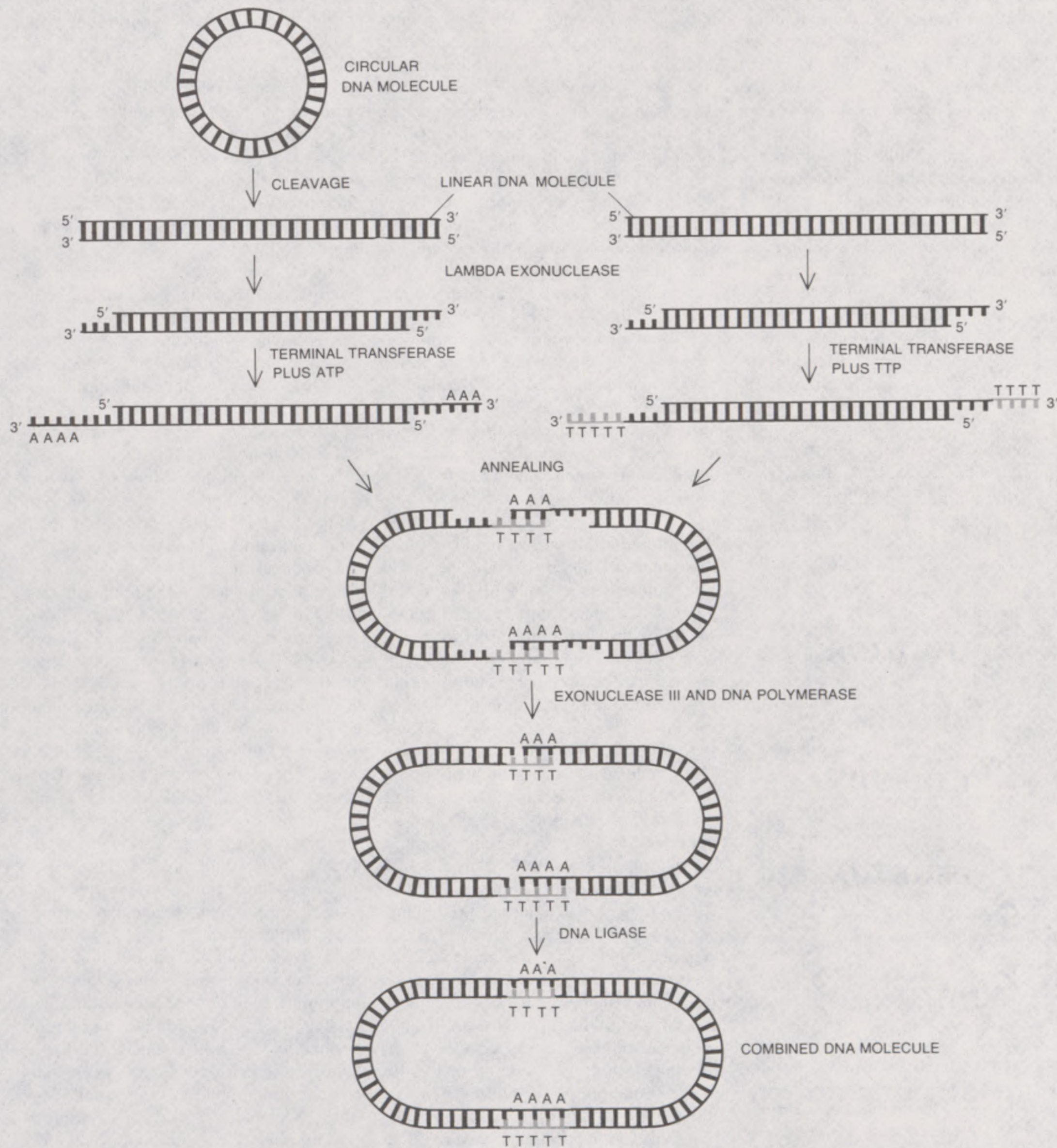
The cleaved linear molecules were treated with an enzyme, produced by the bacterial virus lambda, called an exonuclease because it operates by cutting off nucleotides at the end of a DNA molecule. The lambda exonuclease chewed back the 5' ends of DNA molecules and thus left projecting single-strand ends that had 3' termini to which the blocks of complementary nucleotides could be added. The next step was to add, with the help of terminal transferase, a block of A's at the 3' end of one of the two DNA species to be linked and a block of T's at the 3' ends of the other species. The species were mixed together. Fragments having complementary blocks at their ends could find each other, line up and become annealed by hydrogen bonding, thus forming combined molecules. To fill the gaps at the 5' ends of the original segments the investigators supplied nucleotides and two more enzymes: exonuclease III and DNA polymerase. Finally the nicks in the molecules were sealed with DNA ligase.

The method of making cohesive termini for joining DNA molecules in the first successful genetic-manipulation experiments was conceptually and operationally different from the terminal-transferase procedure. It was also much simpler. It depended on the ability of one of a group of enzymes called restriction endonucleases to make complementary-ended fragments during the cleavage of DNA at a site within the molecule, instead of requiring the addition of new blocks of complementary nucleotides to DNA termini.

Viruses grown on certain strains of *E. coli* were known to be restricted in their ability to grow subsequently on other strains. Investigations had shown that this restriction was due to bacterial enzymes that recognize specific sites on a "foreign" viral DNA and cleave that

DNA. (To protect its own DNA the bacterial cell makes a modification enzyme that adds methyl groups to nucleotides constituting the recognition sites for the restriction endonuclease, making them resistant to cleavage.) Restriction endonucleases (and modification methylases)

are widespread in microorganisms; genes for making them were found on viral chromosomes and extrachromosomal plasmid DNA as well as on many bacterial chromosomes. During the early 1970's the nucleotide sequences at the cleavage sites recognized by several re-



TERMINAL-TRANSFERASE procedure for joining DNA molecules involves a number of steps, each dependent on a different enzyme. If one of the molecules to be joined is a closed loop, it must first be cleaved. The linear molecules are treated with lambda exonuclease, an enzyme that cuts nucleotides off the 5' end of DNA strands (the end with a phosphate group on the No. 5 carbon). Then specific nucleotides are added to the 3' end (the end with an OH group on the No. 3 carbon) by the action of the enzyme termi-

nal transferase. One DNA species is supplied with adenosine triphosphate (ATP), the other with thymidine triphosphate (TTP), so that *A* nucleotides are added to one species and complementary *T* nucleotides to the other. When the two species are mixed, the complementary bases pair up, annealing the molecules. Nucleotides and the enzymes DNA polymerase and exonuclease III are added to fill gaps and DNA ligase is added to seal the DNA backbones. The result is a double molecule composed of two separate DNA segments.

striction endonucleases were identified. In every instance, it developed, the cleavage was at or near an axis of rotational symmetry: a palindrome where the nucleotide base sequences read the same on both strands in the 5'-to-3' direction [see illustration below].

In some instances the breaks in the DNA strands made by restriction enzymes were opposite each other. One particular endonuclease, however, the *Eco* RI enzyme isolated by Robert N. Yoshimori in Boyer's laboratory in San Francisco, had a property that was of special interest. Unlike the other nucleases known at the time, this enzyme introduced breaks in the two DNA strands that were separated by several nucleotides. Because of the symmetrical, palindromic arrangement of the nucleotides in the region of cleavage this separation of the cleavage points on the two strands yielded DNA termini with projecting complementary nucleotide sequences: "sticky" mortise-and-tenon ter-

mini. The *Eco* RI enzyme thus produced in one step DNA molecules that were functionally equivalent to the cohesive-end molecules produced by the complicated terminal-transferase procedure.

The experiments that led to the discovery of the capabilities of *Eco* RI were reported independently and simultaneously in November, 1972, by Janet Mertz and Ronald W. Davis of Stanford and by another Stanford investigator, Vittorio Sgaramella. Sgaramella found that molecules of the bacterial virus P22 could be cleaved with *Eco* RI and would then link up end to end to form DNA segments equal in length to two or more viral-DNA molecules. Mertz and Davis observed that closed-loop SV40-DNA molecules cleaved by *Eco* RI would reform themselves into circular molecules by hydrogen bonding and could be sealed with DNA ligase; the reconstituted molecules were infectious in animal cells growing in tissue culture. Boyer and his colleagues analyzed the nucleotide sequences at the DNA termini produced by *Eco* RI, and their evidence confirmed the complementary nature of the termini, which accounted for their cohesive activity.

In late 1972, then, several methods were available by which one could join double-strand molecules of DNA. That was a major step in the development of a system for manipulating genes. More was necessary, however. Most segments of DNA do not have an inherent capacity for self-replication; in order to reproduce themselves in a biological system they need to be integrated into DNA molecules that can replicate in the particular system. Even a DNA segment that can replicate in its original host was not likely to have the specific genetic signals required for replication in a different environment. If foreign DNA was to be propagated in bacteria, as had long been proposed in speculative scenarios of genetic engineering, a suitable vehicle, or carrier, was required. A composite DNA molecule consisting of the vehicle and the desired foreign DNA would have to be introduced into a population of functional host bacteria. Finally, it would be necessary to select, or identify, those cells in the bacterial population that took up the DNA chimeras. In 1972 it still seemed possible that the genetic information on totally foreign DNA molecules might produce an aberrant situation that would prevent the propagation of hybrid molecules in a new host.

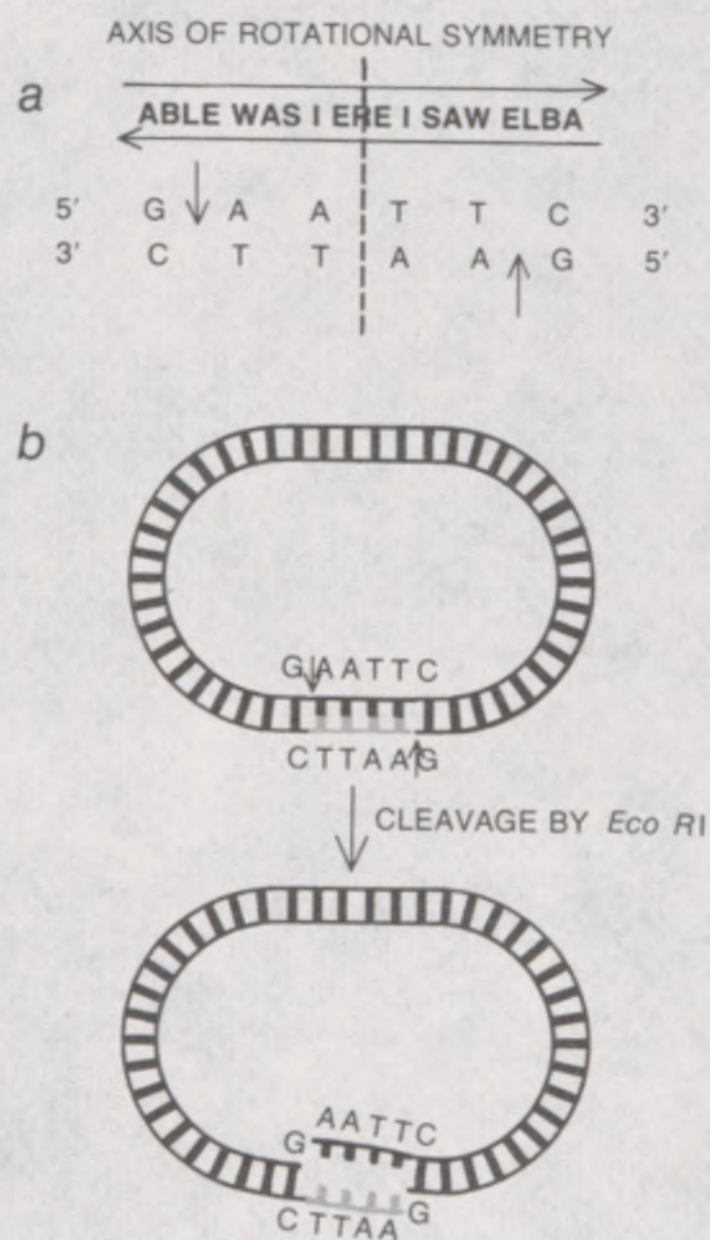
Molecular biologists had focused for many years on viruses and their relations with bacteria, and so it was natu-

ral that bacterial viruses were thought of as the most likely vehicles for genetic manipulation. For some time there had been speculation and discussion about using viruses, such as lambda, that occasionally acquire bits of the *E. coli* chromosome by natural recombination mechanisms for cloning DNA from foreign sources. It was not a virus, however, but a plasmid that first served as a vehicle for introducing foreign genes into a bacterium and that provided a mechanism for the replication and selection of the foreign DNA.

A ubiquitous group of plasmids that confer on their host bacteria the ability to resist a number of antibiotics had been studied intensively for more than a decade. Antibiotic-resistant *E. coli* isolated in many parts of the world, for example, were found to contain plasmids, designated R factors (for "resistance"), carrying the genetic information for products that in one way or another could interfere with the action of specific antibiotics [see "Infectious Drug Resistance," by Tsutomu Watanabe; SCIENTIFIC AMERICAN, December, 1967]. Double-strand circular molecules of R-factor DNA had been separated from bacterial chromosomal DNA by centrifugation in density gradients and had been characterized by biochemical and physical techniques [see "The Molecule of Infectious Drug Resistance," by Royston C. Clowes; SCIENTIFIC AMERICAN, April, 1973].

In 1970 Morton Mandel and A. Higa of the University of Hawaii School of Medicine had discovered that treatment of *E. coli* with calcium salts enabled the bacteria to take up viral DNA. At Stanford, Chang and I, with Leslie Hsu, found that if we made the cell membranes of *E. coli* permeable by treating them with calcium chloride, purified R-factor DNA could be introduced into them [see illustration on opposite page]. The R-factor DNA is taken up in this transformation process by only about one bacterial cell in a million, but those few cells can be selected because they live and multiply in the presence of the antibiotics to which the R factor confers resistance, whereas other cells die. Each transformed cell gives rise to a clone that contains exact replicas of the parent plasmid DNA molecules, and so we reasoned that plasmids might serve as vehicles for propagating new genetic information in a line of *E. coli* cells.

In an effort to explore the genetic and molecular properties of various regions of the R-factor DNA we had begun to take plasmids apart by shearing their DNA mechanically and then transforming *E. coli* with the resulting



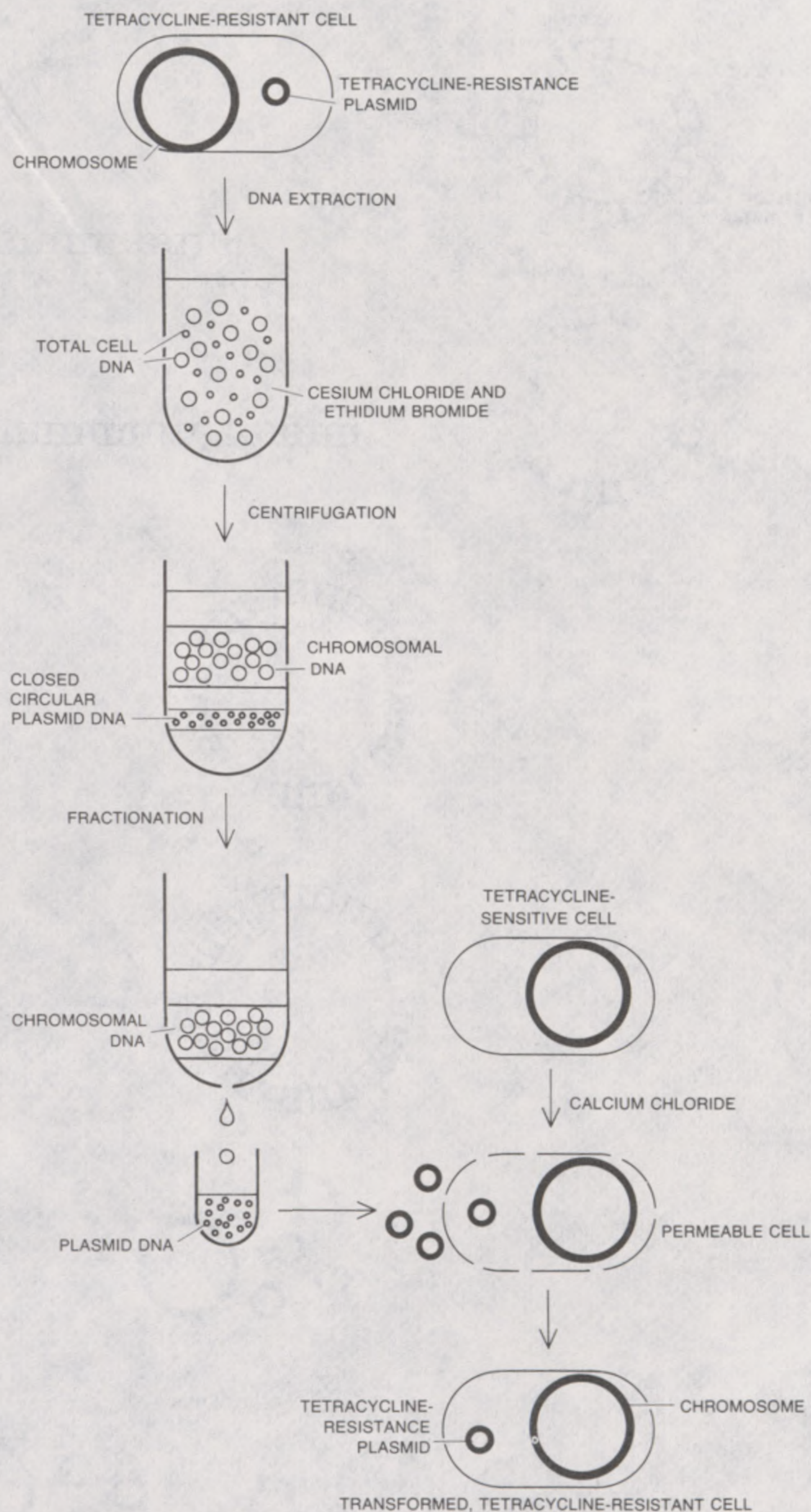
RESTRICTION ENDONUCLEASES cleave DNA at sites where complementary nucleotides are arranged in rotational symmetry: a palindrome, comparable to a word palindrome (a). The endonuclease *Eco* RI has the additional property of cleaving complementary strands of DNA at sites (colored arrows) four nucleotides apart. Such cleavage (b) yields DNA fragments with complementary, overlapping single-strand ends. As a result the end of any DNA fragment produced by *Eco* RI cleavage can anneal with any other fragment produced by the enzyme.

fragments. Soon afterward we began to cleave the plasmids with the *Eco* RI enzyme, which had been shown to produce multiple site-specific breaks in several viruses. It might therefore be counted on to cleave all molecules of a bacterial plasmid in the same way, so that any particular species of DNA would yield a specific set of cleavage fragments, and do so reproducibly. The fragments could then be separated and identified according to the different rates at which they would migrate through a gel under the influence of an electric current.

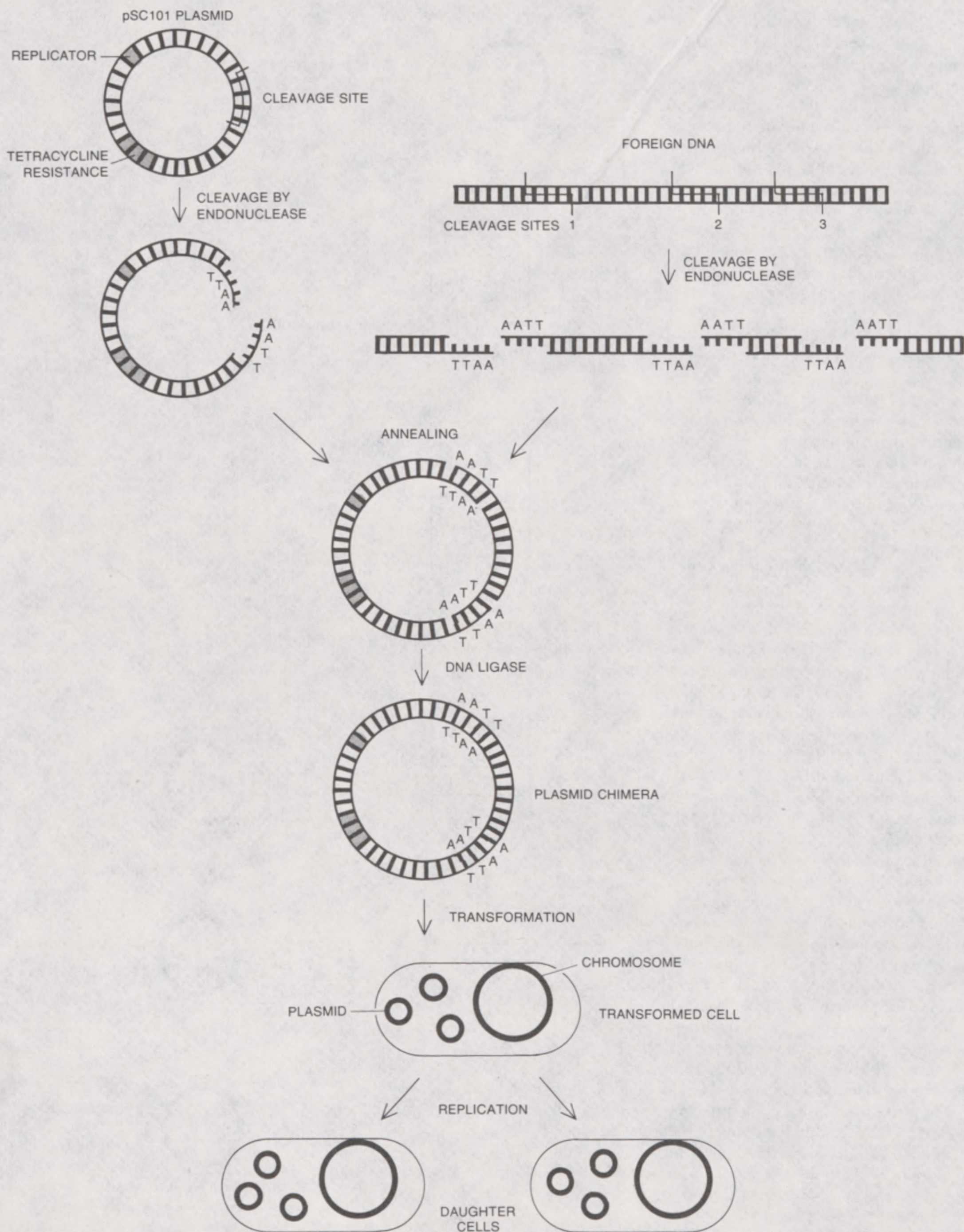
When the DNA termini produced by *Eco* RI endonuclease were found to be cohesive, Chang and I, in collaboration with Boyer and Helling in San Francisco, proceeded to search for a plasmid that the enzyme would cleave without affecting the plasmid's ability to replicate or to confer antibiotic resistance. We hoped that if such a plasmid could be found, we could insert a segment of foreign DNA at the *Eco* RI cleavage site, and that it might be possible to propagate the foreign DNA in *E. coli*.

In our collection at Stanford there was a small plasmid, *pSC101*, that had been isolated following the mechanical shearing of a large plasmid bearing genes for multiple antibiotic resistance. It was less than a twelfth as long as the parent plasmid, but it did retain the genetic information for its replication in *E. coli* and for conferring resistance to one antibiotic, tetracycline. When we subjected *pSC101* DNA to cleavage by *Eco* RI and analyzed the products by gel electrophoresis, we found that the enzyme had cut the plasmid molecule in only one place, producing a single linear fragment. We were able to join the ends of that fragment again by hydrogen bonding and re-seal them with DNA ligase, and when we introduced the reconstituted circular DNA molecules into *E. coli* by transformation, they were biologically functional plasmids: they replicated and conferred tetracycline resistance.

The next step was to see if a fragment of foreign DNA could be inserted at the cleavage site without interfering with replication or expression of tetracycline resistance and thus destroying the plasmid's ability to serve as a cloning vehicle. We mixed the DNA of another *E. coli* plasmid, which carried resistance to the antibiotic kanamycin, with the *pSC101* DNA. We subjected the mixed DNA to cleavage by *Eco* RI and then to ligation, transformed *E. coli* with the resulting DNA and found that some of the transformed bacteria were indeed resist-



PLASMID DNA can be introduced into a bacterial cell by the procedure called transformation. Plasmids carrying genes for resistance to the antibiotic tetracycline (*top left*) are separated from bacterial chromosomal DNA. Because differential binding of ethidium bromide by the two DNA species makes the circular plasmid DNA denser than the chromosomal DNA, the plasmids form a distinct band on centrifugation in a cesium chloride gradient and can be separated (*bottom left*). The plasmid DNA is mixed with bacterial cells that are not resistant to tetracycline and that have been made permeable by treatment with a calcium salt. The DNA enters the cells, replicates there and makes the cells resistant to tetracycline.



FOREIGN DNA is spliced into the pSC101 plasmid and introduced with the plasmid into the bacterium *Escherichia coli*. The plasmid is cleaved by the endonuclease *Eco* RI at a single site that does not interfere with the plasmid's genes for replication or for resistance to tetracycline (*top left*). The nucleotide sequence recognized by *Eco* RI is present also in other DNA, so that a foreign DNA exposed to the endonuclease is cleaved about once in every 4,000 to

16,000 nucleotide pairs on a random basis (*top right*). Fragments of cleaved foreign DNA are annealed to the plasmid DNA by hydrogen bonding of the complementary base pairs, and the new composite molecules are sealed by DNA ligase. The DNA chimeras, each consisting of the entire plasmid and a foreign DNA fragment, are introduced into *E. coli* by transformation, and the foreign DNA is replicated by virtue of the replication functions of the plasmid.

ant to both tetracycline and kanamycin. The plasmids isolated from such transformants contained the entire *pSC101* DNA segment and also a second DNA fragment that carried the information for kanamycin resistance, although it lacked replication functions of its own. The results meant that the *pSC101* could serve as a cloning vehicle for introducing at least a nonreplicating segment of a related DNA into *E. coli*. And the procedure was extraordinarily simple.

Could genes from other species be introduced into *E. coli* plasmids, however? There might be genetic signals on foreign DNA that would prevent its propagation or expression in *E. coli*. We decided to try to combine DNA from a plasmid of another bacterium, the *pI258* plasmid of *Staphylococcus aureus*, with our original *E. coli* plasmid. The staphylococcal plasmid had already been studied in several laboratories; we had found that it was cleaved into four DNA fragments by *Eco* RI. Since *pI258* was not native to *E. coli* or to related bacteria, it could not on its own propagate in an *E. coli* host. And it was known to carry a gene for resistance to still another antibiotic, penicillin, that would serve as a marker for selecting any transformed clones. (Penicillin resistance, like combined resistance to tetracycline and kanamycin, was already widespread among *E. coli* strains in nature. That was important; if genes from a bacterial species that cannot normally exchange genetic information with the colon bacillus were to be introduced into it, it was essential that they carry only antibiotic-resistance traits that were already prevalent in *E. coli*. Otherwise we would be extending the species' antibiotic-resistance capabilities.)

Chang and I repeated the experiment that had been successful with two kinds of *E. coli* plasmids, but this time we did it with a mixture of the *E. coli*'s *pSC101* and the staphylococcal *pI258*: we cleaved the mixed plasmids with *Eco* RI endonuclease, treated them with ligase and then transformed *E. coli*. Next we isolated transformed bacteria that expressed the penicillin resistance coded for by the *S. aureus* plasmid as well as the tetracycline resistance of the *E. coli* plasmid. These doubly resistant cells were found to contain a new DNA species that had the molecular characteristics of the staphylococcal plasmid DNA as well as the characteristics of *pSC101*.

The replication and expression in *E. coli* of genes derived from an organism ordinarily quite unable to exchange genes with *E. coli* represented a breach in the barriers that normally separate

biological species. The bulk of the genetic information expressed in the transformed bacteria defined it as *E. coli*, but the transformed cells also carried replicating DNA molecules that had molecular and biological characteristics derived from an unrelated species, *S. aureus*. The fact that the foreign genes were on a plasmid meant that they would be easy to isolate and purify in large quantities for further study. Moreover, there was a possibility that one might introduce genes into the easy-to-grow *E. coli* that specify a wide variety of metabolic or synthesizing functions (such as photosynthesis or antibiotic production) and that are indigenous to other biological classes. Potentially the *pSC101* plasmid and the molecular-cloning procedure could serve to introduce DNA molecules from complex higher organisms into bacterial hosts, making it possible to apply relatively simple bacterial genetic and biochemical techniques to the study of animal-cell genes.

Could animal-cell genes in fact be introduced into bacteria, and would they replicate there? Boyer, Chang, Helling and I, together with Morrow and Goodman, immediately undertook to find out. We picked certain genes that had been well studied and characterized and were available, purified, in quantity: the genes that code for a precursor of the ribosomes (the structure on which proteins are synthesized) in the toad *Xenopus laevis*. The genes had properties that would enable us to identify them if we succeeded in getting them to propagate in bacteria. The toad DNA was suitable for another reason: although we would be constructing a novel biological combination containing genes from both animal cells and bacteria, we and others expected that no hazard would result from transplanting the highly purified ribosomal genes of a toad.

Unlike the foreign DNA's of our earlier experiments, the toad genes did not express traits (such as antibiotic resistance) that could help us to select bacteria carrying plasmid chimeras. The tetracycline resistance conferred by *pSC101* would make it possible to select transformed clones, however, and we could then proceed to examine the DNA isolated from such clones to see if any clones contained a foreign DNA having the molecular properties of toad ribosomal DNA. The endonuclease-generated fragments of toad ribosomal DNA have characteristic sizes and base compositions; DNA from the transformed cells could be tested for those characteristics. The genes propagated in bac-

teria could also be tested for nucleotide-sequence homology with DNA isolated directly from the toad.

When we did the experiment and analyzed the resulting transformed cells, we found that the animal-cell genes were indeed reproducing themselves in generation after generation of bacteria by means of the plasmid's replication functions. In addition, the nucleotide sequences of the toad DNA were being transcribed into an RNA product in the bacterial cells.

Within a very few months after the first DNA-cloning experiments the procedure was being used in a number of laboratories to clone bacterial and animal-cell DNA from a variety of sources. Soon two plasmids other than *pSC101* were discovered that have a single *Eco* RI cleavage site at a location that does not interfere with essential genes. One of these plasmids is present in many copies in the bacterial cell, making it possible to "amplify," or multiply many times, any DNA fragments linked to it. Investigators at the University of Edinburgh and at Stanford went on to develop mutants of the virus lambda (which ordinarily infects *E. coli*) that made the virus too an effective cloning vehicle. Other restriction endonucleases were discovered that also make cohesive termini but that cleave DNA at different sites from the *Eco* RI enzymes, so that chromosomes can now be taken apart and put together in various ways.

The investigative possibilities of DNA cloning are already being explored intensively. Some workers have isolated from complex chromosomes certain regions that are implicated in particular functions such as replication. Others are making plasmids to order with specific properties that should clarify aspects of extrachromosomal-DNA biology that have been hard to study. The organization of complex chromosomes, such as those of the fruit fly *Drosophila*, is being studied by cloning the animal genes in bacteria. Within the past few months methods have been developed for selectively cloning specific genes of higher organisms through the use of radioactively labeled RNA probes: instead of purifying the genes to be studied before introducing them into bacteria, one can transform bacteria with a heterogeneous population of animal-cell DNA and then isolate those genes that produce a particular species of RNA. It is also possible to isolate groups of genes that are expressed concurrently at a particular stage in the animal's development.

The potential seems to be even broader. Gene manipulation opens the pros-

pect of constructing bacterial cells, which can be grown easily and inexpensively, that will synthesize a variety of biologically produced substances such as antibiotics and hormones, or enzymes that can convert sunlight directly into food substances or usable energy. Perhaps it even provides an experimental basis for introducing new genetic information into plant or animal cells.

It has been clear from the beginning of experimentation in molecular cloning that the construction of some kinds of novel gene combinations may have a potential for biological hazard, and the scientific community has moved quickly to make certain that research in genetic manipulation would not endanger the public. For a time after our initial experiments the pSC101 plasmid was the only vehicle known to be suitable for cloning foreign DNA in *E. coli*, and our colleagues asked for supplies with which to pursue studies we knew were of major scientific and medical importance. Investigators normally facilitate the free exchange of bacteria and other experimental strains they have isolated or developed, but Chang and I were concerned that manipulation of certain genes could give rise to novel organisms whose infectious properties and ecological effects could not be predicted. In agreeing to provide the plasmid we therefore asked for assurance that our colleagues would neither introduce tumor viruses into bacteria nor create antibiotic-resistance combinations that were not already present in nature; we also asked the recipients not to send the plasmid on to other laboratories, so that we could keep track of its distribution.

When still other cloning vehicles were

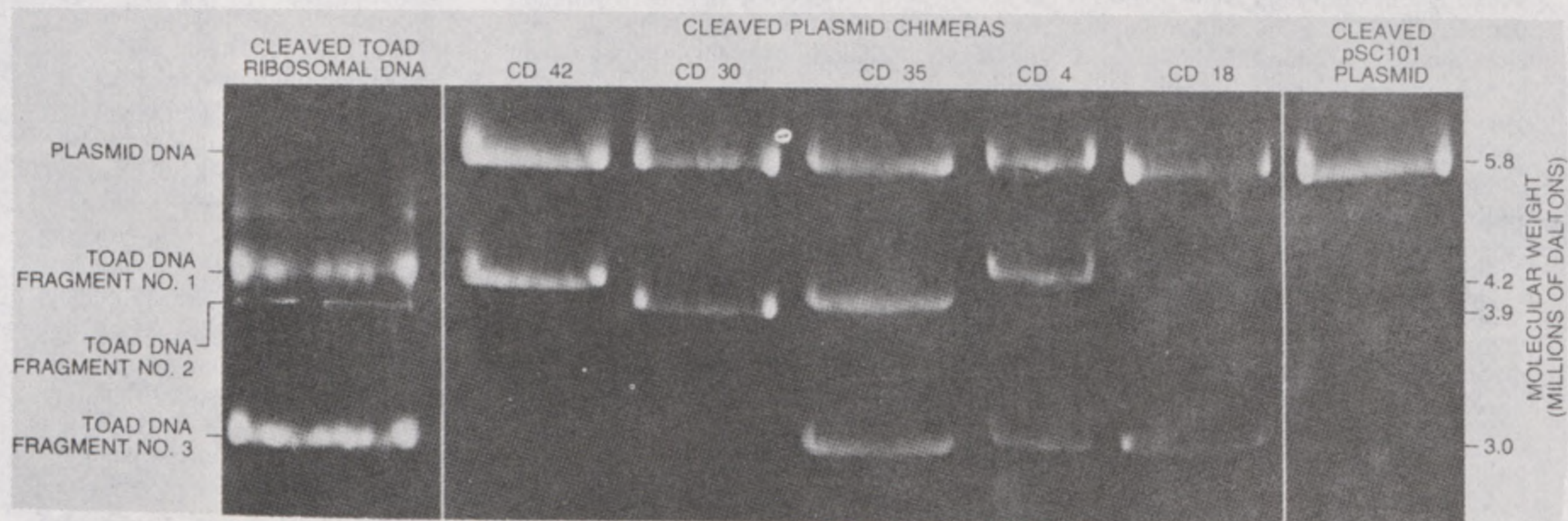
discovered, it became apparent that a more general mechanism for ensuring experimental safety in gene-manipulation research was advisable. The groundwork for such control had been established earlier: the National Academy of Sciences had been urged to consider the "possibility that potentially biohazardous consequences might result from widespread or injudicious use" of these techniques and had asked Paul Berg to form an advisory committee that would consider the issue. Berg too had been concerned about the potential hazards of certain kinds of experimentation for some years, and had himself decided to abandon plans to try to introduce genes from the tumor virus SV40 into bacteria because of the possible danger if the experiment were successful.

Berg brought together a number of investigators, including some who were then directly involved in molecular cloning, in the spring of 1974. In a report released in July and in a letter to leading professional journals the members of the committee expressed their "concern about the possible unfortunate consequences of indiscriminate application" of the techniques and formally asked all investigators to join them in voluntarily deferring two types of experiments (which had, as a matter of fact, been avoided by informal consensus up until that time). Experiments of Type I involved the construction of novel organisms containing combinations of toxin-producing capabilities or of antibiotic-resistance genes not found in nature. Type 2 experiments involved the introduction of DNA from tumor viruses or other animal viruses into bacteria; the committee noted that "such recombinant molecules might be more easily dissemi-

nated to bacterial populations in humans and other species, and might thus increase the incidence of cancer or other diseases."

The Academy committee was concerned largely because of our inability to assess the hazards of certain experiments accurately before the experiments were undertaken. Guidelines for safety had long been available in other areas of potentially hazardous research, such as studies involving known disease-causing bacteria and viruses, radioactive isotopes or toxic chemicals. Because of the newness of the microbial gene-manipulation methods, no such guidelines had yet been developed for work in this area, however; there was the possibility that potentially hazardous experiments might proceed before appropriate guidelines could be considered and implemented. We recognized that most work with the new methods did not and would not involve experiments of a hazardous nature but we recommended the deferral of Type I and Type II experiments until the hazards were more carefully assessed, until it was determined whether or not the work could be undertaken safely and until adequate safety precautions were available. The committee also proposed that an international meeting be held early in 1975 to consider the matter more fully.

Such a meeting was held in February at the Asilomar Conference Center near Pacific Grove, Calif. It brought together 86 American biologists and 53 investigators from 16 other countries, who spent three and a half days reviewing progress in the field of molecular cloning and formulating guidelines that would allow most types of new hereditary characteristics to be introduced into bacteria and



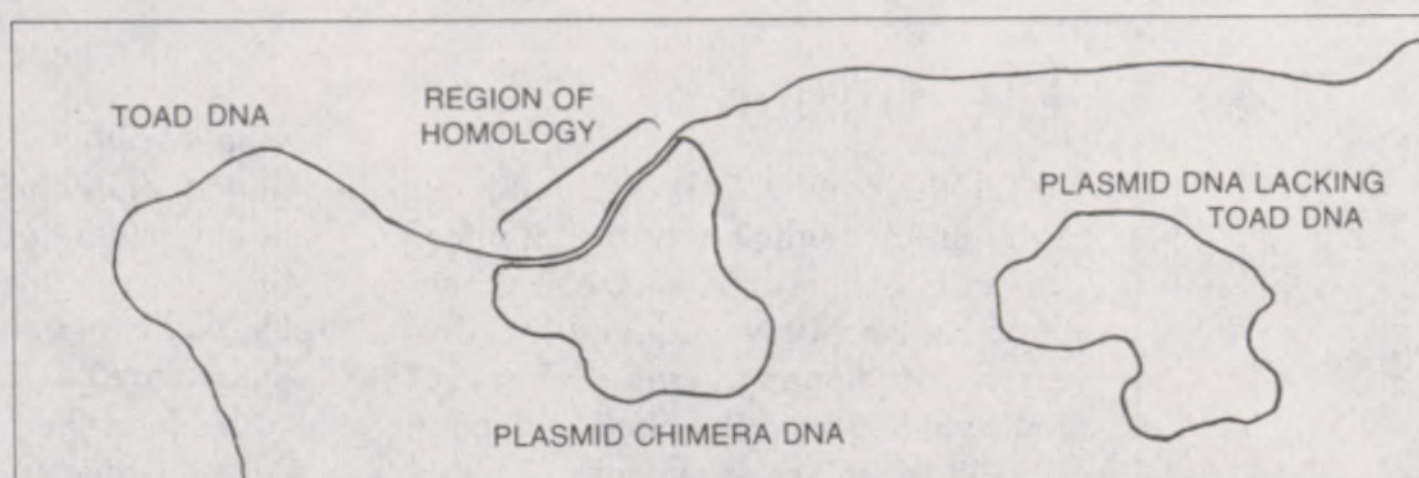
GEL ELECTROPHORESIS demonstrates the presence of toad DNA in chimeric plasmids. Fragments of DNA migrate through a gel at different rates under the influence of an electric current, depending on their size. Linear molecules of plasmid DNA (right) and the cleavage products of toad ribosomal DNA (left) therefore

have characteristic sizes and migrate characteristic distances in a given time. The bands of DNA, visualized by a fluorescent dye, are photographed in ultraviolet. All five chimeric plasmids (center) contain a plasmid DNA molecule; in addition each chimera includes one or more fragments characteristic of original toad DNA.

viruses safely. Invited nonscientists from the fields of law and ethics participated in the discussions and decisions at Asilomar, along with representatives of agencies that provide Federal funds for scientific research; the meetings were open to the press and were fully reported. The issues were complex and there were wide differences of opinion on many of them, but there was consensus on three major points. First, the newly developed cloning methods offer the prospect of dealing with a wide variety of important scientific and medical problems as well as other problems that trouble society, such as environmental pollution and food and energy shortages. Second, the accidental dissemination of certain novel biological combinations may present varying degrees of potential risk. The construction of such combinations should proceed only under a graded series of precautions, principally biological and physical barriers, adequate to prevent the escape of any hazardous organisms; the extent of the actual risk should be explored by experiments conducted under strict containment conditions. Third, some experiments are potentially too hazardous to be carried out for the present, even with the most careful containment. Future research and experience may show that many of the potential hazards considered at the meeting are less serious and less probable than we now suspect. Nevertheless, it was agreed that standards of protection should be high at the beginning and that they can be modified later if the assessment of risk changes.

Physical containment barriers have long been used in the U.S. space-exploration program to minimize the possibility of contamination of the earth by extraterrestrial microbes. Containment procedures are also employed routinely to protect laboratory workers and the public from hazards associated with radioactive isotopes and toxic chemicals and in work with disease-causing bacteria and viruses. The Asilomar meeting formulated the additional concept of biological barriers, which involve fastidious cloning vehicles that are able to propagate only in specialized hosts and equally fastidious bacterial strains that are unable to live except under stringent laboratory conditions.

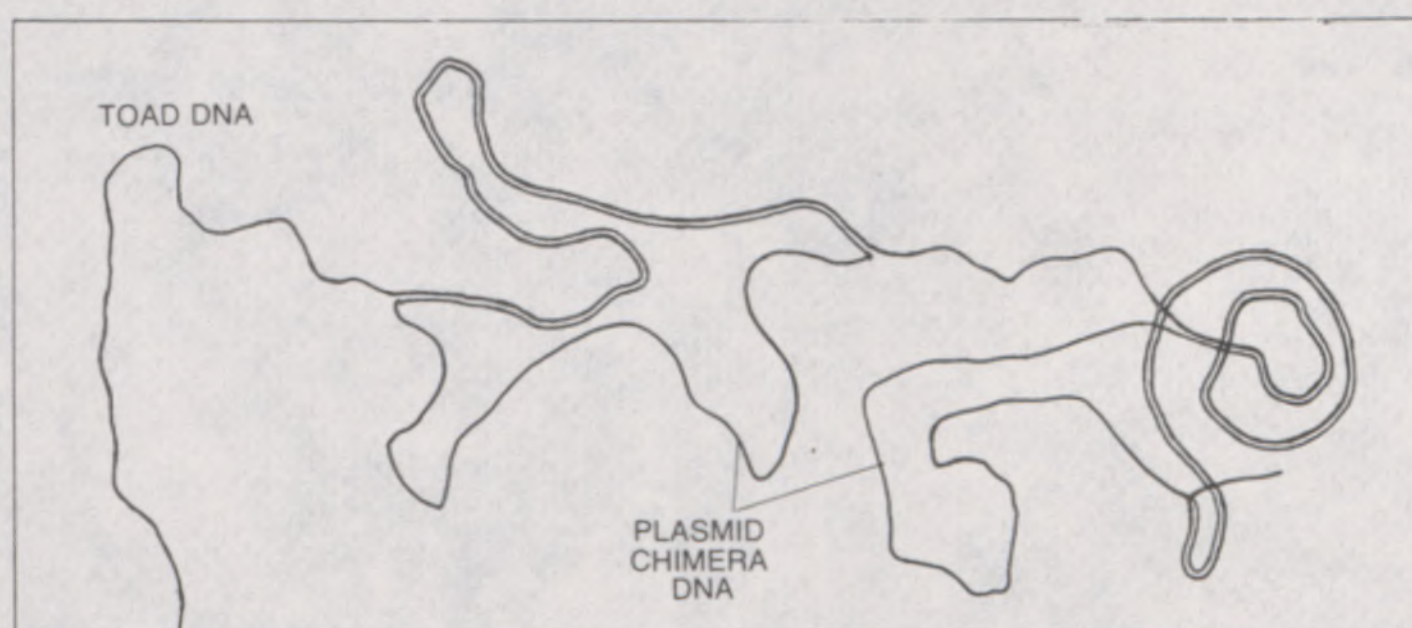
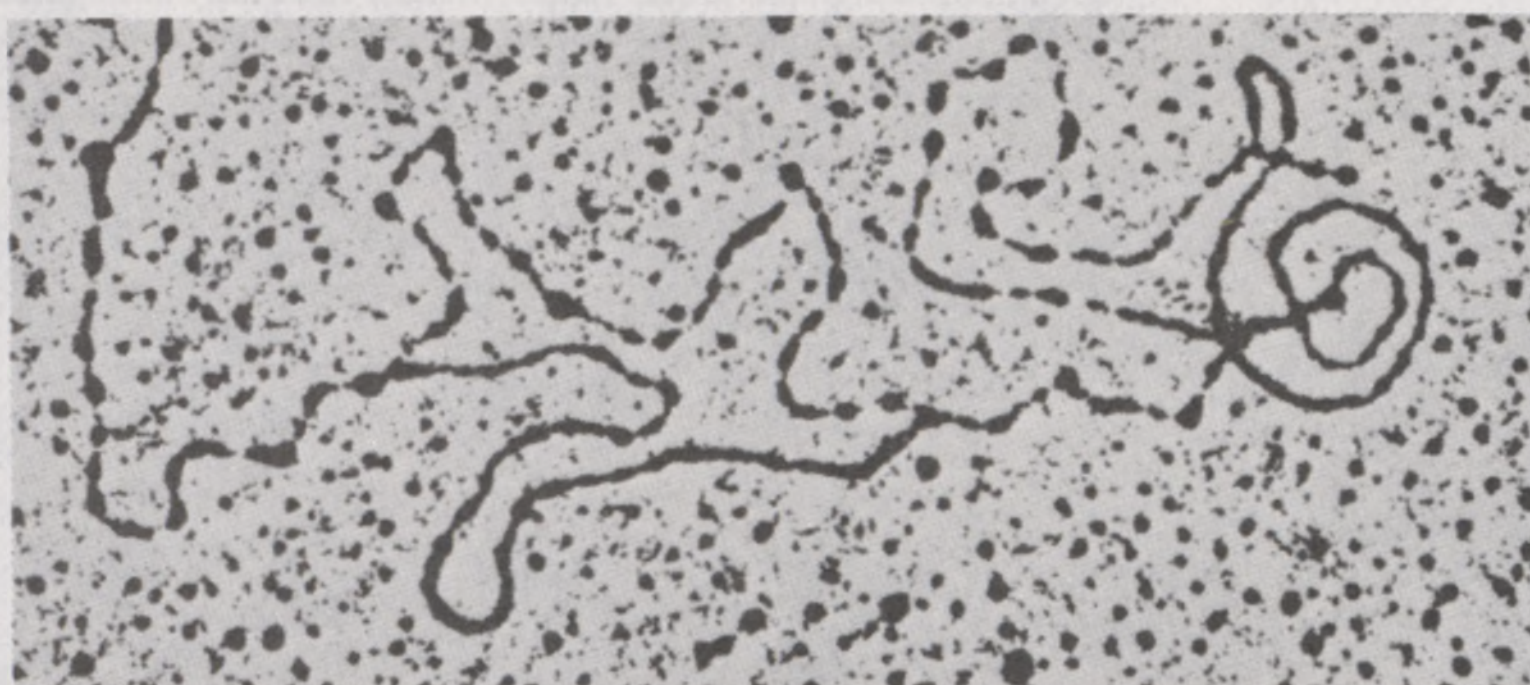
In the past the scientific community has commonly policed its own actions informally, responding to ethical concerns with self-imposed restraint. Usually, but not always, society at large has also considered the public well-being in determining how knowledge obtained by basic scientific research should be applied. Extensive public scrutiny and



HETERODUPLEX ANALYSIS identifies regions of a toad DNA (*black*) that have been incorporated in a chimeric plasmid DNA molecule. DNA isolated from toad eggs and the DNA of the chimera are denatured, that is, each natural double-strand molecule is split into two single strands of DNA, by alkali treatment. The toad and the chimeric DNA's are mixed together, and any complementary sequences are allowed to find each other. The toad DNA incorporated in the chimeras has nucleotide sequences that are complementary to sequences in the DNA taken directly from the animal source. Those homologous sequences anneal to form heteroduplex double-strand DNA that can be identified in electron micrographs.

open discussion by scientists and non-scientists of the possible risks and benefits of a particular line of basic research has been rare, however, when (as in this case) the hazards in question are only potential and, for some experiments, even hypothetical. As this article is being written it is still too early to know what the long-range outcome of the pub-

lic discussions initiated by scientists working in genetic manipulation will be. One can hope that the forthright approach and the rigorous standards that have been adopted for research in the cloning of recombinant DNA molecules will promote a sharper focus on other issues relevant to public and environmental safety.



PRESENCE OF TOAD DNA in two separate chimeric plasmid molecules is demonstrated by an electron micrograph made by John F. Morrow at the Stanford University School of Medicine. As is indicated in the drawing (*bottom*), there are DNA strands from two plasmids and a strand of toad DNA. The micrograph shows thickened regions of DNA where nucleotide sequences are homologous and two single strands have been annealed. The toad DNA in the chimeras codes for ribosomes, and the space between the two heteroduplex regions is compatible with the spacing of multiple ribosomal genes in toad DNA.

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APPENDIX 3

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¹ U.S. Department of Health, Education, and Welfare. Recombinant DNA research. Volume 1. August 1976: 48-58.

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APPENDIX 4

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Summary Statement of the Asilomar Conference on Recombinant DNA Molecules*

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I. INTRODUCTION AND GENERAL CONCLUSIONS

This meeting was organized to review scientific progress in research on recombinant DNA molecules and to discuss appropriate ways to deal with the potential biohazards of this work. Impressive scientific achievements have already been made in this field and these techniques have a remarkable potential for furthering our understanding of fundamental biochemical processes in pro- and eukaryotic cells. The use of recombinant DNA methodology promises to revolutionize the practice of molecular biology. Although there has as yet been no practical application of the new techniques, there is every reason to believe that they will have significant practical utility in the future.

Of particular concern to the participants at the meeting was the issue of whether the pause in certain aspects of research in this area, called for by the Committee on Recombinant DNA Molecules of the National Academy of Sciences, U.S.A. in the letter published in July, 1974** should end; and, if so, how the scientific work could be undertaken with minimal risks to workers in laboratories, to the public at large, and to the animal and plant species sharing our ecosystems.

The new techniques, which permit combination of genetic information from very different organisms, place us in an area of biology with many unknowns. Even in the present, more limited conduct of research in this field, the evaluation of potential biohazards has proved to be extremely difficult. It is this ignorance that has compelled us to conclude that it would be wise to exercise considerable caution in performing this research. Nevertheless, the participants at the Conference agreed that most of the work on construction of recombinant DNA molecules should proceed provided that appropriate safeguards, principally biological and physical barriers ade-

quate to contain the newly created organisms, are employed. Moreover, the standards of protection should be greater at the beginning and modified as improvements in the methodology occur and assessments of the risks change. Furthermore, it was agreed that there are certain experiments in which the potential risks are of such a serious nature that they ought not to be done with presently available containment facilities. In the longer term, serious problems may arise in the large scale application of this methodology in industry, medicine, and agriculture. But it was also recognized that future research and experience may show that many of the potential biohazards are less serious and/or less probable than we now suspect.

II. PRINCIPLES GUIDING THE RECOMMENDATIONS AND CONCLUSIONS

Although our assessments of the risks involved with each of the various lines of research on recombinant DNA molecules may differ, few, if any, believe that this methodology is free from any risk. Reasonable principles for dealing with these potential risks are: (i) that containment be made an essential consideration in the experimental design and, (ii) that the effectiveness of the containment should match, as closely as possible, the estimated risk. Consequently, whatever scale of risks is agreed upon, there should be a commensurate scale of containment. Estimating the risks will be difficult and intuitive at first but this will improve as we acquire additional knowledge; at each stage we shall have to match the potential risk with an appropriate level of containment. Experiments requiring large scale operations would seem to be riskier than equivalent experiments done on a small scale and, therefore, require more stringent containment procedures. The use of cloning vehicles or vectors (plasmids, phages) and bacterial hosts with a restricted capacity to multiply outside of the laboratory would reduce the potential biohazard of a particular experiment. Thus, the ways in which potential biohazards and different levels of containment are matched may vary from time to time, particularly as the containment technology is improved. The means for assessing and balancing risks with appropriate levels of containment will need to be reexamined from time to time. Hopefully, through both formal and informal channels of information within and between the nations of the world, the way in which potential biohazards and levels of containment are matched would be consistent.

* Summary statement of the report submitted to the Assembly of Life Sciences of the National Academy of Sciences and approved by its Executive Committee on 20 May 1975.

Requests for reprints should be addressed to: Division of Medical Sciences, Assembly of Life Sciences, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

** Report of Committee on Recombinant DNA Molecules: "Potential Biohazards of Recombinant DNA Molecules," *Proc. Nat. Acad. Sci. USA* 71, 2593-2594, 1974.

Containment of potentially biohazardous agents can be achieved in several ways. The most significant contribution to limiting the spread of the recombinant DNAs is the use of biological barriers. These barriers are of two types: (i) fastidious bacterial hosts unable to survive in natural environments, and (ii) nontransmissible and equally fastidious vectors (plasmids, bacteriophages, or other viruses) able to grow only in specified hosts. Physical containment, exemplified by the use of suitable hoods, or where applicable, limited access or negative pressure laboratories, provides an additional factor of safety. Particularly important is strict adherence to good microbiological practices which, to a large measure can limit the escape of organisms from the experimental situation, and thereby increase the safety of the operation. Consequently, education and training of all personnel involved in the experiments is essential to the effectiveness of all containment measures. In practice, these different means of containment will complement one another and documented substantial improvements in the ability to restrict the growth of bacterial hosts and vectors could permit modifications of the complementary physical containment requirements.

Stringent physical containment and rigorous laboratory procedures can reduce but not eliminate the possibility of spreading potentially hazardous agents. Therefore, investigators relying upon "disarmed" hosts and vectors for additional safety must rigorously test the effectiveness of these agents before accepting their validity as biological barriers.

III. RECOMMENDATIONS FOR MATCHING TYPES OF CONTAINMENT WITH TYPES OF EXPERIMENTS

No classification of experiments as to risk and no set of containment procedures can anticipate all situations. Given our present uncertainties about the hazards, the parameters proposed here are broadly conceived and meant to provide provisional guidelines for investigators and agencies concerned with research on recombinant DNAs. However, each investigator bears a responsibility for determining whether, in his particular case, special circumstances warrant a higher level of containment than is suggested here.

A. Types of containment

1. *Minimal Risk.* This type of containment is intended for experiments in which the biohazards may be accurately assessed and are expected to be minimal. Such containment can be achieved by following the operating procedures recommended for clinical microbiological laboratories. Essential features of such facilities are no drinking, eating, or smoking in the laboratory, wearing laboratory coats in the work area, the use of cotton-plugged pipettes or preferably mechanical pipetting devices, and prompt disinfection of contaminated materials.

2. *Low Risk.* This level of containment is appropriate for experiments which generate novel biotypes but where the available information indicates that the recombinant DNA cannot alter appreciably the ecological behavior of the recipient species, increase significantly its pathogenicity, or prevent effective treatment of any resulting infections. The key features of this containment (in addition to the minimal procedures mentioned above) are a prohibition on mouth pipetting, access limited to laboratory personnel, and the

use of biological safety cabinets for procedures likely to produce aerosols (e.g., blending and sonication). Though existing vectors may be used in conjunction with low risk procedures, safer vectors and hosts should be adopted as they become available.

3. *Moderate Risk.* Such containment facilities are intended for experiments in which there is a probability of generating an agent with a significant potential for pathogenicity or ecological disruption. The principle features of this level of containment, in addition to those of the two preceding classes, are that transfer operations should be carried out in biological safety cabinets (e.g., laminar flow hoods), gloves should be worn during the handling of infectious materials, vacuum lines must be protected by filters, and negative pressure should be maintained in the limited access laboratories. Moreover, experiments posing a moderate risk must be done only with vectors and hosts that have an appreciably impaired capacity to multiply outside of the laboratory.

4. *High Risk.* This level of containment is intended for experiments in which the potential for ecological disruption or pathogenicity of the modified organism could be severe and thereby pose a serious biohazard to laboratory personnel or the public. The main features of this type of facility, which was designed to contain highly infectious microbiological agents, are its isolation from other areas by air locks, a negative pressure environment, a requirement for clothing changes and showers for entering personnel, and laboratories fitted with treatment systems to inactivate or remove biological agents that may be contaminants in exhaust air and liquid and solid wastes. All persons occupying these areas should wear protective laboratory clothing and shower at each exit from the containment facility. The handling of agents should be confined to biological safety cabinets in which the exhaust air is incinerated or passed through Hepa filters. High risk containment includes, in addition to the physical and procedural features described above, the use of rigorously tested vectors and hosts whose growth can be confined to the laboratory.

B. Types of experiments

Accurate estimates of the risks associated with different types of experiments are difficult to obtain because of our ignorance of the probability that the anticipated dangers will manifest themselves. Nevertheless, experiments involving the construction and propagation of recombinant DNA molecules using DNAs from (i) prokaryotes, bacteriophages, and other plasmids, (ii) animal viruses, and (iii) eukaryotes have been characterized as minimal, low, moderate, and high risks to guide investigators in their choice of the appropriate containment. These designations should be viewed as interim assignments which will need to be revised upward or downward in the light of future experience.

The recombinant DNA molecules themselves, as distinct from cells carrying them, may be infectious to bacteria or higher organisms. DNA preparations from these experiments, particularly in large quantities, should be chemically inactivated before disposal.

1. *Prokaryotes, Bacteriophages, and Bacterial Plasmids.* Where the construction of recombinant DNA molecules and their propagation involves prokaryotic agents that are known to exchange genetic information naturally, the experiments

can be performed in minimal risk containment facilities. Where such experiments pose a potential hazard, more stringent containment may be warranted.

Experiments involving the creation and propagation of recombinant DNA molecules from DNAs of species that ordinarily do not exchange genetic information, generate novel biotypes. Because such experiments may pose biohazards greater than those associated with the original organisms, they should be performed, at least, in low risk containment facilities. If the experiments involve either pathogenic organisms or genetic determinants that may increase the pathogenicity of the recipient species, or if the transferred DNA can confer upon the recipient organisms new metabolic activities not native to these species and thereby modify its relationship with the environment, then moderate or high risk containment should be used.

Experiments extending the range of resistance of established human pathogens to therapeutically useful antibiotics or disinfectants should be undertaken only under moderate or high risk containment, depending upon the virulence of the organism involved.

2. *Animal Viruses.* Experiments involving linkage of viral genomes or genome segments to prokaryotic vectors and their propagation in prokaryotic cells should be performed only with vector-host systems having demonstrably restricted growth capabilities outside the laboratory and with moderate risk containment facilities. Rigorously purified and characterized segments of non-oncogenic viral genomes or of the demonstrably non-transforming regions of oncogenic viral DNAs can be attached to presently existing vectors and propagated in moderate risk containment facilities; as safer vector-host systems become available such experiments may be performed in low risk facilities.

Experiments designed to introduce or propagate DNA from non-viral or other low risk agents in animal cells should use only low risk animal DNAs as vectors (e.g., viral, mitochondrial) and manipulations should be confined to moderate risk containment facilities.

3. *Eukaryotes.* The risks associated with joining random fragments of eukaryote DNA to prokaryotic DNA vectors and the propagation of these recombinant DNAs in prokaryotic hosts are the most difficult to assess.

A priori, the DNA from warm-blooded vertebrates is more likely to contain cryptic viral genomes potentially pathogenic for man than is the DNA from other eukaryotes. Consequently, attempts to clone segments of DNA from such animal and particularly primate genomes should be performed only with vector-host systems having demonstrably restricted growth capabilities outside the laboratory and in a moderate risk containment facility. Until cloned segments of warm-blooded vertebrate DNA are completely characterized, they should continue to be maintained in the most restricted vector-host system in moderate risk containment laboratories; when such cloned segments are characterized, they may be propagated as suggested above for purified segments of virus genomes.

Unless the organism makes a product known to be dangerous (e.g., toxin, virus), recombinant DNAs from cold-blooded vertebrates and all other lower eukaryotes can be constructed and propagated with the safest vector-host system available in low risk containment facilities.

Purified DNA from any source that performs known functions and can be judged to be non-toxic, may be cloned with currently available vectors in low risk containment facilities. (Toxic here includes potentially oncogenic products or substances that might perturb normal metabolism if produced in an animal or plant by a resident microorganism.)

4. *Experiments to be Deferred.* There are feasible experiments which present such serious dangers that their performance should not be undertaken at this time with the currently available vector-host systems and the presently available containment capability. These include the cloning of recombinant DNAs derived from highly pathogenic organisms (i.e., Class III, IV, and V etiologic agents as classified by the United States Department of Health, Education and Welfare), DNA containing toxin genes, and large scale experiments (more than 10 liters of culture) using recombinant DNAs that are able to make products potentially harmful to man, animals, or plants.

IV. IMPLEMENTATION

In many countries steps are already being taken by national bodies to formulate codes of practice for the conduct of experiments with known or potential biohazard.††,‡‡ Until these are established, we urge individual scientists to use the proposals in this document as a guide. In addition, there are some recommendations which could be immediately and directly implemented by the scientific community.

A. Development of safer vectors and hosts

An important and encouraging accomplishment of the meeting was the realization that special bacteria and vectors which have a restricted capacity to multiply outside the laboratory can be constructed genetically, and that the use of these organisms could enhance the safety of recombinant DNA experiments by many orders of magnitude. Experiments along these lines are presently in progress and in the near future, variants of λ bacteriophage, non-transmissible plasmids, and special strains of *Escherichia coli* will become available. All of these vectors could reduce the potential biohazards by very large factors and improve the methodology as well. Other vector-host systems, particularly modified strains of *Bacillus subtilis* and their relevant bacteriophages and plasmids, may also be useful for particular purposes. Quite possibly safe and suitable vectors may be found for eukaryotic hosts such as yeast and readily cultured plant and animal cells. There is likely to be a continuous development in this area and the participants at the meeting agreed that improved vector-host systems which reduce the biohazards of recombinant DNA research will be made freely available to all interested investigators.

B. Laboratory procedures

It is the clear responsibility of the principal investigator to inform the staff of the laboratory of the potential hazards of

†† Advisory Board for the Research Councils, "Report of the Working Party on the Experimental Manipulation of the Genetic Composition of Micro-Organisms. Presented to Parliament by the Secretary of State for Education and Science by Command of Her Majesty, January 1975." London: Her Majesty's Stationery Office, 1975, 23pp.

‡‡ National Institutes of Health Recombinant DNA Molecule Program Advisory Committee.

such experiments before they are initiated. Free and open discussion is necessary so that each individual participating in the experiment fully understands the nature of the experiment and any risk that might be involved. All workers must be properly trained in the containment procedures that are designed to control the hazard, including emergency actions in the event of a hazard. It is also recommended that appropriate health surveillance of all personnel, including serological monitoring, be conducted periodically.

C. Education and reassessment

Research in this area will develop very quickly and the methods will be applied to many different biological problems. At any given time it is impossible to foresee the entire range of all potential experiments and make judgments on them. Therefore, it is essential to undertake a continuing reassessment of the problems in the light of new scientific knowledge. This could be achieved by a series of annual workshops and meetings, some of which should be at the international level. There should also be courses to train individuals in the relevant methods since it is likely that the work will be taken up by laboratories which may not have had extensive experience in this area. High priority should also be given to research that could improve and evaluate the containment effectiveness of new and existing vector-host systems.

V. NEW KNOWLEDGE

This document represents our first assessment of the potential biohazards in the light of current knowledge. However, little is known about the survival of laboratory strains of bacteria and bacteriophages in different ecological niches in the outside

world. Even less is known about whether recombinant DNA molecules will enhance or depress the survival of their vectors and hosts in nature. These questions are fundamental to the testing of any new organism that may be constructed. Research in this area needs to be undertaken and should be given high priority. In general, however, molecular biologists who may construct DNA recombinant molecules do not undertake these experiments and it will be necessary to facilitate collaborative research between them and groups skilled in the study of bacterial infection or ecological microbiology. Work should also be undertaken which would enable us to monitor the escape or dissemination of cloning vehicles and their hosts.

Nothing is known about the potential infectivity in higher organisms of phages or bacteria containing segments of eukaryotic DNA and very little about the infectivity of the DNA molecules themselves. Genetic transformation of bacteria does occur in animals, suggesting that recombinant DNA molecules can retain their biological potency in this environment. There are many questions in this area, the answers to which are essential for our assessment of the biohazards of experiments with recombinant DNA molecules. It will be necessary to ensure that this work will be planned and carried out; and it will be particularly important to have this information before large scale applications of the use of recombinant DNA molecules is attempted.

The work of the committee was assisted by the National Academy of Sciences-National Research Council Staff: Artemis P. Simopoulos (Executive Secretary) and Elena O. Nightingale (Resident Fellow), Division of Medical Sciences, Assembly of Life Sciences, and supported by the National Institutes of Health (Contract NO1-OD-5-2103) and the National Science Foundation (Grant GBMS75-05293).

APPENDIX 5

THE SECRETARY OF HEALTH, EDUCATION, AND WELFARE, Washington, D.C. CHARTER

RECOMBINANT DNA MOLECULE PROGRAM ADVISORY COMMITTEE

Purpose

In accordance with Section 301 of the Public Health Service Act (42 U.S.C. 241), the Secretary of Health, Education, and Welfare is directed to conduct research, investigations, experiments, demonstrations, and studies relating to the causes, diagnosis, treatment, control and prevention of physical diseases and impairments of man. In carrying out this mandate, exploration of the genetics of microbial agents and of animal cells by use of the technology of study of DNA (deoxyribonucleic acid) recombinants offers tremendous promise of uncovering basic aspects of health and disease, and is appropriate for support by the National Institutes of Health. However, the use of this technology has various possible hazards because new types of organisms, some potentially pathogenic, can be introduced into the environment if there are no effective controls. The technology is also capable of producing microbial organisms which can be useful or harmful to agriculture or industry, and thus secondarily affect human health. The goal of the Committee is to investigate the current state of knowledge and technology regarding DNA recombinants, their survival in nature, and transferability to other organisms; to recommend programs of research to assess the possibility of spread of specific DNA recombinants and the possible hazards to public health and to the environment; and to recommend guidelines on the basis of the research results. This Committee is a technical committee, established to look at a specific problem.

Authority

42 U.S.C. 217a. This Committee is established in accordance with, and is governed by, the provisions of Public Law 92-463, which sets forth standards for the formation and use of advisory committees.

Function

The Recombinant DNA Molecule Program Advisory Committee shall advise the Secretary, Health, Education, and Welfare, the Assistant Secretary for Health, Department of Health, Education, and Welfare, and the Director, National Institutes of Health, concerning a program for the evaluation of potential biological and ecological hazards of DNA recombinants of various types, for developing procedures which will minimize the spread of such molecules within human and other populations, and for devising guidelines to be followed by investigators working with potentially hazardous recombinants. The Committee may recommend special workshops for exploration of particular problems.

Structure

The Committee shall consist of twelve members, including the Chairman. Members shall be selected by the Secretary, or his designee, from authorities knowledgeable in the fields of molecular biology, virology, genetics and microbiology.

Members shall be invited to serve for overlapping 4-year terms; terms of more than two years are contingent upon the renewal of the Committee by appropriate action prior to its termination.

Management and staff services shall be provided by the Division of Research Grants, Office of the Associate Director for Scientific Review, who shall designate an Executive Secretary.

Meetings

Meetings shall be held approximately four times a year at the call of the Chairman, with the advance approval of a government official who also approves the agenda. A government official is present at all meetings.

Meetings shall be open to the public except as determined otherwise by the Secretary ; notice of all meetings shall be given to the public.

Meetings shall be conducted, and records of the proceedings kept, as required by applicable laws and Departmental regulations.

RECOMBINANT DNA MOLECULE PROGRAM ADVISORY COMMITTEE

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APPENDIX 6

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A.G. Wedum, Jan. 20, 1976

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APPENDIX 7

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APPENDIX 8

WEDNESDAY, JULY 7, 1976



PART II:

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

National Institutes of Health



RECOMBINANT DNA RESEARCH

Guidelines

27902

NOTICES

DEPARTMENT OF HEALTH,
EDUCATION, AND WELFARENational Institutes of Health
RECOMBINANT DNA RESEARCH
Guidelines

On Wednesday, June 23, 1976, the Director, National Institutes of Health, with the concurrence of the Secretary of Health, Education, and Welfare, and the Assistant Secretary for Health, issued guidelines that will govern the conduct of NIH supported research on recombinant DNA molecules. The NIH is also undertaking an environmental impact assessment of these guidelines for recombinant DNA research in accordance with the National Environmental Policy Act of 1969.

The NIH Guidelines establish carefully controlled conditions for the conduct of experiments involving the production of such molecules and their insertion into organisms such as bacteria. These Guidelines replace the recommendations contained in the 1975 *Summary Statement of the Asilomar Conference on Recombinant DNA Molecules*. The latter would have permitted research under less strict conditions than the NIH Guidelines.

The chronology leading to the present Guidelines is described in detail in the NIH Director's decision document that follows. In summary, scientists engaged in this research called, in 1974, for a moratorium on certain kinds of experiments until an international meeting could be convened to consider the potential hazards of recombinant DNA molecules. They also called upon the NIH to establish a committee to provide advice on recombinant DNA technology.

The international meeting was held at the Asilomar Conference Center, Pacific Grove, California, in February 1975. The consensus of this meeting was that certain experiments should not be done at the present time, but that most of the work on construction of recombinant DNA molecules should proceed with appropriate physical and biological barriers. The Asilomar Conference report also made interim assignments of the potential risks associated with different types of experiments. The NIH then assumed responsibility for translating the broadly based Asilomar recommendations into detailed guidelines for research.

The decision by the NIH Director on these Guidelines was reached after extensive scientific and public airing of the issues during the sixteen months which have elapsed since the Asilomar Conference. The issues were discussed at public meetings of the Recombinant DNA Molecule Program Advisory Committee (Recombinant Advisory Committee) and the Advisory Committee to the NIH Director. The Recombinant Advisory Committee extensively debated three different versions of the Guidelines during this period.

The Advisory Committee to the NIH Director, augmented with consultants representing law, ethics, consumer af-

fairs and the environment, was asked to advise as to whether the proposed Guidelines balanced responsibility to protect the public with the potential benefits through the pursuit of new knowledge. The many different points of view expressed at this meeting were taken into consideration in the decision.

The NIH recognizes a special obligation to disseminate information on these guidelines as widely as possible. Accordingly, the Guidelines will be sent to all of the approximately 25,000 NIH grantees and contractors. Major professional societies which represent scientists working in this area will also be asked to endorse the Guidelines. The Guidelines will be sent to medical and scientific journals and editors of these journals will be asked to request that investigators include a description of the physical and biological containment procedures used in any recombinant research they report on. International health and scientific organizations will also receive copies of the guidelines for their review.

Filing of an environmental impact statement will provide opportunity for the scientific community, Federal, State and local agencies and the general public to address the potential benefits and hazards of this research area. In order for there to be further opportunity for public comment and consideration, these guidelines are being offered for general comment in the *FEDERAL REGISTER*. It must be clearly understood by the reader that the material that follows is *not* proposed rulemaking in the technical sense, but is a document on which early public comment and participation is invited.

Please address any comments on these draft policies and procedures to the Director, National Institutes of Health, 9000 Rockville Pike, Bethesda, Maryland 20014. All comments should be received by November 1, 1976.

Additional copies of this notice are available from the Acting Director, Office of Recombinant DNA Activities, National Institute of General Medical Sciences, National Institutes of Health, 9000 Rockville Pike, Bethesda, Maryland 20014.

DONALD S. FREDRICKSON,
Director,

NIH National Institutes of Health.

JUNE 25, 1976.

DECISION OF THE DIRECTOR, NATIONAL IN-
STITUTES OF HEALTH TO RELEASE GUIDE-
LINES FOR RESEARCH ON RECOMBINANT
DNA MOLECULES

JUNE 23, 1976.

INTRODUCTION

- I. General Policy Considerations.
 - A. Science Policy.
 - B. Implementation Within the NIH.
 - C. Implementation Beyond the Purview of NIH.
 - D. Environmental Policy.
- II. Methods of Containment (See *Guidelines II*).
- III. Prohibited Experiments (See *Guidelines III, A*).
- IV. Permissible Experiments: *E. Coli* K-12 Host-Vector Systems (See *Guidelines III, B, 1*).

V. Classification of Experiments Using the *E. Coli* K-12 Containment Systems (See *Guidelines III, B, 2*).

VI. Classification of Experiments Using Containment Systems Other than *E. Coli* K-12 (See *Guidelines III, B, 4*).

VII. Roles and Responsibilities (See *Guidelines IV*).

INTRODUCTION

Today, with the concurrence of the Secretary of Health, Education, and Welfare and the Assistant Secretary for Health, I am releasing guidelines that will govern the conduct of NIH-supported research on recombinant DNA molecules (molecules resulting from the recombination in cell-free systems of segments of deoxyribonucleic acid, the material that determines the hereditary characteristics of all known cells). These guidelines establish carefully controlled conditions for the conduct of experiments involving the insertion of such recombinant genes into organisms, such as bacteria. The chronology leading to the present guidelines and the decision to release them are outlined in this introduction.

In addition to developing these guidelines, NIH has undertaken an environmental impact assessment of these guidelines for recombinant DNA research in accordance with the National Environmental Policy Act of 1969 (NEPA). The guidelines are being released prior to completion of this assessment. They will replace the current Asilomar guidelines, discussed below, which in many instances allow research to proceed under less strict conditions. Because the NIH guidelines will afford a greater degree of scrutiny and protection, they are being released today, and will be effective while the environmental impact assessment is under way.

Recombinant DNA research brings to the fore certain problems in assessing the potential impact of basic science on society as a whole, including the manner of providing public participation in those assessments. The field of research involved is a rapidly moving one, at the leading edge of biological science. The experiments are extremely technical and complex. Molecular biologists active in this research have means of keeping informed, but even they may fail to keep abreast of the newest developments. It is not surprising that scientists in other fields and the general public have difficulty in understanding advances in recombinant DNA research. Yet public awareness and understanding of this line of investigation is vital.

It was the scientists engaged in recombinant DNA research who called for a moratorium on certain kinds of experiments in order to assess the risks and devise appropriate guidelines. The capability to perform DNA recombinations, and the potential hazards, had become apparent at the Gordon Research Conference on Nucleic Acids in July 1973. Those in attendance voted to send an open letter to Dr. Philip Handler, President of the National Academy of Sciences, and to Dr. John R. Hogness, President of the Institute of Medicine, NAS. The letter, appearing in *Science* 181, 1114, (1973), suggested "that the Academies

[sic] establish a study committee to consider this problem and to recommend specific actions or guidelines, should that seem appropriate."

In response, NAS formed a committee, and its members published another letter in *Science* 185, 303, (1974). Entitled "Potential Biohazards of Recombinant DNA Molecules," the letter proposed:

First, and most important, that until the potential hazards of such recombinant DNA molecules have been better evaluated or until adequate methods are developed for preventing their spread, scientists throughout the world join with the members of this committee in voluntarily deferring . . . [certain] experiments . . .

Second, plans to link fragments of animal DNAs to bacterial plasmid DNA or bacteriophage DNA should be carefully weighted . . .

Third, the Director of the National Institutes of Health is requested to give immediate consideration to establishing an advisory committee charged with (i) overseeing an experimental program to evaluate the potential biological and ecological hazards of the above types of recombinant DNA molecules; (ii) developing procedures which will minimize the spread of such molecules within human and other populations; and (iii) devising guidelines to be followed by investigators working with potentially hazardous recombinant DNA molecules.

Fourth, an international meeting of involved scientists from all over the world should be convened early in the coming year to review scientific progress in this area and to further discuss appropriate ways to deal with the potential biohazards of recombinant DNA molecules.

On October 7, 1974, the NIH Recombinant DNA Molecule Program Advisory Committee (hereafter "Recombinant Advisory Committee") was established to advise the Secretary, HEW, the Assistant Secretary for Health, and the Director, NIH, "concerning a program for developing procedures which will minimize the spread of such molecules within human and other populations, and for devising guidelines to be followed by investigators working with potentially hazardous recombinants."

The international meeting proposed in the *Science* article (185, 303, 1974) was held in February 1975 at the Asilomar Conference Center, Pacific Grove, California. It was sponsored by the National Academy of Sciences and supported by the National Institutes of Health and the National Science Foundation. One hundred and fifty people attended, including 52 foreign scientists from 15 countries, 16 representatives of the press, and 4 attorneys.

The conference reviewed progress in research on recombinant DNA molecules and discussed ways to deal with the potential biohazards of the work. Participants felt that experiments on construction of recombinant DNA molecules should proceed, provided that appropriate biological and physical containment is utilized. The conference made recommendations for matching levels of containment with levels of possible hazard for various types of experiments. Certain experiments were judged to pose such serious potential dangers that the con-

ference recommended against their being conducted at the present time.

A report on the conference was submitted to the Assembly of Life Sciences, National Research Council, NAS, and approved by its Executive Committee on May 20, 1975. A summary statement of the report was published in *Science* 188, 991 (1975), *Nature* 225, 442, (1975), and the *Proceedings of the National Academy of Sciences* 72, 1981, (1975). The report noted that "in many countries steps are already being taken by national bodies to formulate codes of practice for the conduct of experiments with known or potential biohazard. Until these are established, we urge individual scientists to use the proposals in this document as a guide."

The NIH Recombinant Advisory Committee held its first meeting in San Francisco immediately after the Asilomar conference. It proposed that NIH use the recommendations of the Asilomar conference as guidelines for research until the committee had an opportunity to elaborate more specific guidelines, and that NIH establish a newsletter for informal distribution of information. NIH accepted these recommendations.

At the second meeting, held on May 12-13, 1975, in Bethesda, Maryland, the committee received a report on biohazard-containment facilities in the United States and reviewed a proposed NIH contract program for the construction and testing of microorganisms that would have very limited ability to survive in natural environments and would thereby limit the potential hazards. A subcommittee chaired by Dr. David Hogness was appointed to draft guidelines for research involving recombinant DNA molecules, to be discussed at the next meeting.

The NIH committee, beginning with the draft guidelines prepared by the Hogness subcommittee, prepared proposed guidelines for research with recombinant DNA molecules at its third meeting, held on July 18-19, 1975, in Woods Hole, Massachusetts.

Following this meeting, many letters were received which were critical of the guidelines. The majority of critics felt that they were too lax, others that they were too strict. All letters were reviewed by the committee, and a new subcommittee, chaired by Dr. Elizabeth Kutter, was appointed to revise the guidelines.

A fourth committee meeting was held on December 4-5, 1975, in La Jolla, California. For this meeting a "variorum edition" had been prepared, comparing line-for-line the Hogness, Woods Hole, and Kutter guidelines. The committee reviewed these, voting item-by-item for their preference among the three variations and, in many cases, adding new material. The result was the "Proposed Guidelines for Research Involving Recombinant DNA Molecules," which were referred to the Director, NIH, for a final decision in December 1975.

As Director of the National Institutes of Health, I called a special meeting of the Advisory Committee to the Director to review these proposed guidelines. The

meeting was held at NIH, Bethesda, on February 9-10, 1976. The Advisory Committee is charged to advise the Director, NIH, on matters relating to the broad setting—scientific, technological, and socioeconomic—in which the continuing development of the biomedical sciences, education for the health professions, and biomedical communications must take place, and to advise on their implications for NIH policy, program development, resource allocation, and administration. The members of the committee are knowledgeable in the fields of basic and clinical biomedical sciences, the social sciences, physical sciences, research, education, and communications. In addition to current members of the committee, I invited a number of former committee members as well as other scientific and public representatives to participate in the special February session.

The purpose of the meeting was to seek the committee's advice on the guidelines proposed by the Recombinant Advisory Committee. The Advisory Committee to the Director was asked to determine whether, in their judgment, the guidelines balanced scientific responsibility to the public with scientific freedom to pursue new knowledge.

Public responsibility weighs heavily in this genetic research area. The scientific community must have the public's confidence that the goals of this profoundly important research accord respect to important ethical, legal, and social values of our society. A key element in achieving and maintaining this public trust is for the scientific community to ensure an openness and candor in its proceedings. The meetings of the Director's Advisory Committee, the Asilomar group, and the Recombinant Advisory Committee have reflected the intent of science to be an open community in considering the conduct of recombinant DNA experiments. At the Director's Advisory Committee meeting, there was ample opportunity for comment and an airing of the issues, not only by the committee members but by public witnesses as well. All major points of view were broadly represented.

I have been reviewing the guidelines in light of the comments and suggestions made by participants at that meeting, as well as the written comments received afterward. As part of that review I asked the Recombinant Advisory Committee to consider at their meeting of April 1-2, 1976, a number of selected issues raised by the commentators. I have taken those issues and the response of the Recombinant Advisory Committee into account in arriving at my decision on the guidelines. An analysis of the issues and the basis for my decision follow.

I. GENERAL POLICY CONSIDERATIONS

A word of explanation might be interjected at this point as to the nature of the studies in question. Within the past decade, enzymes capable of breaking DNA strands at specific sites and of coupling the broken fragments in new combinations were discovered, thus making possible the insertion of foreign genes into viruses or certain cell particles (plas-

mids). These, in turn, can be used as vectors to introduce the foreign genes into bacteria or into cells of plants or animals in test tubes. Thus transplanted, the genes may impart their hereditary properties to new hosts. These cells can be isolated and cloned—that is, bred into a genetically homogeneous culture. In general, there are two potential uses for the clones so produced: as a tool for studying the transferred genes, and as a new useful agent, say for the production of a scarce hormone.

Recombinant DNA research offers great promise, particularly for improving the understanding and possibly the treatment of various diseases. There is also a potential risk—that microorganisms with transplanted genes may prove hazardous to man or other forms of life. Thus special provisions are necessary for their containment.

All commentators acknowledged the exemplary responsibility of the scientific community in dealing publicly with the potential risks in DNA recombinant research and in calling for a self-imposed moratorium on certain experiments in order to assess potential hazards and devise appropriate guidelines. Most commentators agreed that the process leading to the formulation of the proposed guidelines was a most responsible and responsive one. Suggestions by the commentators on broad policy considerations are presented below. They relate to the science policy aspects of the guidelines, the implementation of the guidelines for NIH grantees and contractors, and the scope and impact of the guidelines nationally and internationally.

A. Science policy considerations

Commentators were divided on how best to steer a course between stifling research through excessive regulation and allowing it to continue with sufficient controls. Several emphasized that the public must have assurance that the controls afford adequate protection against potential hazards. In the views of these commentators, the burden is on the scientific community to show that the danger is minimal and that the benefits are substantial and far outweigh the risks.

Opinion differed on whether the proposed guidelines were an appropriate response to the potential benefits and hazards. Several found the guidelines to so exaggerate safety procedures that inquiry would be unnecessarily retarded, while others found the guidelines weighted toward promoting research. The issue was how to strike a reasonable balance—in fact, a proper policy “bias”—between concerns to “go slow” and those to progress rapidly.

There was strong disagreement about the nature and level of the possible hazards of recombinant DNA research. Several commentators believed that the hazards posed were unique. In their view, the occurrence of an accident or the escape of a vector could initiate an irreversible process, with a potential for creating problems many times greater than those arising from the multitude of

genetic recombinations that occur spontaneously in nature. These commentators stress the moral obligation on the part of the scientific community to do no harm.

Other commentators, however, found the guidelines to be adequate to the hazards posed. In their view, the guidelines struck an appropriate balance so that research could proceed cautiously. Still other commentators found the guidelines too onerous and restrictive in light of the potential benefits of this research for medicine, agriculture, and industry. Some felt that the guidelines are perhaps more stringent than necessary given the available evidence on the likelihood of hazards, but supported them as a compromise that would best serve the scientific community and the public at large. Many commentators urged that the guidelines be adopted as soon as possible to afford more specific direction to this research area.

I understand and appreciate the concerns of those who urge that this research proceed because of the benefits and of those who urge caution because of potential hazards. The guidelines issued today allow the research to go forward in a manner responsive and appropriate to hazards that may be realized in the future.

The object of these guidelines is to ensure that experimental DNA recombination will have no ill effects on those engaged in the work, on the general public, or on the environment. The essence of their construction is subdivision of potential experiments by class, decision as to which experiments should be permitted at present, and assignment to these of certain procedures for containment of recombinant organisms.

Containment is defined as physical and biological. Physical containment involves the isolation of the research by procedures which have evolved over many years of experience in laboratories studying infectious microorganisms. P1 containment—the first physical containment level—is that used in most routine bacteriology laboratories. P2 and P3 afford increasing isolation of the research from the environment. P4 represents the most extreme measures used for containing virulent pathogens, and permits no escape of contaminated air, wastes, or untreated materials. Biological containment is the use of vectors or hosts that are crippled by mutation so that the recombinant DNA is incapable of surviving under natural conditions.

The experiments now permitted under the guidelines involve no known additional hazard to the workers or the environment beyond the relatively low risk known to be associated with the source materials. The additional hazards are speculative and therefore not quantifiable. In a real sense they are considerably less certain than are the benefits now clearly derivable from the projected research.

For example, the ability to produce, through “molecular cloning,” relatively large amounts of pure DNA from the chromosomes of any living organism will

have a profound effect in many areas of biology. No other procedure, not even chemical synthesis, can provide pure material corresponding to particular genes. DNA “probes,” prepared from the clones will yield precise evidence on the presence or absence, the organization, and the expression of genes in health and disease.

Potential medical advances were outlined by scientists active in this research area who were present at the meeting of the Director's Advisory Committee. Of enormous importance, for example, is the opportunity to explore the malfunctioning of cells in complicated diseases. Our ability to understand a variety of hereditary defects may be significantly enhanced, with amelioration of their expression a real possibility. There is the potential to elucidate mechanisms in certain cancers, particularly those that might be caused by viruses.

Instead of mere propagation of foreign DNA, the expression of the genes of one organism by the cell machinery of another may alter the new host and open opportunities for manipulating the biological properties of cells. In certain prokaryotes (organisms with a poorly developed nucleus, like bacteria), this exchange of genetic information occurs in nature. Such exchange explains, for instance, an important mechanism for the changing and spreading of resistance to antibiotics in bacteria. Beneficial effects of this mechanism might be the production of medically important compounds for the treatment and control of disease. Examples frequently cited are the production of insulin, growth hormone, specific antibodies, and clotting factors absent in victims of hemophilia.

Aside from the potential medical benefits, a whole host of other applications in science and technology have been envisioned. Examples are the large-scale production of enzymes for industrial use and the development of bacteria that could ingest and destroy oil spills in the sea. Potential benefits in agriculture include the enhancement of nitrogen fixation in certain plants, permitting increased food production.

While the projected research offers the possibility of many benefits, it must proceed only with assurance that potential hazards can be controlled or prevented. Some commentators are concerned that nature may maintain a barrier to the exchange of DNA between prokaryotes and eukaryotes (higher organisms, with a well-formed nucleus)—a barrier that can now be crossed by experimentalists. They further argue that expression of the foreign DNA may alter the host in unpredictable and undesirable ways. Conceivable harm could result if the altered host has a competitive advantage that would foster its survival in some niche within the ecosystem. Other commentators believe that the endless experiments in recombination of DNA which nature has conducted since the beginning of life on the earth, and which have accounted in part for the evolution of species, have most likely involved exchange of DNA between widely disparate species. They

argue that prokaryotes such as bacteria in the intestines of man do exchange DNA with this eukaryotic host and that the failure of the altered prokaryotes to be detected attests to a sharply limited capacity of such recombinants to survive. Thus nature, this argument runs, has already tested the probabilities of harmful recombination and any survivors of such are already in the ecosystem. The fact is that we do not know which of the above-stated propositions is corrected.

The international scientific community, as exemplified by the Asilomar conference and the deliberations attendant upon preparation of the present guidelines, has indicated a desire to proceed with research in a conservative manner. And most of the considerable public commentary on the subject, while urging caution, has also favored proceeding. Three European groups have independently arrived at the opinion that recombinant DNA research should proceed with caution. These are the Working Party on Experimental Manipulation of the Genetic Composition of Micro-Organisms, whose "Ashby Report" was presented to Parliament in the United Kingdom by the Secretary of State for Education and Science in January 1975; the Advisory Committee on Medical Research of the World Health Organization, which issued a press release in July 1975; and the European Molecular Biology Organization Standing Committee on Recombinant DNA, meeting in February 1976.

There is no means for a flat proscription of such research throughout the world community of science. There is also no need to attempt it. It is likely that the evaluation engendered in the preparation and application of these guidelines will lead to beneficial review of some of the containment practices in other work that is not technically defined as recombinant DNA research.

Recombinant DNA research with which these guidelines are concerned involves microorganisms such as bacteria or viruses or cells of higher organisms growing in tissue culture. It is extremely important for the public to be aware that this research is not directed to altering of genes in humans although some of the techniques developed in this research may have relevance if this is attempted in the future.

NIH recognizes its responsibility to conduct and support research designed to determine the extent to which certain potentially harmful effects from recombinant DNA molecules may occur. Among these are experiments, to be conducted under maximum containment, that explore the capability of foreign genes to alter the character of host or vector, rendering it harmful, as through the production of toxic products.

Given the general desire that no rare and unexpected event arising from this research shall cause irreversible damage, it is obvious that merely to establish conservative rules of conduct for one group of scientists is not enough. The precautions must be uniformly and unanimously observed. Second, there

must be full and timely exchange of experiences so that guidelines can be altered on the basis of new knowledge. The guidelines must also be implemented in a manner that protects all concerned—the scientific workers most likely to encounter unexpected hazards and all forms of life within our biosphere. The responsibility of the scientists involved is as inescapable and extreme as is their opportunity to beneficially enrich our understanding.

B. Implementation considerations within the NIH

All the commentators had suggestions concerning the structure and function of decision making as it relates to the principal investigator, the local biohazards committee, the peer review group, and the NIH Recombinant Advisory Committee. These comments and my response on the section of the guidelines relating to roles and responsibilities of investigators, their institutions, and the National Institutes of Health are presented below.

Of considerable concern to all commentators was the process by which NIH would proceed to implement the guidelines. The scientific community generally urged that there be no Federal regulations, while some of the public commentators recommended the regulatory process.

Many who opposed changing the proposed guidelines into Federal regulations expressed concern for flexibility and administrative efficiency, which could best be achieved, in their view, through voluntary compliance. Other commentators, however, believed it imperative to proceed toward regulation. In their view, the guidelines could be implemented for purposes of NIH funding and would govern the conduct of experiments until regulations were in effect. Another commentator who thought regulation would be harmful rather than helpful suggested that if there were to be regulations, they should be along lines similar to those that govern the sale, distribution, use, and disposal of radioisotopes.

The question of how best to proceed now that the guidelines have been released deserves careful attention. I share the concern of those who feel that the guidelines must remain flexible. It is especially important that there be opportunity to change them quickly, based on new information relating to scientific evidence, potential risks, or safety aspects of the research program.

The suggestions for regulation need further attention at this time. The process for regulation not only involves the Director of NIH, but also the Assistant Secretary for Health and the Secretary of Health, Education, and Welfare. These guidelines are being promulgated now in order to afford additional protection to all concerned. Consideration of their conversion to regulations can proceed with continuing review of their content and present and future implications. Meanwhile, the NIH shall continue to provide the opportunity for public comment and participation at least

equivalent to that provided if steps towards regulations were to proceed immediately. The guidelines will be published in the FEDERAL REGISTER forthwith to allow for further public comment.

C. Implementation considerations beyond the purview of NIH

Special concern has been expressed by many commentators regarding the application of the guidelines to research outside NIH by investigators other than its grantees or contractors. It has been urged that the guidelines be made applicable to recombinant DNA research conducted or supported by other agencies in HEW and by NSF, ERDA, DoD, and other governmental departments. Most commentators believe that these or similar guidelines should also govern research in the private sector, including industry, voluntary organizations, and foundations. Many feel that experiments conducted in colleges, universities, and even in high schools require some form of monitoring. And finally, all agree that in view of the potential hazards of recombinant DNA research to the biosphere, some form of international understanding on guidelines for the research is essential.

The committee, in the proposed guidelines, has suggested as one means of control that a description of the physical and biological containment procedures practiced in a research project be included in the publication of research results. In the scientific community this can be a powerful force for conformity, and we will undertake to present the recommendation to all appropriate journals. We are also prepared to take steps to disseminate the guidelines widely, and to arrange for a continual flow of information outward concerning the activities of the Recombinant Advisory Committee and the Advisory Committee to the Director, NIH, in the evolution of the guidelines and their implementation.

In response to these suggestions, I have already held a meeting with relevant HEW agencies and with representatives from other departments of the Federal Government. The purpose of the meeting was to exchange information on recombinant DNA research and to discuss the NIH guidelines. It served as an important beginning to address a common concern of these public institutions. A number of the representatives indicated that various departments might very well adopt the guidelines for research conducted both in-house and supported outside. Following up, I have begun preliminary discussions with the Assistant Secretary for Health and the Secretary of HEW, to determine possible methods to ensure adoption of the guidelines by all Federal agencies. Encouraged by these efforts, we held a meeting on June 2 with representatives of industry to provide them with full information about the guidelines and to help determine the present and future interests of industrial laboratories in this type of research. The meeting provided one of the first opportunities for industry representatives to convene for a discussion of this research area, and an industry com-

mittee under the auspices of the Pharmaceutical Manufacturers Association will be formed to review the guidelines for potential application to the drug industry. Further meetings will be scheduled with other groups that have an active interest in recombinant DNA research.

It is my hope that the guidelines will be voluntarily adopted and honored by all who support or conduct such research throughout the United States, and that at least very similar guidelines will obtain throughout the rest of the world. NIH places the highest priority on efforts to inform and to work with international organizations, such as the World Health Organization and the International Council of Scientific Unions, with a view to achieving a consensus on safety standards in this most important research area.

There has been considerable international cooperation and activity in the past, and I expect it to continue in the future. The aforementioned Ashby Report, presented to Parliament in January 1975, describes the advances in knowledge and possible benefits to society of the experiments involving recombinant DNA molecules, and attempts to assess the hazards in these techniques. The Asilomar meeting also had a number of international representatives, as mentioned previously. The European Molecular Biology Organization (EMBO) has been involved in considering guidelines for recombinant DNA research. They have closely followed the activities of NIH, and will thus be encouraged, I believe, to monitor their research with augmented cooperation and coordination. For example, EMBO recently announced plans for a voluntary registry of recombinant DNA research in Europe. Following this EMBO initiative, NIH shall similarly maintain a voluntary registry of investigators and institutions engaged in such research in the United States. Plans for establishing this registry are under way.

D. Environmental policy considerations

A number of commentators urged NIH to consider preparing an environmental impact statement on recombinant DNA research activity. They evoked the possibility that organisms containing recombinant DNA molecules might escape and affect the environment in potentially harmful ways.

I am in full agreement that the potentially harmful effects of this research on the environment should be assessed. As discussed throughout this paper, the guidelines are premised on physical and biological containment to prevent the release or propagation of DNA recombinants outside the laboratory. Deliberate release of organisms into the environment is prohibited. In my view, the stipulated physical and biological containment ensures that this research will proceed with a high degree of safety and precaution. But I recognize the legitimate concern of those urging that an environmental impact assessment be done. In view of this concern and ensuing pub-

lic debate, I have reviewed the appropriateness of such an assessment and have directed that one be undertaken.

The purpose of this assessment will be to review the environmental effects, if any, of research that may be conducted under the guidelines. The assessment will provide further opportunity for all concerned to address the potential benefits and hazards of this most important research activity. I expect a draft of the environmental impact statement should be completed by September 1 for comment by the scientific community, Federal and State agencies, and the general public.

It should be noted that the development of the guidelines was in large part tantamount to conducting an environmental impact assessment. For example, the objectives of recombinant DNA research, and alternate approaches to reach those objectives, have been considered. The potential hazards and risks have been analyzed. Alternative approaches have been thoroughly considered, to maximize safety and minimize potential risk. And an elaborate review structure has been created to achieve these safety objectives. From a public policy viewpoint, however, the environmental impact assessment will be yet another review that will provide further opportunity for the public to participate and comment on the conduct of this research.

II. METHODS OF CONTAINMENT

Comments on the containment provisions of the proposed guidelines were directed to the definition of both physical and biological containment and to the safety and effectiveness of the prescribed levels. Several commentators found the concept of physical containment imprecise and too subject to the possibility for human error. Others questioned the concept of biological containment in terms of its safety and purported effectiveness in averting potential hazards. The commentators were divided on which method of containment would provide the most effective and safe system to avoid hazards. Several suggested that each of the physical containment levels be more fully explained.

W. Emmett Barkley, Ph.D., Director of the Office of Research Safety, National Cancer Institute, was asked to review the section on physical containment in light of these comments. Dr. Barkley convened a special committee of safety and health experts, who met to consider not only this section of the guidelines but also the section on the roles and responsibilities of researchers and their institutions. The committee thoroughly reviewed the section on physical containment and recommended a number of changes. The Recombinant Advisory Committee, meeting on April 1-2, 1976, reviewed the recommendations of the Barkley group. These are incorporated, with editorial revisions, in the final version of the guidelines.

The present section on physical containment is directly responsive to those commentators who asked for greater de-

tail and explanation. Although different in detail, the four levels of containment approximate those given by the Center for Disease Control for human etiologic agents and by the National Cancer Institute for oncogenic viruses. For each of the proposed levels, optional items have been excluded, and only those items deemed absolutely necessary for safety are presented. Necessary facilities, practices, and equipment are specified. To give further guidance to investigators and their institutions, a supplement to the guidelines explains more fully safety practices appropriate to recombinant DNA research. And a new section has been added to ensure that shipment of recombinant DNA materials conforms, where appropriate, to the standards, prescribed by the U.S. Public Health Service, the Department of Transportation, and the Civil Aeronautics Board.

The section on physical containment is carefully designed to offer a constructive approach to meeting potential hazards for recombinant experiments at all levels of presumed risk. Certain commentators had suggested that the first level of physical containment (P1) be merged with the second level (P2). This suggestion, however, would tend to apply overly stringent standards for some experiments and might result in a lowering of standards necessary at the second level. I believe the level of control must be consistent with a reasonable estimate of the hazard; and the section on physical containment does provide this consistency. Accordingly, the first and second levels of physical containment remain as separate sections in the guidelines.

Because of the nature and operation of facilities required for experiments to be done at the fourth level of containment (P4), a provision has been included that the NIH shall review such facilities prior to funding them for recombinant DNA studies. The situation merits the special attention of experts who have maximum familiarity with the structure, operation, and potential problems of P4 installations. Several commentators advocated that NIH arrange for sharing of P4 facilities, both in the NIH intramural program and in institutions supported through NIH awards. In response to these suggestions, we are currently reviewing our facilities, including those at the Frederick Cancer Research Center (Fort Detrick), to determine how such a program can best be devised. It is most important that P4 facilities be made available to investigators. It should be noted that incidents of infection by even the most highly infectious and dangerous organisms are extremely infrequent at P4 facilities, and therefore the potential for hazard in certain complex experiments in recombinant DNA research is considerably reduced.

III. PROHIBITED EXPERIMENTS

1. Practically all commentators supported the present prohibition of certain experiments. There were suggestions for a clearer definition of the prohibition of certain experiments where increased antibiotic resistance may result. And it

was urged by some that the prohibition be broadened to include experiments that result in resistance to any antibiotic, irrespective of its use in medicine or agriculture. Consideration of such a suggestion must take into account that antibiotic resistance occurs naturally among bacteria, and that resistance is a valuable marker in the study of microbial genetics in general, and recombinants in particular.

In view of these concerns, however, the Recombinant Advisory Committee was asked to reconsider carefully the prohibition and related sections concerning antibiotic resistance. The committee noted that the prohibition relating to drug resistance was intended to ban those experiments that could compromise drug use in controlling disease agents in veterinary as well as human medicine and this is now clearly stated.

In the draft guidelines there were two statements concerning resistance to drugs which related to experiments with *E. coli*. The statements appeared to allow experiments that would extend the range of resistance of this bacterium to therapeutically useful drugs and disinfectants, and thus seemed to be in conflict with the general prohibition on such research. There are numerous reports in the scientific literature indicating that *E. coli* can acquire resistance to all antibiotics known to act against it. Since *E. coli* acquires resistance naturally, the prohibition directed against increasing resistance does not apply. The ambiguous statements have been deleted from the present guidelines. On the other hand, new language has been inserted in the section dealing with other prokaryote species to set containment levels for permitted experiments.¹

2. The Recombinant Advisory Committee was also asked to clarify whether the prohibition of use of DNA derived from pathogenic organisms (those classified as 3, 4, and 5 by the Center for Disease Control, USPHS) also included the DNA from any host infected with these organisms. The committee explained that this prohibition did extend to experiments with cells known to be so infected. To avoid misunderstanding, the prohibition as now worded includes such cells. In addition, the prohibitions have been extended to include moderate-risk oncogenic viruses, as defined by the National Cancer Institute, and cells known to be infected with them.

3. Two other issues relating to the section on prohibited experiments were raised by Roy Curtiss III, Ph.D., Professor, Department of Microbiology, University of Alabama School of Medicine, Birmingham, who is a member of the Recombinant Advisory Committee. Dr. Curtiss noted that for the class of experiments prohibited on the basis of production of highly toxic substances, only

¹ Specifically, experiments that would extend resistance to therapeutically useful drugs must use P3 physical containment plus a host-vector comparable to EK1, or P2 containment plus a host-vector comparable to EK2.

substances from micro-organisms were cited as examples. He suggested that other examples be included, such as venoms from insects and snakes. The committee approved the suggestion and I concur.

In the proposed guidelines, release of organisms containing recombinant DNA molecules into the environment was prohibited unless a series of controlled tests had been done to leave no reasonable doubt of safety. Dr. Curtiss felt that the guidelines should provide greater specificity for testing and should include some form of review prior to release of the organism. I have decided that the guidelines should, for the present, prohibit any deliberate release of organisms containing recombinant DNA into the environment. With the present limited state of knowledge, it seems highly unlikely that there will be in the near future, any recombinant organism that is universally accepted as being beneficial to introduce into the environment. When the scientific evidence becomes available that the potential benefits of recombinant organisms, particularly for agriculture, are about to be realized, then the guidelines can be altered to meet the needs for release. It is most important that the potential environmental impact of the release be considered.

IV. PERMISSIBLE EXPERIMENTS: *E. COLI* K-12 HOST-VECTOR SYSTEMS

The continued use of *E. coli* as a host has drawn considerable comment, including some suggestions that its use be prohibited presently or within a specified time limit. It should be stressed that the use of *E. coli* as detailed in the guidelines is limited to *E. coli* K-12, a strain that has been carried in the laboratory for decades and does not involve the use of any strain of *E. coli* that is freshly isolated from a natural source. *E. coli* K-12 does not usually colonize the normal bowel, even when given in large doses, and exhibits little if any multiplication while passing through the alimentary canal. For years it has been the subject of more intense investigation than any other single organism, and knowledge of its genetic makeup and recombinant behavior exceeds greatly that pertaining to any other organism. I believe that because of this experience, *E. coli* K-12 will provide a host-vector system that is safer than other candidate microorganisms.

NIH recognizes the importance of supporting the development of alternative host-vector systems (such as *B. subtilis*, which has no ecological niche in man) and will encourage such development. It should be noted, however, that for each new host-vector system, the same questions of risk from altered properties attendant upon the presence of recombinant genes will apply as apply to *E. coli*. NIH does not believe it wise to set a time limit on replacement of *E. coli* systems by other organisms.

There were specific suggestions concerning the three levels of biological containment prescribed for use of *E. coli* K-12 host-vectors. Some commentators requested a more detailed explanation of

the adequacy of protection for laboratory personnel with the first level of containment (EK1).² Sections of the guidelines dealing with physical containment and roles and responsibilities now specify the need for safety practices and accident plans.

For the second level of containment (EK2), it is required that a cloned DNA fragment be contained in a host-vector system that has no greater than a 10^{-8} probability of survival in a nonpermissive or natural environment. It was suggested that the selection of this level of biological containment and the appropriate tests for verification be more fully explained in the guidelines. The committee, in responding to a request for further examination of this point, reviewed at considerable length the testing for an EK2 system and recommended certain modifications. We have accepted the committee's new language that better explains testing of survival of a genetic marker carried on the vector, preferably on an inserted NDA fragment.

Possible tests to determine the level of biological containment afforded by these altered host-vector systems are outlined in this section. Because this is such a new area of scientific research and development, however, it is inappropriate to standardize such testing at the present time. Standards will gradually be set as more experience with EK2 host-vector systems is acquired. The committee, for example, during its April 1976 meetings gave its first approval to an EK2 host-vector system. What is necessary is that new and more effective tests be devised by investigators, and this effort is very likely to occur under the present guidelines. For example, one task recognized by the committee is to clarify how survival of the organism and the cloned DNA should be defined in terms of temperature, medium, and other variables.

It is also very important to note here that the stringent requirements set by the committee for EK2 biological containment jeopardize considerably the capacity of such crippled organisms to survive and replicate even under permissive laboratory conditions. More experience will be required to determine whether EK2 containment will permit some lines of important research to be followed.

Several commentators suggested that methods and procedures to confirm an

² The EK1 system presently consists of a battery of different vectors and of *E. coli* K-12 mutants, all of which afford a considerable degree of biological containment. The diversity of vectors and of host mutants in this battery has permitted a wide range of important scientific questions to be attacked. For example, the availability of different vectors with cleavage sites for different restriction endonucleases have increased the kind of DNA segments that can be cloned. By contrast, the first EK2 host-vector systems are only now being considered by the Recombinant Advisory Committee. While NIH is supporting the development of more EK2 host-vector systems, it is not expected that a battery equivalent to that available for the EK1 system will be certified by the Recombinant Advisory Committee in the near future.

EK system at the third level of containment (EK3) be more fully explained. The Recombinant Advisory Committee was asked to consider this suggestion. After considerable discussion the committee declined to define the procedures more fully at this time, because development of an EK3 system is still far enough in the future not to warrant specific testing procedures. Further, it is not clear what tests are best suited. The language, therefore, remains general. The committee, however, is aware of the concerns for a more completely defined system of testing, and has considered the possibility of organizing a symposium for purposes of designating tests. In my view, more fully developed protocols for testing EK3 systems are warranted, and it is necessary that guidelines here be more fully developed before the committee proceeds to certify such a system. In this regard the NIH is prepared through the National Institute of Allergy and Infectious Diseases to support contracts to accomplish this task. We will seek the advice and assistance of the committee to define the scope of necessary work.

These guidelines also include a statement that for the time being no EK2 or EK3 host-vector system will be considered *bona fide* until the Recombinant Advisory Committee has certified it. I share the concern of the commentators that new host-vector systems require the highest quality of scientific review and scrutiny. At this early stage of development, it is most important that the committee provide that scrutiny. Further, I believe that until more experience has been gained, the committee should encourage and the NIH support research that will independently confirm and augment the data on which certification of EK2 host-vector systems are based.

V. CLASSIFICATION OF EXPERIMENTS USING THE *E. COLI* K-12 CONTAINMENT SYSTEMS

The guidelines assign different levels of containment for experiments in which DNA from different sources is to be introduced into an *E. coli* K-12 host-vector system. The variation is based on both facts and assumptions. There are some prokaryotes (bacteria) which constantly exchange DNA with *E. coli*. Here it is assumed that experimental conditions beyond those obtained in careful, routine microbiology laboratories are superfluous, because any exchange experiments have undoubtedly been performed already in nature.

In every instance of artificial recombination, consideration must be given to the possibility that foreign DNA may be translated into protein (expressed), and also to the possibility that normally repressed genes of the host may be expressed and thus change, undesirably, the characteristics of the cell. It is assumed that the more similar the DNAs of donor and host, the greater the probability of expression of foreign DNA, or of possible derepression of host genes. In those cases where the donor exchanges DNA with *E. coli* in nature, it is unlikely that recombination experiments will create new genetic combinations.

When prokaryote donors not known to exchange DNA with *E. coli* in nature are used, however, there is a greater potential for new genetic combinations to be formed and be expressed. Therefore, it is required that experiments involving prokaryotic DNA from a donor that is not known to exchange DNA with *E. coli* in nature be carried out at a higher level of containment. Recombination using prokaryotic DNA from an organism known to be highly pathogenic is prohibited.

There are only limited data available concerning the expression of DNA from higher forms of life (eukaryotes) in *E. coli* (or any other prokaryote). Therefore, the containment prescriptions for experiments inserting eukaryotic DNA into prokaryotes are based on risks having quite uncertain probabilities.

On the assumption that a prokaryote host might translate eukaryotic DNA, it is further presumed that the product of that foreign gene would be most harmful to man if it were an enzyme, hormone, or other protein that was similar (homologous) to proteins already produced by or active in man. An example is a bacterium that could produce insulin. Such a "rogue" bacterium could be of benefit if contained, a nuisance or possibly dangerous if capable of surviving in nature. This is one reason that the higher the phylogenetic order of the eukaryote, the higher the recommended containment, at least until the efficiency of expression of DNA from higher eukaryotes in prokaryotes can be determined.

There is a second, more concrete reason for scaling containment upward as the eukaryote host becomes similar to man. This is the concern that viruses capable of propagating in human tissue, and possibly causing diseases, can contaminate DNA, replicate in prokaryote hosts and infect the experimentalist. Such risks are greatest when total DNA from donor tissue is used in "shotgun" recombinant experiments; it diminishes to much lower levels when pure cloned DNA is used.

The commentators were clearly divided on the classification of containment criteria for different kinds of recombinant DNAs. Many commentators considered the guidelines too stringent and rigid. Others viewed the guidelines in certain instances as too permissive. And still others endorsed the guidelines as sensible and reasonable, affording the public an enormous degree of protection from the speculative risks. Several suggestions were made for the specific classes of experiments, and they follow:

1. Comment on the use of DNA from animals and plants in recombinant experiments varied widely. Some commentators suggested banning the use of DNA from primates, other mammals, and birds. Others suggested that higher levels of containment be used for all such experiments. Still others believed that the guidelines were too strict for experiments of this class. I have carefully reviewed the issues raised by the commentators and the responses of the committee to certain queries concerning use

of animal and plant DNA in these experiments.

In my view, the classification for the use of DNA from primates, other mammals, and birds is appropriate to the potential hazards that might be posed. The physical and biological containment levels are very strict. For example, biological containment levels are at EK2 or EK3, and will effectively preclude experimentation until useful EK2 and EK3 systems are available. EK2 systems are still in the initial stages of development, and the first system was only certified at the most recent meeting of the Recombinant Advisory Committee. An EK3 host-vector system has yet to be tested, and its certification is far enough in the future to place a moratorium on those experiments requiring biological containment at an EK3 level. The physical containment levels of P3 or P4 themselves afford a very high degree of protection. I am satisfied that the guidelines demonstrate the caution and prudence that must govern the conduct of experiments in this category.

The guidelines allow reduced containment levels for primate DNA when it is derived from embryonic tissue or germ-line cells. This is based on evidence that embryonic material is less likely to contain viruses than is tissue from the adult. Obviously, the embryonic tissue must be free of adult tissue, and the present guidelines so indicate.

I have also carefully considered the special concerns arising from the use of DNA from cold-blooded vertebrates and other cold-blooded animals, because several commentators questioned the basis of lower physical and biological containment levels for DNA from these species. The Recombinant Advisory Committee has debated this extensively, and they were asked to do so once again in April.³ The committee has now recommended high containment levels (P3+EK2) when the DNA is from a cold-blooded vertebrate known to produce a potent toxin. That recommendation is included in the present guidelines. Where no toxin is involved the committee supported lower

³ A committee member, David S. Hogness, Ph. D., Professor, Department of Biochemistry, Stanford University, California, submitted a statement in support of lower containment levels based on current scientific evidence. That evidence is based on certain differences between cold- and warm-blooded vertebrates. One of the criteria used for the evaluation of the relative risk that might be encountered with different levels of shotgun experiment is the degree of sequence homology between the DNA of the given species and that of humans. This criterion is used to estimate the likelihood that segments of DNA from the given species might be integrated into the human genome by recombination; the greater the homology, the greater the likelihood of integration. Studies of sequence homologies indicate that there is a considerable degree of homology between human DNA and DNA from other primates, much less homology between primates and other mammals, and even lower but detectable homology between birds and primates. By contrast, no significant homologies between cold-blooded vertebrates and primates have been detected.

containment levels. The guidelines specify P2+EK2 levels for such work. There was considerable discussion concerning the advisability of recommending lower containment (P2+EK1) when the DNA is isolated from embryonic tissue or germ-line cells from cold-blooded vertebrates. Those supporting lower containment levels argued that the justification for P2+EK2 was the possibility that cold-blooded vertebrates may carry viruses and that the distinction between adult and germ-cell tissue is real. Others argued that, contrary to the situation with primate DNA, viruses are not a central problem with cold-blooded vertebrates and therefore no distinction should be made on the basis of tissue origin. Finally, the committee recommended, on a divided vote (8 to 4), to adopt P2+EK1 when the cold-blooded vertebrate DNA is isolated from embryonic tissue or germ-line cells. Upon reviewing these considerations, I have decided to retain the containment levels for embryonic or germ-line DNA from cold-blooded vertebrates as recommended by the committee.

In April the committee also reviewed, at our request, the classification of experiments where DNA is derived from other cold-blooded animals or lower eukaryotes. Several commentators, for example, had been concerned about the fact that insects are known to carry agents pathogenic to man. In the committee review, it was noted that viruses carried by insects and known to transmit disease to man are RNA rather than DNA viruses and do not reproduce via DNA copied from RNA. In order, however, to make the intent clearer, the guidelines have been rewritten for experiments of this class. New language is inserted to ensure that strict containment levels are employed when the DNA comes from known pathogens or species known to carry them. Further, to reduce the potential hazards, we have also included in the guidelines the requirement that any insect must be grown under laboratory conditions for at least 10 generations prior to its use as a DNA source.

2. As alluded to above, certain commentators expressed concern that when *E. coli* becomes the host of recombinant DNA from prokaryotes with which DNA is not usually exchanged, there is hazard of altered host characteristics resulting from translation of the DNA into functioning proteins. The committee was asked to review the guidelines and take into account this potential hazard. They agreed that the containment levels should be increased for this category of experiment, from P2+EK1 to either P2+EK2 or P3+EK1. That recommendation is included in the present guidelines.

Comments were made concerning that class of experiments in which the recombinant DNA, regardless of source, has been cloned. A clone is a population of cells derived from a single cell and therefore all the cells are presumed to be genetically identical. As outlined in the proposed guidelines, clones could be used at lower containment levels if they had

been rigorously characterized and shown to be free of harmful genes. Several commentators inquired how the characterization was to be performed and the freedom from harmful genes demonstrated. Although the committee acknowledges that these terms are unavoidably vague, they do cite appropriate scientific methods to make relevant determinations. Again, this is a rapidly changing area and more clarity and precision can be expected with experience. Reduced containment requirements for this class of experiment are warranted because of the purified nature of clones. Further, the granting agency must approve the clone before containment conditions can be reduced, thus providing an additional element of review.

4. Another comment was related to the use of DNA from organelles (intracellular elements that contain special groups of genes for particular cell functions). Concern was expressed about the potential contamination of purified organelle DNA with DNA from viruses because of the similarity of their structures. The committee agrees, and the guidelines now specify a requirement, that the organelles be isolated prior to extracting DNA, as a further means of reducing the hazard of viral contamination.

5. Some commentators were troubled about the lowering of containment for that class of experiments involving recombinations with cell DNA segments purified by chemical or physical methods. They asked that procedures for determining the state of purification be more fully detailed and that the Recombinant Advisory Committee certify the purity. There are, however, appropriate techniques, such as gel electrophoresis, with which a purity of 99 percent by mass can be achieved and ascertained. There is no way for the committee to certify these results beyond repeating the experiments themselves. These techniques are well documented and described in the literature. I do not believe it is necessary or feasible for the committee to review each procedure for purification of DNA.

6. Comments were made concerning the use of DNA derived from animal viruses. It was urged that containment levels for this class of experiment be increased. On the basis of my review, I find the containment conditions appropriate to the potential hazard posed. As defined in the guidelines, experiments are to be done at very strict levels of containment and these can be lowered only when the cloned DNA recombinants have been shown to be free of possibly harmful genes by suitable biochemical and biological tests. This also pertains to DNA that is copied from RNA viruses. In no instance are the guidelines more lenient, and in most instances they are more stringent than conditions obtaining in many laboratories where such viruses are studied in non-DNA-recombinant experiments.

VI. CLASSIFICATION OF EXPERIMENTS USING CONTAINMENT SYSTEMS OTHER THAN *E. COLI* K-12

1. No issue with regard to these guidelines raised more comment than the use

of animal viruses as vectors. Of special concern to many commentators was the use of the simian (monkey) virus 40 (hereafter "SV40"). Some suggested a complete ban on the use of this virus; others urged its retention as a vector. SV40 is not known to produce any disease in man, although it can be grown in human cells and on very rare occasions has been isolated from humans. Many humans have received SV40 virus inadvertently in vaccines prepared from virus grown in monkey kidney-cell cultures. An intensive search has been made and is continuing for evidence that SV40 might cause cancer or be otherwise pathogenic for man. At present, it is my view that the extensive knowledge we have of SV40 virus provides us with sufficient sophistication to ensure its safe handling under the conditions developed for its use in the guidelines.

I believe work with SV40 should continue under the most careful conditions, but I do recognize and appreciate the concerns expressed over its possible harmful effects in humans. In light of these concerns, I asked the Recombinant Advisory Committee to review this section of the guidelines. The committee reconsidered the containment conditions for this class of experiments and judged them appropriate to meet the potential hazards.*

This class of experiments will proceed under the most careful and stringent conditions. Work with SV40 virus will be done at the maximum level of physical containment (P4). The extraordinary precautions required in a P4 facility lessen the likelihood of a potential hazard from this work. Only defective SV40 virus will be used as vector; that is, the SV40 virus particles that carry the foreign DNA cannot multiply by themselves. When a number of strict conditions are met, this work will be permitted to go on at the third level of containment (P3), which in itself requires care and precision. It should be noted that SV40 virus and its DNA can be efficiently disinfected by Clorox and autoclaving. These are customary procedures for disinfecting glassware and other items used in SV40 animal-cell work.

Some commentators suggested that the containment criteria for experiments using polyoma virus as the vector be strengthened. There is no evidence that polyoma infects humans or replicates to any significant extent in human cells. It holds promise as a vector, as is more fully documented in an appendix to these guidelines.

2. Several commentators found the guidelines inadequate regarding experiments with plant host-vector systems. Because NIH shared these concerns, a group with extensive experience with plants was appointed to review this section. The group met concurrently with

*One member dissented from this position. During the discussion, additional language was recommended (and adopted) to ensure that the defective SV40-virus/helper-virus system, with its inserted non-SV40 DNA segment, does not replicate in human cells with significantly more efficiency than does SV40.

the Recombinant Advisory Committee in April 1976 and made several modifications. The suggested revisions were acceptable to the full committee, and we have included them in the guidelines.

The modifications are responsive to the stated concerns of the commentators. A description of greenhouse facilities is given, and physical containment conditions have been modified to take into account operations with whole plants. On the whole, the respective portions of the guidelines relating to plants are more fully explained and the intent is clarified.

I have also accepted the recommendation of the subcommittee to lower the biological containment level from EK2 to EK1 for experiments in which the DNA from plants is used in conjunction with the *E. coli* K-12 host-vector system, thereby setting containment in this instance at the same level required for experiments with lower-eukaryote DNA.

VII. ROLES AND RESPONSIBILITIES

1. Most commentators had suggestions for the section on the roles and responsibilities of investigators, their local institutions, and NIH. Commentators generally urged openness, candor, and public participation in the process, emphasizing shared responsibility and accountability from the local to the national level. We reviewed that section of the guidelines in light of these comments and have asked the Recombinant Advisory Committee to review certain issues.

It is clear that much of the success of the guidelines will lie in the wisdom with which they are implemented. Because of the importance of this section, especially in terms of safety programs and plans, we have carefully weighed the comments and suggestions made in this regard. NIH has a special responsibility to take a leading role in ensuring that safety programs are part of all recombinant DNA research. Dr. Barkley and a specially convened committee were asked to provide greater detail for safety, accident, and training plans for this section of the guidelines. Based on their recommendations, the section has been extensively rewritten to clarify the respective responsibilities of the principal investigator, the institution (including the institutional biohazards committee), the NIH initial review group (study section), the NIH Recombinant DNA Molecule Program Advisory Committee, and NIH staff.

This section has a definitive administrative framework for assuring that safety is an essential and integrated component of research involving recombinant DNA molecules. The guidelines require investigators to institute, monitor, and evaluate containment and safety practices and procedures. Before research is done, the investigator must have safety and accident plans in place and training exercises for the staff well under way.

Some commentators suggested that the investigator be required to obtain informed consent of laboratory personnel prior to their participation. Rather than rely explicitly on an informed consent document, the guidelines now make the

investigator responsible for advising his program and support staff as to the nature and assessment of the real and potential biohazards. He must explain and provide for any advised or requested precautionary medical policies, vaccinations, or serum collections. Further, an appendix to the guidelines includes detailed explanations for dealing with accidents, as well as instructions for the training of staff in safety and accident procedures.

In response to suggestions for epidemiological monitoring, the guidelines now require the principal investigator to report certain categories of accidents, in writing, to appropriate officials. NIH is investigating procedures for long-term surveillance of workers engaged in recombinant DNA research.

2. A number of comments on the role and responsibilities of the institutional biohazards committee were received. Comments were directed to the structure of the committee, the scope of its responsibility, and the methods for operation. Comments on structure included suggestions that the committee have a broadly based representation, especially in terms of health and safety expertise. Some others suggested NIH require certain classes of representation. In response to these suggestions, the guidelines now recommend membership from a diversity of disciplines relevant to recombinant DNA molecule technology, biological safety, and engineering.

For broader representation beyond the immediate scientific expertise, the guidelines now recommend that local committees should possess, or have available, the competence necessary to determine the acceptability of their findings in terms of applicable laws, regulations, standards of practice, community attitudes, and health and environmental considerations. The names of and relevant background information on the committee members will be reported to NIH.

In response to suggestions that decisions of the committee be made publicly available, the guidelines now recommend that minutes of the meetings should be kept and made available for public inspection.

Commentators generally approved of the responsibility given to the institutional biohazards committee to serve as a source of advice and reference to the investigator on scientific and safety questions. It was further suggested that the committee's responsibility be broadened in the development, monitoring, and evaluation of safety standards and procedures. In response to these suggestions, the guidelines now indicate that the institutional biohazards committee has the responsibility to certify, and recertify annually, to NIH that the facilities, procedures, practices, training, and expertise of involved personnel have been reviewed and approved. The Recombinant Advisory Committee suggested that examination might be unnecessary for P1 facilities, but we believe that all facilities should be reviewed to emphasize the importance of safety programs.

Some commentators suggested that the guidelines should stipulate that the local

committees be required to determine the containment conditions to be imposed for a given project (which the draft guidelines specifically noted was not their responsibility). The Recombinant Advisory Committee took exception to this suggestion. They urged NIH not to include these conditions as local requirements, arguing among other things that review by the NIH study sections would provide the necessary scrutiny at the national level and assure uniformity of standards in application of the guidelines. I do not believe that NIH should require the local institution to have its biohazards committee assess what containment conditions are required for a given project. On the other hand, the guidelines should not prohibit the local institution from having its biohazards committee perform this function. Accordingly, I have deleted the prohibition that appeared in the proposed guidelines.

Another suggestion was that the local committee ensure that research is carried out in accordance with standards and procedures under the Occupational Safety and Health Act (OSHA). This is an area of importance to the local institutions under Federal and State law, but need not be included as a requirement in the guidelines. NIH will maintain liaison with the Occupational Safety and Health Administration (Department of Labor) to ensure maximum Federal cooperation in this venture.

I would also encourage all institutions, as suggested by several commentators, to review their insurance compensation programs to determine whether their laboratory personnel, in the research area, are covered for injuries.

3. The commentators approved of having the NIH study sections responsible for making an independent evaluation of the classification of the proposed research under the guidelines, along with the customary judgment of the scientific merit of each grant application. This additional element of review will ensure careful attention to potential hazards in the research activity. The study sections will also scrutinize the proposed safeguards. Biological safety expertise shall be available to the study section for consultation and guidance in this regard.

4. Several commentators made suggestions concerning the structure, function, and scope of responsibility of the NIH Recombinant DNA Molecule Program Advisory Committee.

Comments on possible structural mechanisms for decision making included suggestions that there be a scientific and technical committee and a general advisory public policy committee. It was also suggested that the scientific committee include scientists who are not actively engaged in recombinant research, and that the public policy committee have a broad scientific and public representation.

I have carefully reviewed these comments and suggestions. In response, the following structure has been devised. The Recombinant Advisory Committee shall serve as the scientific and technical committee. Its membership shall continue to

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include scientists who represent disciplines actively engaged in recombinant DNA research. In my view, it is most important that this committee have the necessary expertise to assure that the guidelines are of the highest scientific quality. The committee has provided this expertise in the past, and it must continue to do so. The committee shall also include members from other scientific disciplines.

It should be noted that the present committee recommended on its own initiative that a nonscientist be appointed. Emmette S. Redford, Ph.D., LL.D., Ashbel Smith Professor of Government and Public Affairs at the Lyndon B. Johnson School of Public Affairs, University of Texas at Austin, serves in that capacity. An ethicist has also been nominated for appointment.

The Advisory Committee to the Director, NIH, shall serve to provide the broader public policy perspectives. This committee, at its meeting on February 9-10, 1976, reviewed the proposed guidelines with the participation of public witnesses, and shall continue to provide such review for future activities of the Recombinant Advisory Committee.

In response to suggestions, the responsibilities of the Recombinant Advisory Committee have been expanded. In addition to reviewing the guidelines for possible modification as scientific evidence warrants, the committee will certify EK2 and EK3 systems. In response to requests by the investigator, local committee, or study section, the committee will also provide evaluation and review in order to advise on levels of required containment, on lowering of requirements when cloned recombinants are to be used, and on questions concerning potential biohazard and adequacy of containment provisions.

Commentators also asked that the committee review ongoing research initiated prior to the implementation of the guidelines. Now that the guidelines are being released, NIH-funded investigators in this field will be asked to give assurance, within a given period, that they will comply. Any investigators who constructed clones under the Asilomar guidelines will be asked to petition NIH for special consideration of their case, if the new guidelines require higher containment than did the Asilomar guidelines. Here the advice of the Recombinant Advisory Committee will be sought.

There were also suggestions that the committee certify chemical purification of recombinant DNA, but as I indicated earlier, these procedures are too well known to require NIH monitoring.

5. In light of comments received, NIH will provide review, through appropriate NIH offices, of data from institutional biohazards committees (including accident reports) and will ensure dissemination of these findings as appropriate. Dr. William Gartland will head the newly created NIH Office of Recombinant DNA Activities for these purposes. In addition, NIH will provide for rapid dissemination of information through its Nucleic Acid Recombinant Scientific

Memoranda (NARSM), distributed by the National Institute for Allergy and Infectious Diseases. NIH will also provide an appropriate mechanism for approving and certifying clones before containment conditions can be lowered.

With these extended modifications, the section of the guidelines dealing with roles and responsibilities now sets forth a more fully developed review structure involving the principal investigator, local biohazards committees, and the Recombinant Advisory Committee, as well as peer review committees. Guidelines now provide extensive opportunity for advice, from the local to the national level. Several levels of review and scrutiny are provided, ensuring the highest standards for scientific merit and conditions for safety.

The Recombinant Advisory Committee in conjunction with the Director's Advisory Committee shall continue to serve as an ongoing forum for examining progress in the technology and safety of recombinant DNA research. Their responsibility, and that of the NIH Director, is to ensure that the guidelines, through modification when called for, reflect the soundest scientific and safety evidence as it accrues in this area. Their task, in a sense, is just beginning.

DONALD S. FREDRICKSON,
Director,
National Institute of Health.

GUIDELINES FOR RESEARCH INVOLVING RECOMBINANT DNA MOLECULES

JUNE 1976

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 - C. NIH Initial Review Group (Study Sections);

- D. NIH Recombinant DNA Molecule Program Advisory Committee;
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- A. Statement on the use of *Bacillus subtilis* in recombinant molecule technology.
- B. Polyoma and SV40 Virus.
- C. Summary of Workshop on the Design and Testing of Safer Prokaryotic Vehicles and Bacterial Hosts for Research on Recombinant DNA Molecules.
- D. Supplementary Information on Physical Containment (Including Detailed Contents).

I. INTRODUCTION

The purpose of these guidelines is to recommend safeguards for research on recombinant DNA molecules to the National Institutes of Health and to other institutions that support such research. In this context we define recombinant DNAs as molecules that consist of different segments of DNA which have been joined together in cell-free systems, and which have the capacity to infect and replicate in some host cell, either autonomously or as an integrated part of the host's genome.

This is the first attempt to provide a detailed set of guidelines for use by study sections as well as practicing scientists for evaluating research on recombinant DNA molecules. We cannot hope to anticipate all possible lines of imaginative research that are possible with this powerful new methodology. Nevertheless, a considerable volume of written and verbal contributions from scientists in a variety of disciplines has been received. In many instances the views presented to us were contradictory. At present, the hazards may be guessed at, speculated about, or voted upon, but they cannot be known absolutely in the absence of firm experimental data—and, unfortunately, the needed data were, more often than not, unavailable. Our problem then has been to construct guidelines that allow the promise of the methodology to be realized while advocating the considerable caution that is demanded by what we and others view as potential hazards.

In designing these guidelines we have adopted the following principles, which are consistent with the general conclusions that were formulated at the International Conference on Recombinant DNA Molecules held at Asilomar Conference Center, Pacific Grove, California, in February 1975 (3): (i) There are certain experiments for which the assessed potential hazard is so serious that they are not to be attempted at the present time. (ii) The remainder can be undertaken at the present time provided that the experiment is justifiable on the basis that new knowledge or benefits to humankind will accrue that cannot readily be obtained by use of conventional methodology and that appropriate safeguards are incorporated into the design and execution of the experiment. In addition to an insistence on the practice of good microbiological techniques, these safeguards consist of providing both physical

and biological barriers to the dissemination of the potentially hazardous agents. (iii) The level of containment provided by these barriers is to match the estimated potential hazard for each of the different classes of recombinants. For projects in a given class, this level is to be highest at initiation and modified subsequently only if there is a substantiated change in the assessed risk or in the applied methodology. (iv) The guidelines will be subjected to periodic review (at least annually) and modified to reflect improvements in our knowledge of the potential biohazards and of the available safeguards.

In constructing these guidelines it has been necessary to define boundary conditions for the different levels of physical and biological containment and for the classes of experiments to which they apply. We recognize that these definitions do not take into account existing and anticipated special procedures and information that will allow particular experiments to be carried out under different conditions than indicated here without sacrifice of safety. Indeed, we urge that individual investigators devise simple and more effective containment procedures and that study sections give consideration to such procedures which may allow change in the containment levels recommended here.

It is recommended that all publications dealing with recombinant DNA work include a description of the physical and biological containment procedures practiced, to aid and forewarn others who might consider repeating the work.

II. CONTAINMENT

Effective biological safety programs have been operative in a variety of laboratories for many years. Considerable information therefore already exists for the design of physical containment facilities and the selection of laboratory procedures applicable to organisms carrying recombinant DNAs (4-17). The existing programs rely upon mechanisms that, for convenience, can be divided into two categories: (i) a set of standard practices that are generally used in microbiological laboratories, and (ii) special procedures, equipment, and laboratory installations that provide physical barriers which are applied in varying degrees according to the estimated biohazard.

Experiments on recombinant DNAs by their very nature lend themselves to a third containment mechanism—namely, the application of highly specific biological barriers. In fact, natural barriers do exist which either limit the infectivity of a vector or vehicle (plasmid, bacteriophage or virus) to specific hosts, or its dissemination and survival in the environment. The vectors that provide the means for replication of the recombinant DNAs and/or the host cells in which they replicate can be genetically designed to decrease by many orders of magnitude the probability of dissemination of recombinant DNAs outside the laboratory.

As these three means of containment are complementary, different levels of

containment appropriate for experiments with different recombinants can be established by applying different combinations of the physical and biological barriers to a constant use of the standard practices. We consider these categories of containment separately here in order that such combinations can be conveniently expressed in the guidelines for research on the different kinds of recombinant DNA (Section III).

A. Standard practices and training. The first principle of containment is a strict adherence to good microbiological practices (4-13). Consequently, all personnel directly or indirectly involved in experiments on recombinant DNAs must receive adequate instruction. This should include at least training in aseptic techniques and instruction in the biology of the organisms used in the experiments so that the potential biohazards can be understood and appreciated.

Any research group working with agents with a known or potential biohazard should have an emergency plan which describes the procedures to be followed if an accident contaminates personnel or environment. The principal investigator must ensure that everyone in the laboratory is familiar with both the potential hazards of the work and the emergency plan. If a research group is working with a known pathogen for which an effective vaccine is available, all workers should be immunized. Serological monitoring, where appropriate, should be provided.

B. Physical containment levels. A variety of combinations (levels) of special practices, equipment, and laboratory installations that provide additional physical barriers can be formed. For example, 31 combinations are listed in "Laboratory Safety at the Center for Disease Control" (4); four levels are associated with the "Classification of Etiologic Agents on the Basis of Hazard" (5); four levels were recommended in the "Summary Statement of the Asilomar Conference on Recombinant DNA Molecules" (3); and the National Cancer Institute uses three levels for research on oncogenic viruses (6). We emphasize that these are an aid to, and not a substitute for, good technique. Personnel must be competent in the effective use of all equipment needed for the required containment level as described below. We define only four levels of physical containment here, both because the accuracy with which one can presently assess the biohazards that may result from recombinant DNAs does not warrant a more detailed classification, and because additional flexibility can be obtained by combination of the physical with the biological barriers. Though different in detail, these four levels ($P1 < P2 < P3 < P4$) approximate those given for human etiologic agents by the Center for Disease Control (i.e., classes 1 through 4; ref. 5), in the Asilomar summary statement (i.e., minimal, low, moderate, and high; ref. 3), and by the National Cancer Institute for oncogenic viruses (i.e., low, moderate, and high; ref. 6), as is indicated by the P-number or adjective in the following

headings. It should be emphasized that the descriptions and assignments of physical containment detailed below are based on existing approaches to containment of hazardous organisms.

We anticipate, and indeed already know of, procedures (14) which enhance physical containment capability in novel ways. For example, miniaturization of screening, handling, and analytical procedures provides substantial containment of a given host-vector system. Thus, such procedures should reduce the need for the standard types of physical containment, and such innovations will be considered by the Recombinant DNA Molecule Program Advisory Committee.

The special practices, equipment and facility installations indicated for each level of physical containment are required for the safety of laboratory workers, other persons, and for the protection of the environment. Optional items have been excluded; only those items deemed absolutely necessary for safety are presented. Thus, the listed requirements present basic safety criteria for each level of physical containment. Other microbiological practices and laboratory techniques which promote safety are to be encouraged. Additional information giving further guidance on physical containment is provided in a supplement to the guidelines (Appendix D).

P1 Level (Minimal). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P1 level is a laboratory that possesses no special engineering design features. It is a laboratory commonly used for microorganisms of no or minimal biohazard under ordinary conditions of handling. Work in this laboratory is generally conducted on open bench tops. Special containment equipment is neither required nor generally available in this laboratory. The laboratory is not separated from the general traffic patterns of the building. Public access is permitted.

The control of biohazards at the P1 level is provided by standard microbiological practices of which the following are examples: (i) Laboratory doors should be kept closed while experiments are in progress. (ii) Work surfaces should be decontaminated daily and following spills of recombinant DNA materials. (iii) Liquid wastes containing recombinant DNA materials should be decontaminated before disposal. (iv) Solid wastes contaminated with recombinant DNA materials should be decontaminated or packaged in a durable leak-proof container before removal from the laboratory. (v) Although pipetting by mouth is permitted, it is preferable that mechanical pipetting devices be used. When pipetting by mouth, cotton-plugged pipettes shall be employed. (vi) Eating, drinking, smoking, and storage of food in the working area should be discouraged. (vii) Facilities to wash hands should be available. (viii) An insect and rodent control program should be provided. (ix) The use of laboratory gowns, coats, or uniforms is discretionary with the laboratory supervisor.

P2 Level (Low). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P2 level is similar in construction and design to the P1 laboratory. The P2 laboratory must have access to an autoclave within the building; it may have a Biological Safety Cabinet.¹ Work which does not produce a considerable aerosol is conducted on the open bench. Although this laboratory is not separated from the general traffic patterns of the building, access to the laboratory is limited when experiments requiring P2 level physical containment are being conducted. Experiments of lesser biohazard potential can be carried out concurrently in carefully demarcated areas of the same laboratory.

The P2 laboratory is commonly used for experiments involving microorganisms of low biohazard such as those which have been classified by the Center for Disease Control as Class 2 agents (5).

The following practices shall apply to all experiments requiring P2 level physical containment: (i) Laboratory doors shall be kept closed while experiments are in progress. (ii) Only persons who have been advised of the potential biohazard shall enter the laboratory. (iii) Children under 12 years of age shall not enter the laboratory. (iv) Work surfaces shall be decontaminated daily and immediately following spills of recombinant DNA materials. (v) Liquid wastes of recombinant DNA materials shall be decontaminated before disposal. (vi) Solid wastes contaminated with recombinant DNA materials shall be decontaminated or packaged in a durable leak-proof container before removal from the laboratory. Packaged materials shall be disposed of by incineration or sterilized before disposal by other methods. Contaminated materials that are to be processed and reused (i.e., glassware) shall be decontaminated before removal from the laboratory. (vii) Pipetting by mouth is prohibited; mechanical pipetting devices shall be used. (viii) Eating, drinking, smoking, and storage of food are not permitted in the working area. (ix) Facilities to wash hands shall be available within the laboratory. Persons handling recombinant DNA materials should be encouraged to wash their hands frequently and when they leave the laboratory. (x) An insect and rodent control program shall be provided. (xi) The use of laboratory gowns, coats, or uniforms is required. Such clothing shall not be worn to the lunch room or outside the building. (xii) Animals not related to the experiment shall not be permitted in the laboratory. (xiii) Biological Safety Cabinets¹ and/or other physical containment equipment shall be used to minimize the hazard of aerosolization of recombinant DNA materials from operations or devices that produce a considerable aerosol (e.g., blender, lyophilizer, sonicator, shaking machine, etc.). (xiv) Use of the hypodermic needle and syringe shall be avoided when alternate methods are available.

¹ Footnotes at end of article.

P3 Level (Moderate). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P3 level has special engineering design features and physical containment equipment. The laboratory is separated from areas which are open to the general public. Separation is generally achieved by controlled access corridors, air locks, locker rooms or other double-doored facilities which are not available for use by the general public. Access to the laboratory is controlled. Biological Safety Cabinets¹ are available within the controlled laboratory area. An autoclave shall be available within the building and preferably within the controlled laboratory area. The surfaces of walls, floors, bench tops, and ceilings are easily cleanable to facilitate housekeeping and space decontamination.

Directional air flow is provided within the controlled laboratory area. The ventilation system is balanced to provide for an inflow of supply air from the access corridor into the laboratory. The general exhaust air from the laboratory is discharged outdoors and so dispersed to the atmosphere as to prevent reentry into the building. No recirculation of the exhaust air shall be permitted without appropriate treatment.

No work in open vessels involving hosts or vectors containing recombinant DNA molecules requiring P3 physical containment is conducted on the open bench. All such procedures are confined to Biological Safety Cabinets.¹

The following practices shall apply to all experiments requiring P3 level physical containment: (i) The universal biohazard sign is required on all laboratory access doors. Only persons whose entry into the laboratory is required on the basis of program or support needs shall be authorized to enter. Such persons shall be advised of the potential biohazards before entry and they shall comply with posted entry and exit procedures. Children under 12 years of age shall not enter the laboratory. (ii) Laboratory doors shall be kept closed while experiments are in progress. (iii) Biological Safety Cabinets¹ and other physical containment equipment shall be used for all procedures that produce aerosols of recombinant DNA materials (e.g., pipetting, plating, flaming, transfer operations, grinding, blending, drying, sonicating, shaking, etc.). (iv) The work surfaces of Biological Safety Cabinets¹ and other equipment shall be decontaminated following the completion of the experimental activity contained within them. (v) Liquid wastes containing recombinant DNA materials shall be decontaminated before disposal. Solid wastes contaminated with recombinant DNA materials shall be decontaminated or packaged in a durable leak-proof container before removal from the laboratory. Packaged material shall be sterilized before disposal. Contaminated materials that are to be processed and reused (i.e., glassware) shall be sterilized in the controlled laboratory area or placed in a durable leak-proof container before removal

from the controlled laboratory area. This container shall be sterilized before the materials are processed. (vii) Pipetting by mouth is prohibited; mechanical pipetting devices shall be used. (viii) Eating, drinking, smoking, and storage of food are not permitted in the laboratory. (ix) Facilities to wash hands shall be available within the laboratory. Persons shall wash hands after experiments involving recombinant DNA materials and before leaving the laboratory. (x) In insect and rodent control program shall be provided. (xi) Laboratory clothing that protects street clothing (i.e., long sleeve solid-front or wrap-around gowns, no-button or slipover jackets, etc.) shall be worn in the laboratory. **FRONT-BUTTON LABORATORY COATS ARE UNSUITABLE.** Gloves shall be worn when handling recombinant DNA materials. Provision for laboratory shoes is recommended. Laboratory clothing shall not be worn outside the laboratory and shall be decontaminated before it is sent to the laundry. (xii) Raincoats, overcoats, topcoats, coats, hats, caps, and such street outerwear shall not be kept in the laboratory.

(xiii) Animals and plants not related to the experiment shall not be permitted in the laboratory. (xiv) Vacuum lines shall be protected by filters and liquid traps. (xv) Use of the hypodermic needle and syringe shall be avoided when alternate methods are available. (xvi) If experiments of lesser biohazard potential are to be conducted in the same laboratory concurrently with experiments requiring P3 level physical containment they shall be conducted only in accordance with all P3 level requirements. (xvii) Experiments requiring P3 level physical containment can be conducted in laboratories where the directional air flow and general exhaust air conditions described above cannot be achieved, provided that this work is conducted in accordance with all other requirements listed and is contained in a Biological Safety Cabinet¹ with attached glove ports and gloves. All materials before removal from the Biological Safety Cabinet¹ shall be sterilized or transferred to a non-breakable, sealed container, which is then removed from the cabinet through a chemical decontamination tank, autoclave, ultraviolet air lock, or after the entire cabinet has been decontaminated.

P4 Level (High). Experiments involving recombinant DNA molecules requiring physical containment at the P4 level shall be confined to work areas in a facility of the type designed to contain microorganisms that are extremely hazardous to man or may cause serious epidemic disease. The facility is either a separate building or it is a controlled area, within a building, which is completely isolated from all other areas of the building. Access to the facility is under strict control. A specific facility operations manual is available. Class III Biological Safety Cabinets¹ are available within work areas of the facility.

A P4 facility has engineering features which are designed to prevent the escape of microorganisms to the environment (14, 15, 16, 17). These features include:

(i) Monolithic walls, floors, and ceilings in which all penetrations such as for air ducts, electrical conduits, and utility pipes are sealed to assure the physical isolation of the work area and to facilitate housekeeping and space decontamination; (ii) air locks through which supplies and materials can be brought safely into the facility; (iii) contiguous clothing change and shower rooms through which personnel enter into and exit from the facility; (iv) double-door autoclaves to sterilize and safely remove wastes and other materials from the facility; (v) a biowaste treatment system to sterilize liquid effluents if facility drains are installed; (vi) a separate ventilation system which maintains negative air pressures and directional air flow within the facility; and (vii) a treatment system to decontaminate exhaust air before it is dispersed to the atmosphere. A central vacuum utility system is not encouraged; if one is installed, each branch line leading to a laboratory shall be protected by a high efficiency particulate air filter.

The following practices shall apply to all experiments requiring P4 level physical containment: (i) The universal biohazard sign is required on all facility access doors and all interior doors to individual laboratory rooms where experiments are conducted. Only persons whose entry into the facility or individual laboratory rooms is required on the basis of program or support needs shall be authorized to enter. Such persons shall be advised of the potential biohazards and instructed as to the appropriate safeguards to ensure their safety before entry. Such persons shall comply with the instructions and all other posted entry and exit procedures. Under no condition shall children under 15 years of age be allowed entry. (ii) Personnel shall enter into and exit from the facility only through the clothing change and shower rooms. Personnel shall shower at each exit from the facility. The air locks shall not be used for personnel entry or exit except for emergencies. (iii) Street clothing shall be removed in the outer facility side of the clothing change area and kept there. Complete laboratory clothing including undergarments, pants and shirts or jumpsuits, shoes, head cover, and gloves shall be provided and used by all persons who enter into the facility. Upon exit, this clothing shall be stored in lockers provided for this purpose or discarded into collection hampers before personnel enter into the shower area. (iv) Supplies and materials to be taken into the facility shall be placed in an entry air lock. After the outer door (opening to the corridor outside of facility) has been secured, personnel occupying the facility shall retrieve the supplies and materials by opening the interior air lock door. This door shall be secured after supplies and materials are brought into the facility. (v) Doors to laboratory rooms within the facility shall be kept closed while experiments are in progress. (vi) Experimental procedures requiring P4 level physical containment shall be confined to Class III Biological Safety Cabinets.¹ All materials, before

removal from these cabinets, shall be sterilized or transferred to a non-breakable sealed container, which is then removed from the system through a chemical decontaminated tank, autoclave, or after the entire system has been decontaminated.

(vii) No materials shall be removed from the facility unless they have been sterilized or decontaminated in a manner to prevent the release of agents requiring P4 physical containment. All wastes and other materials and equipment not damaged by high temperature or steam shall be sterilized in the double-door autoclave. Biological materials to be removed from the facility shall be transferred to a non-breakable sealed container which is then removed from the facility through a chemical decontamination tank or a chamber designed for gas sterilization. Other materials which may be damaged by temperature or steam shall be sterilized by gaseous or vapor methods in an air lock or chamber designed for this purpose. (viii) Eating, drinking, smoking, and storage of food are not permitted in the facility. Foot-operated water fountains located in the facility corridors are permitted. Separate potable water piping shall be provided for these water fountains. (ix) Facilities to wash hands shall be available within the facility. Persons shall wash hands after experiments. (x) An insect and rodent control program shall be provided. (xi) Animals and plants not related to the experiment shall not be permitted in the facility. (xii) If a central vacuum system is provided, each vacuum outlet shall be protected by a filter and liquid trap in addition to the branch line HEPA filter mentioned above. (xiii) Use of the hypodermic needle and syringe shall be avoided when alternate methods are available. (xiv) If experiments of lesser biohazard potential are to be conducted in the facility concurrently with experiments requiring P4 level containment, they shall be confined in Class I or Class II Biological Safety Cabinets¹ or isolated by other physical containment equipment. Work surfaces of Biological Safety Cabinets¹ and other equipment shall be decontaminated following the completion of the experimental activity contained within them. Mechanical pipetting devices shall be used. All other practices listed above with the exception of (vi) shall apply.

C. *Shipment.* To protect product, personnel, and the environment, all recombinant DNA material will be shipped in containers that meet the requirements issued by the U.S. Public Health Service (Section 72.25 of Part 72, Title 42, Code of Federal Regulations), Department of Transportation (Section 173.387(b) of Part 173, Title 49, Code of Federal Regulations) and the Civil Aeronautics Board (C.A.B. No. 82, Official Air Transport Restricted Articles Tariff No. 6-D) for shipment of etiologic agents. Labeling requirements specified in these Federal regulations and tariffs will apply to all viable recombinant DNA materials in which any portion of the material is derived from an etiologic agent listed in

paragraph (c) of 42 CFR 72.25. Additional information on packing and shipping is given in a supplement to the guidelines (Appendix D, part X).

D. *Biological containment levels.* Biological barriers are specific to each host-vector system. Hence the criteria for this mechanism of containment cannot be generalized to the same extent as for physical containment. This is particularly true at the present time when our experience with existing host-vector systems and our predictive knowledge about projected systems are sparse. The classification of experiments with recombinant DNAs that is necessary for the construction of the experimental guidelines (Section III) can be accomplished with least confusion if we use the host-vector system as the primary element and the source of the inserted DNA as the secondary element in the classification. It is therefore convenient to specify the nature of the biological containment under host-vector headings such as those given below for *Escherichia coli* K-12.

III. EXPERIMENTAL GUIDELINES

A general rule that, though obvious, deserves statement is that the level of containment required for any experiment on DNA recombinants shall never be less than that required for the most hazardous component used to construct and clone the recombinant DNA (i.e., vector, host, and inserted DNA). In most cases the level of containment will be greater, particularly when the recombinant DNA is formed from species that ordinarily do not exchange genetic information. Handling the purified DNA will generally require less stringent precautions than will propagating the DNA. However, the DNA itself should be handled at least as carefully as one would handle the most dangerous of the DNAs used to make it.

The above rule by itself effectively precludes certain experiments—namely, those in which one of the components is in Class 5 of the "Classification of Etiologic Agents on the Basis of Hazard" (5), as these are excluded from the United States by law and USDA administrative policy. There are additional experiments which may engender such serious biohazards that they are not to be performed at this time. These are considered prior to presentation of the containment guidelines for permissible experiments.

A. *Experiments that are not to be performed.* We recognize that it can be argued that certain of the recombinants placed in this category could be adequately contained at this time. Nonetheless, our estimates of the possible dangers that may ensue if that containment fails are of such a magnitude that we consider it the wisest policy to at least defer experiments on these recombinant DNAs until there is more information to accurately assess that danger and to allow the construction of more effective biological barriers. In this respect, these guidelines are more stringent than those initially recommended (1).

The following experiments are not to be initiated at the present time: (1) Clon-

¹ See footnotes at end of article.

ing of recombinant DNAs derived from the pathogenic organisms in Classes 3, 4, and 5 of "Classification of Etiologic Agents on the Basis of Hazard" (5), or oncogenic viruses classified by NCI as moderate risk (6), or cells known to be infected with such agents, regardless of the host-vector system used. (ii) Deliberate formation of recombinant DNAs containing genes for the biosynthesis of potent toxins (e.g., botulinum or diphtheria toxins; venoms from insects, snakes, etc.). (iii) Deliberate creation from plant pathogens of recombinant DNAs that are likely to increase virulence and host range. (iv) Deliberate release into the environment of any organism containing a recombinant DNA molecule. (v) Transfer of a drug resistance trait to microorganisms that are not known to acquire it naturally if such acquisition could compromise the use of a drug to control disease agents in human or veterinary medicine or agriculture.

In addition, at this time large-scale experiments (e.g., more than 10 liters of culture) with recombinant DNAs known to make harmful products are not to be carried out. We differentiate between small- and large-scale experiments with such DNAs because the probability of escape from containment barriers normally increases with increasing scale. However, specific experiments in this category that are of direct societal benefit may be excepted from this rule if special biological containment precautions and equipment designed for large-scale operations are used, and provided that these experiments are expressly approved by the Recombinant DNA Molecule Program Advisory Committee of NIH.

B. Containment guidelines for permissible experiments. It is anticipated that most recombinant DNA experiments initiated before these guidelines are next reviewed (i.e., within the year) will employ *E. coli* K-12 host-vector systems. These are also the systems for which we have the most experience and knowledge regarding the effectiveness of the containment provided by existing hosts and vectors necessary for the construction of more effective biological barriers.

For these reasons, *E. coli* K-12 appears to be the system of choice at this time, although we have carefully considered arguments that many of the potential dangers are compounded by using an organism as intimately connected with a man as is *E. coli*. Thus, while proceeding cautiously with *E. coli*, serious efforts should be made toward developing alternate host-vector systems; this subject is discussed in considerable detail in Appendix A.

We therefore consider DNA recombinants in *E. coli* K-12 before proceeding to other host-vector systems.

1. *Biological containment criteria using E. coli K-12 host-vectors—EK1 host-vectors.* These are host-vector systems that can be estimated to already provide a moderate level of containment, and include most of the presently available systems. The host is always *E. coli* K-12, and the vectors include nonconjugative plasmids [e.g., pSC101, ColE1 or deriva-

tives thereof (19-26)] and variants of bacteriophage λ (27-29).

The *E. coli* K-12 nonconjugative plasmid system is taken as an example to illustrate the approximate level of containment referred to here. The available data from experiments involving the feeding of bacteria to humans and calves (30-32) indicate that *E. coli* K-12 did not usually colonize the normal bowel, and exhibited little, if any, multiplication while passing through the alimentary tract even after feeding high doses (i.e., 10^9 to 10^{10} bacteria per human or calf). However, general extrapolation of these results may not be warranted because the implantation of bacteria into the intestinal tract depends on a number of parameters, such as the nature of the intestinal flora present in a given individual and the physiological state of the inoculum. Moreover, since viable *E. coli* K-12 can be found in the feces after humans are fed 10^7 bacteria in broth (30) or 3×10^4 bacteria protected by suspension in milk (31), transductional and conjugational transfer of the plasmid vectors from *E. coli* K-12 to resident bacteria in the fecal matter before and after excretion must also be considered.

The nonconjugative plasmid vectors cannot promote their own transfers, but require the presence of a conjugative plasmid for mobilization and transfer to other bacteria. When present in the same cell with derepressed conjugative plasmids such as F or R1drd19, the nonconjugative ColE1, ColE1-*trp* and pSC101 plasmids are transferred to suitable recipient strains under ideal laboratory conditions at frequencies of about 0.5, 10^{-4} to 10^{-5} , and 10^{-6} per donor cell, respectively. These frequencies are reduced by another factor of 10^3 to 10^4 if the conjugative plasmid employed is repressed with respect to expression of donor fertility.

The experimental transfer system which most closely resembles nonconjugative plasmid transfer in nature is a triparental mating. In such matings, the bacterial cell possessing the nonconjugative plasmid must first acquire a conjugative plasmid from another cell before it can transfer the nonconjugative plasmid to a secondary recipient. With ColE1, the frequencies of transfer are 10^{-2} and 10^{-4} to 10^{-6} when using conjugative plasmid donors possessing derepressed and repressed plasmids, respectively. Mobilization of ColE1-*trp* and pSC101 under similar laboratory conditions is so low as to be usually undetectable (33). Since most conjugative plasmids in nature are repressed for expression of donor fertility, the frequency at which nonconjugative plasmids are mobilized and transferred by this sequence of events *in vivo* is difficult to estimate. However, in calves fed on an antibiotic-supplemented diet, it has been estimated that such triparental nonconjugative R plasmid transfer occurs at frequencies of no more than 10^{-10} to 10^{-12} per 24 hours per calf (32). In terms of considering other means for plasmid transmission in nature, it should be noted that transduction does operate *in*

vivo for *Staphylococcus aureus* (34) and probably for *E. coli* as well. However, no data are available to indicate the frequencies of plasmid transfer *in vivo* by either transduction or transformation.

These observations indicate the low probabilities for possible dissemination of such plasmid vectors by accidental ingestion, which would probably involve only a few hundred or thousand bacteria provided that at least the standard practices (Section II-A above) are followed, particularly the avoidance of mouth pipetting. The possibility of colonization and hence of transfer are increased, however, if the normal flora in the bowel is disrupted by, for example, antibiotic therapy (35). For this reason, persons receiving such therapy must not work with DNA recombinants formed with any *E. coli* K-12 host-vector system during the therapy period and for seven days thereafter; similarly, persons who have achlorhydria or who have had surgical removal of part of the stomach or bowel should avoid such work, as should those who require large doses of antacids.

The observations on the fate of *E. coli* K-12 in the human alimentary tract are also relevant to the containment of recombinant DNA formed with bacteriophage λ variants. Bacteriophage can escape from the laboratory either as mature infectious phage particles or in bacterial host cells in which the phage genome is carried as a plasmid or prophage. The fate of *E. coli* K-12 host cells carrying the phage genome as a plasmid or prophage is similar to that for plasmid-containing host cells as discussed above. The survival of the λ phage genome when released as infectious particles depends on their stability in nature, their infectivity and on the probability of subsequent encounters with naturally occurring λ -sensitive *E. coli* strains. Although the probability of survival of λ and its infection of resident intestinal *E. coli* in animals and humans has not been measured, it is estimated to be small given the high sensitivity of λ to the low pH of the stomach, the insusceptibility to λ infection of smooth *E. coli* cells (the type that normally resides in the gut), the infrequency of naturally occurring λ -sensitive *E. coli* (36) and the failure to detect infective λ particles in human feces after ingestion of up to 10^{11} λ particles (37). Moreover, λ particles are very sensitive to desiccation.

Establishment of λ as a stable lysogen is a frequent event (10^6 to 10^{-1}) for the *att⁺ int⁺ cI⁺* phage so that this mode of escape would be the preponderant laboratory hazard; however, most EK1 λ vectors currently in use lack the *att* and *int* functions (27-29) thus reducing the probability of lysogenization to about 10^{-5} to 10^{-6} (38-40). The frequency for the conversion of λ to a plasmid state for persistence and replication is also only about 10^{-6} (41). Moreover, the routine treatment of phage lysates with chloroform (42) should eliminate all surviving bacteria including lysogens and λ plasmid carriers. Lysogenization could also occur

when an infectious λ containing cloned DNA infects a λ -sensitive cell in nature, and recombines with a resident lambdoid prophage. Although λ -sensitive *E. coli* strains seem to be rare, a significant fraction do carry lambdoid prophages (43-44) and thus this route of escape should be considered.

While not exact, the estimates for containment afforded by using these host-vectors are at least as accurate as those for physical containment, and are sufficient to indicate that currently employed plasmid and λ vector systems provide a moderate level of biological containment. Other nonconjugative plasmids and bacteriophages that, in association with *E. coli* K-12 can be estimated to provide the same approximate level of moderate containment are included in the EK1 class.

EK2 host-vectors. These are host-vector systems that have been genetically constructed and shown to provide a high level of biological containment as demonstrated by data from suitable tests performed in the laboratory. The genetic modifications of the *E. coli* K-12 host and/or the plasmid or phage vector should not permit survival of a genetic marker carried on the vector, preferably a marker within an inserted DNA fragment, in other than specially designed and carefully regulated laboratory environments at a frequency greater than 10^{-6} . This measure of biological containment has been selected because it is a measurable entity. Indeed, by testing the contributions of preexisting and newly introduced genetic properties of vectors and hosts, individually or in various combinations, it should be possible to estimate with considerable precision, that the specially designed host-vector system can provide a margin of biological containment in excess of that required. For the time being, no host-vector system will be considered to be a bona fide EK2 host-vector system until it is so certified by the NIH Recombinant DNA Molecule Program Advisory Committee.

For EK2 host-vector systems in which the vector is a plasmid, no more than one in 10^4 host cells should be able to perpetuate the vector and/or a cloned DNA fragment under non-permissive conditions designed to represent the natural environment either by survival of the original host or as a consequence of transmission of the vector and/or a cloned DNA fragment by transformation, transduction or conjugation to a host with properties common to those in the natural environment.

In terms of potential EK2 plasmid-host systems, the following types of genetic modifications should reduce survival of cloned DNA. *The examples given are for illustrative purposes and should not be construed to encompass all possibilities.* The presence of the non-conjugative plasmids ColE1-*trp* and pS101 in an *E. coli* K-12 strain possessing a mutation eliminating host-controlled restriction and modification (*hsdS*) results in about 10^2 -fold reduction in mobilization to restriction-proficient recipients. The combination of the *dapD8*, Δ *bioH*-*asd*, Δ *gal*-

chl^r and *rfb* mutations in *E. coli* K-12 results in no detectable survivors in feces of rats following feeding by stomach tube of 10^{10} cells in milk and similarly leads to complete lysis of cells suspended in broth medium lacking diaminopimelic acid. *E. coli* K-12 strains with Δ *thyA* and *deoC* (*dra*) mutations undergo thymineless death in growth medium lacking thymine and give a 10^3 -fold reduced survival during passage through the rat intestine compared to wild-type *thy*⁺ *E. coli* K-12. (However, the Δ *thyA* mutation alone or in combination with a *deoB* (*drm*) mutation only reduces *in vivo* survival by a factor of 10^2 .) Other host mutations, as yet untested, that might further reduce survival of the plasmid-host system or reduce plasmid transmission are: the combination *polA* (TS) *recA* (TS) Δ *thyA* which might interfere with ColE1 replication and lead to DNA degradation at body temperatures; *Con*⁻ mutations that reduce the ability of conjugative plasmids to enter the plasmid-host complex and thus should reduce mobilization of the cloned DNA to other strains; and mutations that confer resistance to known transducing phages. Mutations can also be introduced into the plasmid to cause it to be dependent on a specific host, to make its replication thermosensitive and/or to endow it with a killer capability such that all cells (other than its host) into which it might be transferred will not survive.

In the construction of EK2 plasmid-host systems it is important to use the most stable mutations available, preferably deletions. Obviously, the presence of all mutations contributing to higher degrees of biological containment must be verified periodically by appropriate tests. In testing the level of biological containment afforded by a proposed EK2 plasmid-host system, it is important to design relevant tests to evaluate the survival of the vector and/or a cloned DNA fragment under conditions that are possible in nature and that are also most advantageous for its perpetuation. For example, one might conduct a triparental mating with a primary donor possessing a derepressed F-type or I-type conjugative plasmid, the safer host with Δ *bioH*-*asd*, *dapD8*, Δ *gal*-*chl*^r, *rfb*, Δ *thyA*, *deoC*, *trp* and *hsdS* mutations and a plasmid vector carrying an easily detectable marker such as for ampicillin resistance or an inserted gene such as *trp*⁺, and a secondary recipient that is Su⁺ *hsdS* *trp* (i.e., permissive for the recombinant plasmid). Such matings would be conducted in a medium lacking diaminopimelic acid and thymine and survival of the Ap^r or *trp*⁺ marker in any of the three strains followed as a function of time. Survival of the vector and/or a cloned marker by transduction could also be evaluated by introducing a known generalized transducing phage into the system. Similar experiments should also be done using a secondary recipient that is restrictive for the plasmid vector as well as with primary donors possessing repressed conjugative plasmids with incompatibility group properties like those commonly found in enteric microorgan-

isms. Since a common route of escape of plasmid-host systems in the laboratory might be by accidental ingestion, it is suggested that the same types of experiments be conducted in suitable animal-model systems. In addition to these tests on survival of the vector and/or a cloned DNA fragment, it would be useful to determine the survival of the host strain under nongrowth conditions such as in water and as a function of drying time after a culture has been spilled on a lab bench.

For EK2 host-vector systems in which the vector is a phage, no more than one in 10^4 phage particles should be able to perpetuate itself and/or a cloned DNA fragment under non-permissive conditions designed to represent the natural environment either (a) as a prophage or plasmid in the laboratory host used for phage propagation or (b) by surviving in natural environments and transferring itself and/or a cloned DNA fragment to a host (or its resident lambdoid prophage) with properties common to those in the natural environment.

In terms of potential EK2 λ -host systems, the following types of genetic modification should reduce survival of cloned DNA. *The examples given are for illustrative purposes and should not be construed to encompass all possibilities.* The probability of establishing λ lysogeny in the normal laboratory host should be reduced by removal of the phage *att* site, the *Int* function, the repressor gene(s) and adding virulence-enhancing mutations. The frequency of plasmid formation, although normally already less than 10^{-6} , could be further reduced by defects in the *p_R-Q* region, including mutations such as *vir-s*, *cro* (TS), *c17*, *ri*⁻, *O* (TS), *P* (TS), and *nin*. Moreover, chloroform treatment used routinely following cell lysis would reduce the number of surviving cells, including possible lysogens or plasmid carriers, by more than 10^4 . The host may also be modified by deletion of the host λ *att* site and inclusion of one or more of the mutations described above for plasmid-host systems to further reduce the chance of formation and survival of any lysogen or plasmid carrier cell.

The survival of escaping phage and the chance of encountering a sensitive host in nature are very low, as discussed for EK1 systems. The infectivity of the phage particles could be further reduced by introducing mutations (e.g., suppressed ambers) which would make the phage particles extremely unstable except under special laboratory conditions (e.g., high concentrations of salts or putrescine). Another means would be to make the phage itself a two-component system, by eliminating the tail genes and reproducing the phage as heads packed with DNA; when necessary and under specially controlled conditions, these heads could be made infective by adding tail preparations. An additional safety factor in this regimen is the extreme instability of the heads, unless they are stored in 10mM putrescine, a condition easy to obtain in the laboratory but not in nature. The propagation of the es-

caping phage in nature could further be blocked by adding various conditional mutations which would permit growth only under special laboratory conditions or in a special permissive laboratory host with suppressor or *gro*-type (*mop*, *dnaB*, *rpoB*) mutations. An additional safety feature would be the use of an *r^m* (*hsdS*) laboratory host, which produces phage with unmodified DNA which should be restricted in *r^m* bacteria that are probably prevalent in nature. The likelihood of recombination between the λ vector and lambdoid prophages which are present in some *E. coli* strains might be reduced by elimination of the Red function and the presence of the recombination-reducing Gam function together with mutations contributing to the high lethality of the λ phage. However, these second-order precautions might not be relevant if the stability and infectivity of the escaping λ particles are reduced by special mutations or by propagating the highly unstable heads.

Despite multiple mutations in the phage vectors and laboratory hosts, the yield of phage particles under suitable laboratory conditions should be high (10^8 - 10^{11} particles/ml). This permits phage propagation in relatively small volumes and constitutes an additional safety feature.

The phenotypes and genetic stabilities of the mutations and chromosome alterations included in these λ -host systems indicate that containment well in excess of the required 10^{-6} or lower survival frequency for the λ vector with or without a cloned DNA fragment should be attained. Obviously the presence of all mutations contributing to this high degree of biological containment must be verified periodically by appropriate tests. Laboratory tests should be performed with the bacterial host to measure all possible routes of escape such as the frequency of lysogen formation, the frequency of plasmid formation and the survival of the lysogen or carrier bacterium. Similarly, the potential for perpetuation of a cloned DNA fragment carried by infectious phage particles can be tested by challenging typical wild-type *E. coli* strains or a λ -sensitive nonpermissive laboratory K-12 strain, especially one lysogenic for a lambdoid phage.

In view of the fact that accurate assessment of the probabilities for escape of infections λ -grown on *r^m Su⁺* hosts is dependent upon the frequencies of *r^m*, *Su⁺*, and λ -sensitive strains in nature, investigators need to screen *E. coli* strains for these properties. These data will also be useful in predicting frequencies of successful escape of plasmid cloning vectors harbored in *r^m Su⁺* strains.

When any investigator has obtained data on the level of containment provided by a proposed EK2 system, these should be reported as rapidly as possible to permit general awareness and evaluation of the safety features of the new system. Investigators are also encouraged to make such new safer cloning systems generally available to other scientists. NIH will take appropriate steps to aid

in the distribution of these safer vectors and hosts.

EK3 host-vectors. These are EK2 systems for which the specified containment shown by laboratory tests has been independently confirmed by appropriate tests in animals, including humans or primates, and in other relevant environments in order to provide additional data to validate the levels of containment afforded by the EK2 host-vector systems. Evaluation of the effects of individual or combinations of mutations contributing to the biological containment should be performed as a means to confirm the degree of safety provided and to further advance the technology of developing even safer vectors and hosts. For the time being, no host-vector system will be considered to be a bona fide EK3 host-vector system, until it is so certified by the NIH Recombinant DNA Molecule Program Advisory Committee.

2. Classification of experiments using the *E. coli* K-12 containment systems. In the following classification of containment criteria for different kinds of recombinant DNAs, the stated levels of physical and biological containment are minimums. Higher levels of biological containment (EK3 > EK2 > EK1) are to be used if they are available and are equally appropriate for the purposes of the experiment.

(a) Shotgun Experiments. These experiments involve the production of recombinant DNAs between the vector and the total DNA or (preferably) any partially purified fraction thereof from the specified cellular source.

(i) Eukaryotic DNA recombinants—Primates. P3 physical containment + an EK3 host-vector, or P4 physical containment + an EK2 host-vector, except for DNA from uncontaminated embryonic tissue or primary tissue cultures therefrom, and germ-line cells for which P3 physical containment + an EK2 host-vector can be used. The basis for the lower estimated hazard in the case of DNA from the latter tissues (if freed of adult tissue) is their relative freedom from horizontally acquired adventitious viruses.

Other mammals. P3 physical containment + an EK2 host-vector.

Birds. P3 physical containment + an EK2 host-vector.

Cold-blooded vertebrates. P2 physical containment + an EK2 host-vector except for embryonic or germ-line DNA which require P2 physical containment + an EK1 host-vector. If the eukaryote is known to produce a potent toxin, the containment shall be increased to P3 + EK2.

Other cold-blooded animals and lower eukaryotes. This large class of eukaryotes is divided into the following two groups:

(1) Species that are known to produce a potent toxin or are known pathogens (i.e., an agent listed in Class 2 of ref. 5 or a plant pathogen) or are known to carry such pathogenic agents must use P3 physical containment + an EK2 host-vector. Any species that has a demonstrated capacity for carrying particular

pathogenic agents is included in this group unless it has been shown that those organisms used as the source of DNA do not contain these agents; in this case they may be placed in the second group.

(2) The remainder of the species in this class can use P2 + EK1. However, any insect in this group should have been grown under laboratory conditions for at least 10 generations prior to its use as a source of DNA.

Plants. P2 physical containment + an EK1 host-vector. If the plant carries a known pathogenic agent or makes a product known to be dangerous to any species, the containment must be raised to P3 physical containment + an EK2 host-vector.

(ii) Prokaryotic DNA recombinants—Prokaryotes that exchange genetic information with *E. coli*. The level of physical containment is directly determined by the rule of the most dangerous component (see introduction to Section III). Thus P1 conditions can be used for DNAs from those bacteria in Class 1 of ref. 5 ("Agents of no or minimal hazard ***") which naturally exchange genes with *E. coli*; and P2 conditions should be used for such bacteria if they fall in Class 2 of ref. 5 ("Agents of ordinary potential hazard * * *"), or are plant pathogens or symbionts. EK1 host-vectors can be used for all experiments requiring only P1 physical containment; in fact, experiments in this category can be performed with *E. coli* K-12 vectors exhibiting a lesser containment (e.g., conjugative plasmids) than EK1 vectors. Experiments with DNA from species requiring P2 physical containment which are of low pathogenicity (for example, enteropathogenic *Escherichia coli*, *Salmonella typhimurium*, and *Klebsiella pneumoniae*) can use EK1 host-vectors, but those of moderate pathogenicity (for example, *Salmonella typhi*, *Shigella dysenteriae* type I, and *Vibrio cholerae*) must use EK2 host-vectors. A specific example of an experiment with a plant pathogen requiring P2 physical containment + an EK2 host-vector would be cloning the tumor gene of *Agrobacterium tumefaciens*.

Prokaryotes that do not exchange genetic information with *E. coli*. The minimum containment conditions for this class consist of P2 physical containment + an EK2 host-vector or P3 physical containment + an EK1 host-vector, and apply when the risk that the recombinant DNAs will increase the pathogenicity or ecological potential of the host is judged to be minimal. Experiments with DNAs from pathogenic species (Class 2 ref. 5 plus plant pathogens) must use P3 + EK2.

(iii) Characterized clones of DNA recombinants derived from shotgun experiments. When a cloned DNA recombinant has been rigorously characterized⁴ and there is sufficient evidence that it is free of harmful genes,⁴ then experiments involving this recombinant DNA can be carried out under P1 + EK1 conditions if the inserted DNA is from a

See footnotes at end of article.

species that exchanges genes with *E. coli*, and under P2 + EK1 conditions if not.

(b) *Purified cellular DNAs other than plasmids, bacteriophages, and other viruses.* The formation of DNA recombinants from cellular DNAs that have been enriched⁵ by physical and chemical techniques (i.e., not by cloning) and which are free of harmful genes can be carried out under lower containment conditions than used for the corresponding shotgun experiment. In general, the containment can be decreased one step in physical containment (P4→P3→P2→P1) while maintaining the biological containment specified for the shotgun experiment, or one step in biological containment (EK3→EK2→EK1) while maintaining the specified physical containment—provided that the new condition is not less than that specified above for characterized clones from shotgun experiments (Section (a)—iii).

(c) *Plasmids, bacteriophages, and other viruses.* Recombinants formed between EK-type vectors and other plasmid or virus DNAs have in common the potential for acting as double vectors because of the replication functions in these DNAs. The containment conditions given below apply only to propagation of the DNA recombinants in *E. coli* K-12 hosts. They do not apply to other hosts where they may be able to replicate as a result of functions provided by the DNA inserted into the EK vectors. These are considered under other host-vector systems.

(i) *Animal viruses.* P4+EK2 or P3EK3 shall be used to isolate DNA recombinants that include all or part of the genome of an animal virus. This recommendation applies not only to experiments of the "shotgun" type but also to those involving partially characterized subgenomic segments of viral DNAs (for example, the genome of defective viruses, DNA fragments isolated after treatment of viral genomes with restriction enzymes, etc.). When cloned recombinants have been shown by suitable biochemical and biological tests to be free of harmful regions, they can be handled in P3+EK2 conditions. In the case of DNA viruses, harmless regions include the late region of the genome; in the case of DNA copies of RNA viruses, they might include the genes coding for capsid proteins or envelope proteins.

(ii) *Plant viruses.* P3+EK1 or P2+EK2 conditions shall be used to form DNA recombinants that include all or part of the genome of a plant virus.

(iii) *Eukaryotic organelle DNAs.* The containment conditions given below apply only when the organelle DNA has been purified⁶ from isolated organelles. Mitochondrial DNA from primates: P3+EK1 or P2+EK2. Mitochondrial or chloroplast DNA from other eukaryotes: P2+EK1. Otherwise, the conditions given under shotgun experiments apply.

(iv) *Prokaryotic plasmid and phage DNAs—Plasmids and phage from hosts that exchange genetic information with *E. coli*.* Experiments with DNA recombinants formed from plasmids or phage genomes that have not been character-

ized with regard to presence of harmful genes or are known to contribute significantly to the pathogenicity of their normal hosts must use the containment conditions specified for shotgun experiments with DNAs from the respective host. If the DNA recombinants are formed from plasmids or phage that are known not to contain harmful genes, or from purified⁶ and characterized plasmid or phage DNA segments known not to contain harmful genes, the experiments can be performed with P1 physical containment + an EK1 host-vector.

*Plasmids and phage from hosts that do not exchange genetic information with *E. coli*.* The rules for shotgun experiments with DNA from the host apply to their plasmids or phages. The minimum containment conditions for this category (P2+EK2, or P3+EK1) can be used for plasmid and phage, or for purified⁶ and characterized segments of plasmid and phage DNAs, when the risk that the recombinant DNAs will increase the pathogenicity or ecological potential of the host is judged to be minimal.

NOTE.—Where applicable, cDNAs (i.e., complementary DNAs) synthesized *in vitro* from cellular or viral RNAs are included within each of the above classifications. For example, cDNAs formed from cellular RNAs that are not purified and characterized are included under (a), shotgun experiments; cDNAs formed from purified and characterized RNAs are included under (b); cDNAs formed from viral RNAs are included under (c); etc.

3: *Experiments with other prokaryotic host-vectors.* Other prokaryotic host-vector systems are at the speculative, planning, or developmental stage, and consequently do not warrant detailed treatment here at this time. However, the containment criteria for different types of DNA recombinants formed with *E. coli* K-12 host-vectors can, with the aid of some general principles given here, serve as a guide for containment conditions with other host-vectors when appropriate adjustment is made for their different habitats and characteristics. The newly developed host-vector systems should offer some distinct advantage over the *E. coli* K-12 host-vectors—for instance, thermophilic organisms or other host-vectors whose major habitats do not include humans and/or economically important animals and plants. In general, the strain of any prokaryotic species used as the host is to conform to the definition of Class 1 etiologic agents given in ref. 5 (i.e., "Agents of no or minimal hazard. . ."), and the plasmid or phage vector should not make the host more hazardous. Appendix A gives a detailed discussion of the *B. subtilis* system, the most promising alternative to date.

At the initial stage, the host-vector must exhibit at least a moderate level of biological containment comparable to EK1 systems, and should be capable of modification to obtain high levels of containment comparable to EK2 and EK3. The type of confirmation test(s) required to move a host-vector from an EK2-type classification to an EK3-type will clearly

depend upon the preponderant habitat of the host-vector. For example, if the unmodified host-vector propagates mostly in, on, or around higher plants, but not appreciably in warm-blooded animals, modification should be designed to reduce the probability that the host-vector can escape to and propagate in, on, or around such plants, or transmit recombinant DNA to other bacterial hosts that are able to occupy these ecological niches, and it is these lower probabilities which must be confirmed. The following principles are to be followed in using the containment criteria given for experiments with *E. coli* K-12 host-vectors as a guide for other prokaryotic systems. Experiments with DNA from prokaryotes (and their plasmids or viruses) are classified according to whether the prokaryote in question exchanges genetic information with the host-vector or not, and the containment conditions given for these two classes with *E. coli* K-12 host-vectors applied. Experiments with recombinants between plasmid or phage vectors and DNA that extends the range of resistance of the recipient species to therapeutically useful drugs must use P3 physical containment + a host-vector comparable to EK1 or P2 physical containment + a host-vector comparable to EK2. Transfer of recombinant DNA to plant pathogens can be made safer by using nonreverting, doubly auxotrophic, non-pathogenic variants. Experiments using a plant pathogen that affects an element of the local flora will require more stringent containment than if carried out in areas where the host plant is not common.

Experiments with DNAs from eukaryotes (and their plasmids or viruses) can also follow the criteria for the corresponding experiments with *E. coli* K-12 vectors if the major habitats of the given host-vector overlap those of *E. coli*. If the host-vector has a major habitat that does not overlap those of *E. coli* (e.g., root nodules in plants), then the containment conditions for some eukaryotic recombinant DNAs need to be increased (for instance, higher plants and their viruses in the preceding example), while others can be reduced.

4. *Experiments with eukaryotic host-vectors—(a) Animal host-vector systems.* Because host cell lines generally have little if any capacity for propagation outside the laboratory, the primary focus for containment is the vector, although cells should also be derived from cultures expected to be of minimal hazard. Given good microbiological practices, the most likely mode escape of recombinant DNAs from a physically contained laboratory is carriage by humans; thus vectors should be chosen that have little or no ability to replicate in human cells. To be used as a vector in a eukaryotic host, a DNA molecule needs to display all of the following properties:

(1) It shall not consist of the whole genome of any agent that is infectious for humans or that replicates to a significant extent in human cells in tissue culture.

(2) Its functional anatomy should be known—that is, there should be a clear

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idea of the location within the molecule of:

(a) The sites at which DNA synthesis originates and terminates,

(b) The sites that are cleaved by restriction endonucleases,

(c) The template regions for the major gene products.

(3) It should be well studied genetically. It is desirable that mutants be available in adequate number and variety, and that quantitative studies of recombination have been performed.

(4) The recombinant must be defective, that is, its propagation as a virus is dependent upon the presence of a complementing helper genome. This helper should either (a) be integrated into the genome of a stable line of host cells (a situation that would effectively limit the growth of the vector to that particular cell line) or (b) consist of a defective genome or an appropriate conditional lethal mutant virus (in which case the experiments would be done under non-permissive conditions), making vector and helper dependent upon each other for propagation. However, if none of these is available, the use of a non-defective genome as helper would be acceptable.

Currently only two viral DNAs can be considered as meeting these requirements: these are the genomes of polyoma virus and SV40.

Of these, polyoma virus is highly to be preferred. SV40 is known to propagate in human cells, both *in vivo* and *in vitro*, and to infect laboratory personnel, as evidenced by the frequency of their conversion to producing SV40 antibodies. Also, SV40 and related viruses have been found in association with certain human neurological and malignant diseases. SV40 shares many properties, and gives complementation, with the common human papova viruses. By contrast, there is no evidence that polyoma infects humans, nor does it replicate to any significant extent in human cells *in vitro*. However, this system still needs to be studied more extensively. Appendix B gives further details and documentation.

Taking account of all these factors:

(1) *Polyoma Virus*. (a) Recombinant DNA molecules consisting of defective polyoma virus genomes plus DNA sequences of any nonpathogenic organism, including Class 1 viruses (5), can be propagated in or used to transform cultured cells. P3 conditions are required. Appropriate helper virus can be used if needed. Whenever there is a choice, it is urged that mouse cells, derived preferably from embryos, be used as the source of eukaryotic DNA. Polyoma virus is a mouse virus and recombinant DNA molecules containing both viral and cellular sequences are already known to be present in virus stocks grown at a high multiplicity. Thus, recombinants formed *in vitro* between polyoma virus DNA and mouse DNA are presumably not novel from an evolutionary point of view.

(b) Such experiments are to be done under P4 conditions if the recombinant DNA contains segments of the genomes of Class 2 animal viruses (5). Once it

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has been shown by suitable biochemical and biological tests that the cloned recombinant contains only harmless regions of the viral genome (see Section IIIB-2-c-i) and that the host range of the polyoma virus vector has not been altered, experiments can be continued under P3 conditions.

(2) *SV40 Virus*.

(a) Defective SV40 genomes, with appropriate helper, can be used as a vector for recombinant DNA molecules containing sequences of any non-pathogenic organism or Class I virus (5), (i.e., a shotgun type experiment). P4 conditions are required. Established lines of cultured cells should be used.

(b) Such experiments are to be carried out in P3 (or P4) conditions if the non-SV40 DNA segment is (a) a purified segment of prokaryotic DNA lacking toxigenic genes, or (b) a segment of eukaryotic DNA whose function has been established, which does not code for a toxic product, and which has been previously cloned in a prokaryotic host-vector system. It shall be confirmed that the defective virus-helper virus system does not replicate significantly more efficiently in human cells in tissue culture than does SV40, following infection at a multiplicity of infection of one or more helper SV40 viruses per cell.

(c) A recombinant DNA molecule consisting of defective SV40 DNA lacking substantial segments of the late region, plus DNA from non-pathogenic organisms or Class I viruses (5), can be propagated as an autonomous cellular element in established lines of cells under P3 conditions provided that there is no exogenous or endogenous helper, and that it is demonstrated that no infectious virus particles are being produced. Until this has been demonstrated, the appropriate containment conditions specified in 2. a. and 2. b. shall be used.

(d) Recombinant DNA molecules consisting of defective SV40 DNA and sequences from non-pathogenic prokaryotic or eukaryotic organisms or Class I viruses (5) can be used to transform established lines of non-permissive cells under P3 conditions. It must be demonstrated that no infectious virus particles are being produced; rescue of SV40 from such transformed cells by co-cultivation or transfection techniques must be carried out in P4 conditions.

(3) Efforts are to be made to ensure that all cell lines are free of virus particles and mycoplasma.

Since SV40 and polyoma are limited in their scope to act as vectors, chiefly because the amount of foreign DNA that the normal virions can carry probably cannot exceed 2×10^6 daltons, the development of systems in which recombinants can be cloned and propagated purely in the form of DNA, rather than in the coats of infectious agents is necessary. Plasmid forms of viral genomes or organelle DNA need to be explored as possible cloning vehicles in eukaryotic cells.

(b) *Plant host-vector systems*. For cells in tissue cultures, seedlings, or plant parts (e.g. tubers, stems, fruits, and de-

tached leaves) or whole mature plants of small species (e.g., *Arabidopsis*) the P1-P4 containment conditions that we have specified previously are relevant concepts. However, work with most plants poses additional problems. The greenhouse facilities accompanying P2 laboratory physical containment conditions can be provided by: (i) Insect-proof greenhouses, (ii) appropriate sterilization of contaminated plants, pots, soil, and runoff water, and (iii) adoption of the other standard practices for microbiological work. P3 physical containment can be sufficiently approximated by confining the operations with whole plants to growth chambers like those used for work with radioactive isotopes, provided that (i) such chambers are modified to produce a negative pressure environment with the exhaust air appropriately filtered, (ii) that other operations with infectious materials are carried out under the specified P3 conditions, and (iii) to guard against inadvertent insect transmission of recombinant DNA, growth chambers are to be routinely fumigated and only used in insect proof rooms. The P2 and P3 conditions specified earlier are therefore extended to include these cases for work on higher plants.

The host cells for experiments on recombinant DNAs may be cells in culture, in seedling or plant parts. Whole plants or plant parts that cannot be adequately contained shall not be used as hosts for shotgun experiments at this time, and attempts to infect whole plants with recombinant DNA shall not be initiated until the effects on host cells in culture, seedlings or plant parts have been thoroughly studied.

Organelle or plasmid DNAs or DNAs of viruses of restricted host range may be used as vectors. In general, similar criteria for selecting host-vectors to those given in the preceding section on animal systems are to apply to plant systems.

DNA recombinants formed between the initial moderately contained vectors and DNA from cells of species in which the vector DNA can replicate, require P2 physical containment. However, if the source of the DNA is itself pathogenic or known to carry pathogenic agents, or to produce products dangerous to plants, or if the vector is an unmodified virus of unrestricted host range, the experiments shall be carried out under P3 conditions.

Experiments on recombinant DNAs formed between the above vectors and DNAs from other species can also be carried out under P2 if that DNA has been purified* and determined not to contain harmful genes. Otherwise, the experiments shall be carried out under P3 conditions if the source of the inserted DNA is not itself a pathogen, or known to carry such pathogenic agents, or to produce harmful products—and under P4 conditions if these conditions are not met.

The development and use of host-vector systems that exhibit a high level of biological containment permit a decrease or one step in the physical con-

tainment specified above (P4→P3→P2→P1).

(c) *Fungal or similar lower eukaryotic host-vector systems.* The containment criteria for experiments on recombinant DNAs using these host-vectors most closely resemble those for prokaryotes, rather than those for the preceding eukaryotes, in that the host cells usually exhibit a capacity for dissemination outside the laboratory that is similar to that for bacteria. We therefore consider that the containment guidelines given for experiments with *E. coli* K-12 and other prokaryotic host-vectors (Sections IIIB-1 and -2, respectively) provide adequate direction for experiments with these lower eukaryotic host-vectors. This is particularly true at this time since the development of these host-vectors is presently in the speculative stage.

IV. ROLES AND RESPONSIBILITIES

Safety in research involving recombinant DNA molecules depends upon how the research team applies these guidelines. Motivation and critical judgment are necessary, in addition to specific safety knowledge, to ensure protection of personnel, the public, and the environment.

The guidelines given here are to help the principal investigator determine the nature of the safeguards that should be implemented. These guidelines will be incomplete in some respects because all conceivable experiments with recombinant DNAs cannot now be anticipated. Therefore, they cannot substitute for the investigator's own knowledgeable and discriminating evaluation. Whenever this evaluation calls for an increase in containment over that indicated in the guidelines, the investigator has a responsibility to institute such an increase. In contrast, the containment conditions called for in the guidelines should not be decreased without review and approval at the institutional and NIH levels.

The following roles and responsibilities define an administrative framework in which safety is an essential and integrated function of research involving recombinant DNA molecules.

A. Principal Investigator. The principal investigator has the primary responsibility for: (i) Determining the real and potential biohazards of the proposed research, (ii) determining the appropriate level of biological and physical containment, (iii) selecting the microbiological practices and laboratory techniques for handling recombinant DNA materials, (iv) preparing procedures for dealing with accidental spills and overt personnel contamination, (v) determining the applicability of various precautionary medical practices, serological monitoring, and immunization, when available, (vi) securing approval of the proposed research prior to initiation of work, (vii) submitting information on purported EK2 and EK3 systems to the NIH Recombinant DNA Molecule Program Advisory Committee and making the strains available to others, (viii) reporting to the institutional biohazards committee and the NIH Office of Recombinant DNA

Activities new information bearing on the guidelines, such as technical information relating to hazards and new safety procedures or innovations, (ix) applying for approval from the NIH Recombinant DNA Molecule Program Advisory Committee for large scale experiments with recombinant DNAs known to make harmful products (i.e., more than 10 liters of culture), and (x) applying to NIH for approval to lower containment levels when a cloned DNA recombinant derived from a shotgun experiment has been rigorously characterized and there is sufficient evidence that it is free of harmful genes.

Before work is begun, the principal investigator is responsible for: (1) Making available to program and support staff copies of those portions of the approved grant application that describe the biohazards and the precautions to be taken, (ii) advising the program and support staff of the nature and assessment of the real and potential biohazards, (iii) instructing and training this staff in the practices and techniques required to ensure safety, and in the procedures for dealing with accidentally created biohazards, and (iv) informing the staff of the reasons and provisions for any advised or requested precautionary medical practices, vaccinations, or serum collection.

During the conduct of the research, the principal investigator is responsible for: (i) Supervising the safety performance of the staff to ensure that the required safety practices and techniques are employed, (ii) investigating and reporting in writing to the NIH Office of Recombinant DNA Activities and the institutional biohazards committee any serious or extended illness of a worker or any accident that results in (a) inoculation of recombinant DNA materials through cutaneous penetration, (b) ingestion of recombinant DNA materials, (c) probable inhalation of recombinant DNA materials following gross aerosolization, or (d) any incident causing serious exposure to personnel or danger of environmental contamination, (iii) investigating and reporting in writing to the NIH Office of Recombinant DNA Activities and the institutional biohazards committee any problems pertaining to operation and implementation of biological and physical containment safety practices and procedures, or equipment or facility failure, (iv) correcting work errors and conditions that may result in the release of recombinant DNA materials, and (v) ensuring the integrity of the physical containment (e.g., biological safety cabinets) and the biological containment (e.g., genotypic and phenotypic characteristics, purity, etc.).

B. Institution. Since in almost all cases, NIH grants are made to institutions rather than to individuals, all the responsibilities of the principal investigator listed above are the responsibilities of the institution under the grant, fulfilled on its behalf by the principal investigator. In addition, the institution is responsible for establishing an institutional biohazards committee⁷ to: (1) Advise the

institution on policies, (ii) create and maintain a central reference file and library of catalogs, books, articles, newsletters, and other communications as a source of advice and reference regarding, for example, the availability and quality of the safety equipment, the availability and level of biological containment for various host-vector systems, suitable training of personnel and data on the potential biohazards associated with certain recombinant DNAs, (iii) develop a safety and operations manual for any P4 facility maintained by the institution and used in support of recombinant DNA research, (iv) certify to the NIH on applications for research support and annually thereafter, that facilities, procedures, and practices and the training and expertise of the personnel involved have been reviewed and approved by the institutional biohazards committee.

The biohazards committee must be sufficiently qualified through the experience and expertise of its membership and the diversity of its membership to ensure respect for its advice and counsel. Its membership should include individuals from the institution or consultants, selected so as to provide a diversity of disciplines relevant to recombinant DNA technology, biological safety, and engineering. In addition to possessing the professional competence necessary to assess and review specific activities and facilities, the committee should possess or have available to it, the competence to determine the acceptability of its findings in terms of applicable laws, regulations, standards of practices, community attitudes, and health and environmental considerations. Minutes of the meetings should be kept and made available for public inspection. The institution is responsible for reporting names of and relevant background information on the members of its biohazards committee to the NIH.

C. NIH Initial Review Groups (Study Sections). The NIH Study Sections, in addition to reviewing the scientific merit of each grant application involving recombinant DNA molecules, are responsible for: (i) Making an independent evaluation of the real and potential biohazards of the proposed research on the basis of these guidelines, (ii) determining whether the proposed physical containment safeguards certified by the institutional biohazards committee are appropriate for control of these biohazards, (iii) determining whether the proposed biological containment safeguards are appropriate, (iv) referring to the NIH Recombinant DNA Molecule Program Advisory Committee or the NIH Office of Recombinant DNA Activities those problems pertaining to assessment of biohazards or safeguard determination that cannot be resolved by the Study Sections.

The membership of the Study Sections will be selected in the usual manner. Biological safety expertise, however, will be available to the Study Sections for consultation and guidance.

D. NIH Recombinant DNA Molecule Program Advisory Committee. The Recombinant DNA Molecule Program Advisory Committee advises the Secretary, Department of Health, Education, and

⁷ See footnotes at end of article.

Welfare, the Assistant Secretary for Health, Department of Health, Education, and Welfare, and the Director, National Institutes of Health, on a program for the evaluation of potential biological and ecological hazards of recombinant DNAs (molecules resulting from different segments of DNA that have been joined together in cell-free systems, and which have the capacity to infect and replicate in some host cell, either autonomously or as an integrated part of their host's genome), on the development of procedures which are designed to prevent the spread of such molecules within human and other populations, and on guidelines to be followed by investigators working with potentially hazardous recombinants.

The NIH Recombinant DNA Molecule Program Advisory Committee has responsibility for: (i) Revising and updating guidelines to be followed by investigators working with DNA recombinants, (ii) for the time being, receiving information on purported EK2 and EK3 systems and evaluating and certifying that host-vector systems meet EK2 or EK3 criteria, (iii) resolving questions concerning potential biohazard and adequacy of containment capability if NIH staff or NIH Initial Review Group so request, and (iv) reviewing and approving large scale experiments with recombinant DNAs known to make harmful products (e.g., more than 10 liters of culture).

E. NIH Staff. NIH Staff has responsibility for: (i) Assuring that no NIH grants or contracts are awarded for DNA recombinant research unless they (a) conform to these guidelines, (b) have been properly reviewed and recommended for approval, and (c) include a properly executed Memorandum of Understanding and Agreement, (ii) reviewing and responding to questions or problems or reports submitted by institutional biohazards committees or principal investigators, and disseminating findings, as appropriate, (iii) receiving and reviewing applications for approval to lower containment levels when a cloned DNA recombinant derived from a shotgun experiment has been rigorously characterized and there is sufficient evidence that it is free of harmful genes, (iv) referring items covered under (ii) and (iii) above to the NIH Recombinant DNA Molecule Program Advisory Committee, as deemed necessary, and (v) performing site inspections of all P4 physical containment facilities, engaged in DNA recombinant research, and of other facilities as deemed necessary.

V. FOOTNOTES

¹ Biological Safety Cabinets referred to in this section are classified as Class I, Class II or Class III cabinets. A Class I cabinet is a ventilated cabinet for personnel protection having an inward flow of air away from the operator. The exhaust air from this cabinet is filtered through a high efficiency or high efficiency particulate air (HEPA) filter before being discharged to the outside atmosphere. This cabinet is used in three operational modes; (1) with an 8 inch high full width open front, (2) with an installed front closure panel (having four eight inch diameter

openings) without gloves, and (3) with an installed front closure panel equipped with arm length rubber gloves. The face velocity of the inward flow of air through the full width open front is 75 feet per minute or greater. A Class II cabinet is a ventilated cabinet for personnel and product protection having an open front with inward air flow for personnel protection, and HEPA filtered mass recirculated air flow for product protection. The cabinet exhaust air is filtered through a HEPA filter. The face velocity of the inward flow of air through the full width open front is 75 feet per minute or greater. Design and performance specifications for Class II cabinets have been adopted by the National Sanitation Foundation, Ann Arbor, Michigan. A Class III cabinet is a closed front ventilated cabinet of gas tight construction which provides the highest level of personnel protection of all Biohazard Safety Cabinets. The interior of the cabinet is protected from contaminants exterior to the cabinet. The cabinet is fitted with arm length rubber gloves and is operated under a negative pressure of at least 0.5 inches water gauge. All supply air filtered through HEPA filters. Exhaust air is filtered through HEPA filters or incinerated before being discharged to the outside environment.

² Defined as observable under optimal laboratory conditions by transformation, transduction, phage infection and/or conjugation with transfer of phage, plasmid and/or chromosomal genetic information.

³ The bacteria which constitute Class 2 of ref. 5 ("Agents of ordinary potential hazard * * *") represent a broad spectrum of etiologic agents which possess different levels of virulence and degrees of communicability. We think it appropriate for our specific purpose to further subdivide the agents of Class 2 into those which we believe to be of relatively low pathogenicity and those which are moderately pathogenic. The several specific examples given may suffice to illustrate the principle.

⁴ The terms "characterized" and "free of harmful genes" are unavoidably vague. But, in this instance, before containment conditions lower than the ones used to clone the DNA can be adopted, the investigator must obtain approval from the National Institutes of Health. Such approval would be contingent upon data concerning: (a) the absence of potentially harmful genes (e.g., sequences contained in indigenous tumor viruses or which code for toxic substances), (b) the relation between the recovered and desired segment (e.g., hybridization and restriction endonuclease fragmentation analysis where applicable), and (c) maintenance of the biological properties of the vector.

⁵ A DNA preparation is defined as enriched if the desired DNA represents at least 99% (w/w) of the total DNA in the preparation. The reason for lowering the containment level when this degree of enrichment has been obtained is based on the fact that the total number of clones that must be examined to obtain the desired clone is markedly reduced. Thus, the probability of cloning a harmful gene could, for example, be reduced by more than 10⁶-fold when a nonrepetitive gene from mammals was being sought. Furthermore, the level of purity specified here makes it easier to establish that the desired DNA does not contain harmful genes.

⁶ The DNA preparation is defined as purified if the desired DNA represents at least 99% (w/w) of the total DNA in the preparation, provided that it was verified by more than one procedure.

⁷ In special circumstances, in consultation with the NIH Office of Recombinant DNA Activities, an area biohazards committee may be formed, composed of members from the institution and/or other organizations be-

yond its own staff, as an alternative when additional expertise outside the institution is needed for the indicated reviews.

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APPENDIX A—STATEMENT ON THE USE OF "Bacillus subtilis" IN RECOMBINANT MOLECULE TECHNOLOGY

Unquestionably, *Escherichia coli* is the most well characterized unicellular organism. Years of basic research have enabled investigators to develop a well characterized genetic map, to obtain detailed knowledge of virulent and temperate bacteriophages, and to explore the physiology, genetics, and regulation of plasmids. More recently, the development of DNA-mediated transformation has permitted exogenous fragments or molecules of DNA to be incorporated into the genome or to reside as self-replicating units. The discovery of transformation of *Bacillus subtilis* by Spizizen (1) stimulated the development of an alternative model system. The purpose of this report is to summarize the current status of this genetic system and to describe the actual and potential vectors and vehicles available for recombinant molecule technology.

A. CURRENT KNOWLEDGE OF THE CHROMOSOMAL ARCHITECTURE AND MECHANISMS OF GENETIC EXCHANGE IN B. "SUBTILIS"

Two mechanisms of genetic exchange have been utilized to establish the linkage map of *B. subtilis*, DNA-mediated transformation (capable of transferring approximately 1% of the genome) and transduction with bacteriophage PBS1 (capable of transferring 5-8% of the chromosome). Recent detailed genetic studies with PBS1 by Lepesant-Kejzlorová et al. (2) have resulted in the development of a circular genetic map for this organism. The current edition of the map (3) contains 196 loci. Biophysical analyses have established that the chromosome is circular (4) and replicates bidirectionally (5).

Transformation with purified fragments of DNA is a highly efficient process in *B. subtilis* with frequencies of 1 to 4% usually attained for any auxotrophic or antibiotic resistance markers. Frequencies of approximately 10% transformation can be achieved with DNA prepared from gently lysed L-forms or protoplasts (6). These large fragments of DNA are readily incorporated by the recipient cell. Generalized transduction occurs with bacteriophages SP10 (7), PBS1 (8), and SPP1 (9), while a low frequency of specialized transduction has been reported with bacteriophage ϕ 105 (10).

Although transformation is most efficient in homologous crosses (*B. subtilis* into *B. subtilis*), it has also been possible to exchange DNA among closely related species (11). The most extensively studied members of the *B. subtilis* genospecies include *B. licheniformis*, *B. pumilus*, *B. amyloliquefaciens*, and *B. globigii* (refer to reference 12 for a review and references 13-15 for examples of this heterologous exchange). This exchange occurs even

though there is a surprisingly wide discrepancy between DNA-DNA hybridization among these organisms (16). Even though the frequency of transformation is low in the heterologous cross [e.g., *B. amyloliquefaciens* (donor)/*B. subtilis* (recipient)], the newly acquired DNA from *B. amyloliquefaciens* in the *B. subtilis* background can be readily transferred at high efficiencies to other recipient strains of *B. subtilis* (14). Therefore, the extremely high frequency of transformation permits the recognition and selection of rare events.

B. CURRENT AND POTENTIAL VECTORS FOR RECOMBINANT MOLECULE EXPERIMENTS

Lovett and coworkers have recently described cryptic plasmids in *B. pumilus* (17) and *B. subtilis* (18). Of these organisms, *B. subtilis* ATCC 7003 appears to be the most useful since it carries one to two copies of a plasmid with a molecular weight of 46×10^6 . This strain is also closely related to *B. subtilis* 168. Another strain of *B. subtilis* (ATCC 15841) contains 16 copies of a plasmid with a molecular weight of 4.6×10^6 . Currently it is not known whether genetic markers can be readily introduced into these plasmids. To date it has not been possible to readily stabilize plasmids derived from *B. pumilus* in *B. subtilis* even with heavy selective pressure (P. Lovett, personal communication).

Two temperate bacteriophages are under development as vectors in *B. subtilis*, $\phi 3T$ and SP02. Lysogeny of thymine auxotrophs (strains carrying *thyA* *thyB*) by bacteriophage $\phi 3T$ results in "conversion" to a *Thy*⁺ phenotype. The attachment site for this bacteriophage and the bacteriophage gene for thymidylate synthetase (*thyP*) map between the bacterial *thyA* and *thyB* loci in the terminal region of the chromosome of *B. subtilis* (19). The viral genome is readily cleaved by the site-specific endonuclease, Bam 1 (20), to produce 5 fragments (one of which carries the *thyP* gene). The *thyP* carrying gene can be integrated into the bacterial genome in the absence of the intact viral genome. Because deletions are available that include the *thyP* region, it is theoretically possible to introduce *thyP* at many sites on the chromosome. The *thyP* gene can be readily purified for insertion into plasmids or utilized as a scaffold to integrate other heterologous DNA into the chromosome of *B. subtilis*. Alternatively, it is possible to purify fragments of the chromosome by gel electrophoresis (21, 22), for insertion into bacteriophage $\phi 3T$ or SP02. At present, unfortunately, only the former carries a selective marker, i.e., the gene for thymidylate synthetase, *thyP*.

C. DEVELOPMENT OF VEHICLES

B. subtilis is a Gram-positive sporulating rod that usually inhabits soil. Although it can exist on cutaneous surfaces of man (23) and experimental animals, it rarely produces disease. To develop a suitable vehicle it is imperative to have a host that is asporogenic. The most appropriate deletion mutation is deletion 29 (cit D). In addition to a deficiency in sporulation this mutant rapidly lyses when it has reached the end of its growth cycle. Presumably this is due to the failure to inactivate one of the autolytic enzymes (24). Through the introduction of a D-alanine requirement (34 $\mu\text{g}/\text{ml}$) it is possible to block transport of compounds that are transported by active transport (25, 26). The further introduction of thymine auxotrophy (defects in the *thyA* *thyB* loci) will enable the strain to survive only with a plasmid vector carrying the purified *thyP* gene from bacteriophage $\phi 3T$ or a defective bacteriophage $\phi 3T$ carrying the *thyP* gene but attached to the chromosome at an alternative site (due to the presence of deletion

29 in the host). We have recently isolated temperature-sensitive *thyP* mutants. If we can isolate a temperature-dependent lysogen that will grow only at 48°C it should be possible to make an unusual vehicle.

D. SITE-SPECIFIC ENDONUCLEASES

Recently two restriction modification systems have been observed between *B. subtilis* 168 and other bacilli. Trautner *et al.* have isolated an effective system that inhibits infection of the R strain of *B. subtilis* by bacteriophage SPP1 propagated on *B. subtilis* 168 (27). The site-specific nuclease recognizes the sequence GGCC. Young, Radnay, and CCGG

Wilson observed a restriction modification system between *B. amyloliquefaciens* and *B. subtilis* 168 (28). The endonuclease from *B. amyloliquefaciens* (20) recognizes the sequence GGATCC (29). More recently, two additional enzymes have been isolated from *B. globigii* (30). The recognition sequence is not known.

E. ADVANTAGES AND LIABILITIES OF THE B. "SUBTILIS SYSTEM"

a. Advantages

1. *B. subtilis* is nonpathogenic. Asporogenic deletion mutants are available to preclude the problem of persistence through sporulation.
2. The circular chromosomal map is well defined. At least 196 loci have been positioned.
3. The organism is commercially important in the fermentation industry.
4. Large numbers of organisms can be disposed of readily with minimal environmental impact.
5. Unlike *E. coli*, it lacks endotoxin in the cell wall. Therefore the cells can be used as a single cell protein source.
6. The frequency of transformation is very high, facilitating the detection of rare events.
7. A unique bacteriophage, $\phi 3T$, exists that carries a gene that can be readily purified for "scaffolding" experiments.

b. Disadvantages

1. The knowledge of genetics and physiology of plasmids and viruses is primitive compared with *E. coli*.
2. High-frequency, specialized transduction is not available as a means of gene enrichment.

Based on its promise, it seems appropriate, and not chauvinistic, to urge development of this system.

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APPENDIX B.—POLYOMA AND SV40 VIRUS

Polyoma virus is a virus of mice, and infection of wild mouse populations is a common event, for the virus has often been isolated from a high proportion of healthy adult animals, both wild and laboratory bred, of many colonies (Gross, L., *Proc. Soc. Exp. Biol.* 88, 362-368, 1955; Rowe, W. P., *Bact. Rev.* 25, 18-31, 1961). As far as is known the virus almost never causes a disease in these animals. However, when large quantities of the virus are inoculated into newborn or suckling mice or hamsters, a variety of solid tumors is induced (Gross, L., *Oncogenic Viruses*, Second Edition, Pergamon Press, NY).

Polyoma virus grows lytically in mouse cells in tissue culture. Thus mouse cells in culture are probably transformed only by virus particles that contain certain kinds of defective genomes. Cells of other rodent species, however, can be transformed by polyoma virus particles that contain complete genomes (Folk, W., *J. Virol.*, 11, 424-431, 1973). The virus does not replicate to a significant extent in human cells in tissue culture (Eddy, B. E., *Virol. Monogr.*, 7, 1-114, 1969; Pollack, R. E., Salas, J., Wang, R., Kusano, T., and Green, H., *J. Cell Physiol.* 77, 117-120, 1971). The resistance of the cells seems to be a consequence of the failure of the virus to absorb or uncoat. However even when naked viral DNA is introduced into the cells only an abortive cycle of replication ensues; early viral proteins are made, there is induction of cellular DNA synthesis, but no expression of late viral proteins is detectable (Gruen, R., Grassmann, M., and Grassmann, A., *Virology*, 58, 290-293, 1974).

There is no evidence that polyoma virus can infect humans (Hartley, J., Huebner, R., Parker, J., and Rowe, W. P., unpublished data). Thus no antibodies to the virus have been detected in people living in buildings that are infested with virus-infected mice, nor in laboratory workers who have been exposed to the virus for a number of years.

At most, a small segment of polyoma virus DNA shows weak homology with a portion of the late region of SV40 DNA (Ferguson, J., and Davis, R. W., *J. Biol. Biol.*, 94, 135-150, 1975). However, there appears to be no genetic interaction between the two viruses and there is no immunological cross-reaction between the gene products of the two viruses.

SV40 causes persistent but apparently harmless infections of the kidneys of virtually all adult rhesus monkeys (Hsiung, G. D., *Bact. Revs.* 32, 185-205, 1968). It causes tumors when injected into newborn hamsters (Girardi, A. J., Sweet, B. H., Slotnick, V. B., and Hilleman, M. R., *Proc. Soc. Exp. Biol. Med.*, 105, 420-427, 1964) and transforms cells of several mammalian species (including human). SV40 is able to infect human since antibodies to the virus are found in a small proportion of the human population (Shah, K. V., Goverdhan, M. K., and Ozer, H. L., *Am. J. Epid.* 93, 291-298, 1970) and serum conversions have been noted in many laboratory personnel who have been exposed to the virus (Horvath, L. B., *Acta Microbiol. Acta Sci. Hung.* 12, 201-206, 1965).

Isolations of SV40 have been reported from humans, twice from patients suffering from the rare demyelinating disease, progressive multifocal leukoencephalopathy (Weiner, L., Herndon, R., Narayan, O., Johnson, R. T.,

Shah, K., Rubinstein, L. G., Preziosi, T. J., and Conley, F. K., *New England J. Med.* 286, 385-390, 1972) and apparently from a tumor of a person with metastatic melanoma (Sorianno, F., Shelburne, C. E., and Gokcen, M., *Nature*, 249, 421-424, 1974). In other studies a non-structural antigen characteristic of papovaviruses, T antigen, has been detected in the nuclei of cells cultured from 2 meningiomas, while another SV40-specific antigen, U antigen, has been found in the cells of a third tumor of the same type (Weiss, A. F., Portman, R., Fisher, H., Simon, J., and Zang, K. D., *Proc. Nat. Acad. Sci. USA* 72, 609-613, 1975). Furthermore new papovaviruses have been isolated from the brains of patients with PML (JC virus—Padgett, B. L., Walker, D. L., zur Rhein, G. M., Eckroade, R. I., and Dessel, B. H., *Lancet* 1, 1257-1260, 1971), from the urine of a patient carrying a renal allograft (BK virus—Gardner, S. D., Field, A. M., Coleman, D. V., and Hulme, B., *Lancet* 1, 1253-1257, 1971) and from a reticulum cell sarcoma and the urine of patients with the sex-linked recessive disorder, Wiscott-Aldrich syndrome (Takemoto, K. K., Rabson, A. S., Mullarkey, M. F., Blaese, R. M., Garon, C. F., and Nelson, D. J., *Nat. Cancer Inst.*, 53, 1205-1207, 1974). All of these viruses which are distributed widely throughout human populations share antigenic and biological properties with SV40; the virus particles are identical in size and architecture (Madeley, C. R., *In Virus Morphology*, Churchill-Livingstone, London, 134-135, 1972); the non-structural intracellular T antigen, which appears to be coded by the A gene of SV40 cross reacts extensively with antigens found in cells infected or transformed by BK or JC viruses; both JC or BK viruses induce tumors in newborn hamsters (Walter, D. L., Padgett, B. L., zur Rhein, B. M., Albert, A. E., and Marsh, R. F., *Science* 181, 674-676, 1973; Shah, K. V., Daniel, R. W., and Strandberg, J., *J. Nat. Cancer Inst.* 54, 945-950, 1975); BK virus causes transformation of hamster cells in culture (Major, E. D., and DiMayorca, G., *Proc. Nat. Acad. Sci. US*, 70, 3210-3212, 1973; Portolani, M., Barbanti, A., Brodano, G., and LaPlaca, M. J., *Virol.* 15, 420-422, 1975) and is able to complement the growth of certain temperature-sensitive mutants of SV40 (Mason, D. H. and Takemoto, K. K., submitted for publication).

FURTHER WORK

At present, a potential eukaryotic vector of choice is polyoma virus. And while available information indicates that it fulfills all the necessary criteria, we recommend that the following subjects be further investigated:

1. The molecular mechanism of resistance of human cells to the virus.
2. The extent of homology between polyoma virus DNA and the DNAs of human papovaviruses.
3. The ability of human papovaviruses to complement defective polyoma virus genomes.

Report of a working group consisting of: Dr. Bernard Fields, Harvard University School of Medicine; Dr. Thomas J. Kelly, Jr., Johns Hopkins University School of Medicine; Dr. Andrew Lewis, National Institute of Allergy and Infectious Diseases; Dr. Malcolm Martin, National Institute of Allergy and Infectious Diseases; Dr. Robert Martin, National Institute of Arthritis, Metabolism, and Digestive Diseases; Dr. Elmer Pfefferkorn, Dartmouth Medical School; Dr. Wallace P. Rowe, National Institute of Allergy and Infectious Diseases; Dr. Aaron Shatkin, Roche Institute of Molecular Biology; Dr. Maxine Singer, National Cancer Institute. Rapporteur: Dr. Joe Sambrook, Cold Spring Harbor Laboratory.

APPENDIX C.—SUMMARY OF THE WORKSHOP ON THE DESIGN AND TESTING OF SAFER PROKARYOTIC VEHICLES AND BACTERIAL HOSTS FOR RESEARCH ON RECOMBINANT DNA MOLECULES

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The development of techniques for the cloning of DNA from both prokaryotic and eukaryotic organisms in bacteria has had great impact on research in biology and medicine and promises extraordinary social benefits. The biohazards involved in the use of this technology in many instances are very difficult to assess. For this reason codes of practice are being formulated in the United States and other countries for the conduct of those experiments that present a potential biohazard. One of the requirements for conducting certain cloning experiments is the use of safer vector (bacteriophage or plasmid) -host systems, i.e., vector-bacterium systems that have restricted capacity to survive outside of controlled conditions in the laboratory. Approximately sixty scientists from the United States and several foreign countries participated in a workshop on the Design and Testing of Safer Prokaryotic Vehicles and Bacterial Hosts for Research on Recombinant DNA Molecules at La Jolla, California, on 1 to 3 December, 1975. The workshop was sponsored by the Research Resources Branch of the National Institute of Allergy and Infectious Diseases. The purposes of the meeting were the exchange of recent data on the development of safer prokaryotic host-vector systems, devising methods of testing the level of containment provided by these systems and exploring the various directions that future research should take in the construction of safer bacterial systems for the cloning of foreign DNA.

The first session of the workshop, chaired by W. Szybalski (University of Wisconsin), was devoted to bacteriophage vectors. Szybalski outlined the main safety features of the two-component, phage-bacterial system, in which the host bacteria offer the safety feature of not carrying the cloned DNA, and the phage vectors cannot be propagated in the absence of an appropriate host. There are two primary escape routes for the clones of foreign DNA carried by the phage vector: (1) establishment of a stable prophage or plasmid in the laboratory host used for phage propagation, and subsequent escape of this self replicating lysogen or carrier system, and (2) escape of the phage vector which carries the cloned DNA and its subsequent productive encounter with a suitable host in the natural environment. The general consensus was that to ensure safety, both routes should be blocked by appropriate genetic modifications. For phage λ , route (1) can be blocked by phage mutations that interfere with lysogenization (*att*-, *int*-, *cI*-, *cIII*-, *vir*) and plasmid formation (*N*-, *ninR*-, *vS*, *ri*-, *cI7*, *Ots*, *cro*), and by mutations on the *Escherichia coli* host that affect these processes (*attB*-, *dncA*ts) and host survival. Route (2), [which is of low probability since λ phages do not survive well in natural environments (no λ phage was recovered after ingestion of 10^8 - 10^{11} particles), are killed by desiccation, and have a low chance to encounter a naturally sensitive host] can be blocked further by the following phage modifications: (a) mutations which result in extreme instability of the infectious phage particles under all conditions other than those specially designed for phage propagation in the laboratory (e.g., high concentrations of putrescine or some other compound), or (b) employing phage vectors in which the tail genes are deleted and which permit propagation of only the DNA-packed heads; only under laboratory conditions could such heads be made transiently infec-

tious by rejoining them with separately prepared tails. The high instability of the phage would minimize the possibility of transfer of the cloned genes into receptive bacteria found in nature. Moreover, the propagation of the phage can be blocked by many conditional mutations, which would be designed to block any secondary route of escape, mainly depending on transfer of the cloned DNA into another phage or bacterial host. It was recommended further that the vector be designed in such a manner as to permit easy insertion and monitoring of the foreign DNA and rapid assay of the safety features and give a high yield of cloned DNA (not less than 10^{11} molecules per ml). There also was general agreement that host-phage systems other than *E. coli* should be considered, especially those restricted to very rare and unusual environments. Also, plasmids derived from phage vectors and which give very high DNA yields while exhibiting safety features, e.g., λ dvcrts, should be considered as vehicles for cloned DNA.

Szybalski and S. Brenner (Cambridge University) stressed that research on recombinant DNA molecules may lend itself to very simple and inexpensive mechanical containment, e.g., a small sealed glove box, since all the vectors that carry such recombinant molecules possibly can be both created and destroyed in such a box, while development of special methods might permit study of many properties of the recombinant DNA, without ever removing it from the box.

These safety features were reflected in the subsequent presentations. F. Blattner and W. Williams (University of Wisconsin) described four specially constructed λ - ϕ 80 phages which incorporate many of these safety features, and which they named Charon phages, for the mythical boatman of the river Styx. Some of these highly contained phages give yields of over 10^{11} particles/ml. R. Davis, J. Cameron and K. Struhl (Stanford University) found that λ phages that carry foreign DNA never grow as well as the parental vector, which would select against their survival in nature. They also reported that some eukaryotic genes could be expressed in *E. coli*, partially compensating for deficiencies in the histidine pathway or in *polA* or *Hg* functions. These investigators surveyed over 1000 strains of *E. coli* isolated in the natural environment and did not find a single strain that could support propagation of the λ vir vector.

V. Bode (Kansas State University) discussed the possibility of growing tail-free λ heads. Such heads, which are packed with DNA, are very fragile, unless stored in 0.01 M putrescine buffer. Head yields close to 10^{11} /ml could easily be attained and, when required, heads could be quantitatively re-joined with separately supplied tails under special laboratory conditions. W. Arber, D. Scandella and J. Elliott (University of Basel) described bacterial host mutants that permit efficient infection only by phages with a full complement of DNA. This permits selecting for vectors that carry long fragments of foreign DNA.

K. Matsubara, T. Mukai and Y. Takagi (University of Osaka and Kyushu University), and G. Hobom and P. Philippson (University of Freiburg and Stanford University) described various defective λ plasmids (λ dv) that could be used as efficient vectors. Matsubara has shown that temperature-sensitive *cro* mutations permit obtaining between 1000 and 3000 cloned molecules per cell and at the same time result in killing of the carrier cells at body temperature. The mutations *Ots* and *Pts* were also evaluated as safety features. Philippson described many new λ dv plasmids created by cutting λ DNA with *HindIII* and *BamI* restriction endonucleases followed by ligation. The final talk

by F. Young, G. Wilson and M. Williams (University of Rochester) summarized the progress on the development of safer *Bacillus subtilis* host mutants and phages, especially ϕ 3, as vectors. New restriction nucleases, *Bgl*-1 and *Bgl*-2, were also described.

The morning session on bacteriophage vectors was followed by a session on plasmid vectors that was chaired by D. Helinski (University of California, San Diego). Helinski presented the following properties as highly desirable characteristics of a safer plasmid vehicle: (a) non-conjugative; (b) non-mobilizable or poorly mobilizable by a conjugative plasmid; (c) possesses little or no extraneous genetic information; (d) poorly recombines or does not recombine with the chromosome of the host cell; (e) provides no selective advantage to the host cell or the selective property is conditional; and (f) possesses mutations that restrict its maintenance to a specific host, prevent replication at mammalian body temperature and/or provide the plasmid with the capability of killing any cell to which it might be transmitted other than the host cell. V. Hersfield (University of California, San Diego) described the properties of a variety of derivatives of the ColEI plasmid and the broad-host range, P-type plasmid, RK2. One of the ColEI derivatives, ColEI-*trp*, constructed in collaboration with C. Yanofsky and N. Franklin (Stanford University) provides the means to use the tryptophan genes of *E. coli* as a selective marker in transformation with recombinant DNA in situations where it is desirable to avoid antibiotic resistance genes. In addition, Hersfield described collaborative work with H. Boyer that resulted in the development of a mini-ColEI plasmid and derivatives of this plasmid (mini-ColEI-*kan* and mini-ColEI-*trp*) as cloning vehicles. Finally, she described the temperature-sensitivity properties of *trp* and *kan* derivatives of a temperature sensitive replication mutant of ColEI isolated by J. Collins (Molecular biology Institute, Stockholm) and hybrid ColEI plasmids carrying the *EcoRI* generated *Ots* fragment of bacteriophage λ -*trp*81.

J. Carbon (University of California, Santa Barbara) described a replica plating method that greatly facilitates the detection of *E. coli* clones bearing ColEI plasmids. The procedure, which utilizes the *F'* plasmid to promote the transfer of a hybrid ColEI plasmid to a suitable auxotrophic recipient, was successful in identifying clones bearing hybrid plasmids carrying a number of different regions of the *E. coli* chromosome. The contributions of A. J. Clark and collaborators (University of California, Berkeley) were relevant to the problem of the mobilization and subsequent transfer of non-conjugative plasmids carrying foreign DNA of a potentially hazardous nature. Clark described the variations in transmission frequencies between the nonconjugative plasmids pSC101, pML31, pSC138 and a number of pSC101 hybrids containing various *EcoRI* fragments of *F* when the conjugal transfer of these plasmids was promoted by several different conjugative plasmids.

I. C. Gunsalus and collaborators (University of Illinois) and A. Chakrabarty (General Electric Research and Development Center) described the properties of a variety of plasmids isolated from *Pseudomonas putida*. These contributions were followed by a discussion on the merits of developing plasmid-host systems involving *Pseudomonas* strains that naturally exhibit unusual growth requirements. Similar studies with plasmids isolated from *Bacillus megaterium* by B. Carlton (University of Georgia) from *B. subtilis* by P. Lovett (University of Maryland) and other naturally occurring *Bacillus* species by W. Goebel and K. Bernhard (Mi-

crobiology Institute, Wurzberg) were discussed and their further development as plasmid-host cloning systems was explored. It was clear from these presentations that considerable progress has been made recently in the identification and characterization of a variety of plasmid elements that occur naturally in *Pseudomonas* and *Bacillus* species. Several of the plasmids described show considerable promise as plasmid cloning systems involving a host other than *E. coli*.

A third session on the ecology and epidemiology of vector-host systems was chaired by S. Falkow (University of Washington). This workshop emerged, in part, from expressed fears that microorganisms containing cloned fragments of foreign DNA potentially pose a threat to health or disrupt the normal ecological chain in some manner. Consequently, this session was devoted to a review of currently available information on the ecology and epidemiology of *E. coli* and related bacterial species since it was recognized that *E. coli* K-12 would be the prokaryotic host most commonly employed in the cloning of DNA molecules in the immediate future. F. Orskov (Escherichia Reference Center, Copenhagen) reviewed the state of *E. coli* serotyping and what has been learned about the distribution of *E. coli* types in health and disease. Only certain *E. coli* types are generally recognized as good colonizers of the human gut and such strains come from a handful of the 160 well defined O (lipopolysaccharide) antigen types and invariably possess K (acidic polysaccharide capsule) antigens. Some serotypes apparently have become disseminated worldwide and possibly represent the proliferation of a bacterial clone because of, as yet unknown, selective pressures. In contrast, *E. coli* K-12 has no detectable O or K antigens and is considered to be rough. This may account, at least in part, for its demonstrable poor ability to colonize the human or animal gut. However, R. Freter (University of Michigan) point out that we still remain largely ignorant of the factors which control intestinal *E. coli* populations. Freter also noted that while adherence to the mucosal surface of the small intestine is important in the pathogenesis of *E. coli* diarrheal disease, the "normal" long-lasting symbiotic relationship between a mammalian host and bacterium is established in the cecum and colon. It is in these locations that factors come into play to determine whether an *E. coli* strain passing through the intestine will become successfully implanted or whether it will be quickly eliminated in the feces.

The factors controlling implantation include competition for substrates, inhibitors and the physiological state of the organism when it reaches the large bowel. For example, ingested *E. coli* previously grown under usual laboratory conditions fare poorly while cells of the same strain "pre-adapted" in Eh, pH, etc., often colonize well. Freter has developed a continuous flow culture model which may be useful in studying the mechanisms of implantation. Falkow reviewed the pathogenicity of *E. coli*. *E. coli* causes diarrheal disease either by direct invasion of the bowel epithelium or by elaboration of enterotoxin(s). While invasive *E. coli* appear to owe their pathogenicity to a constellation of at least five unlinked chromosomal gene clusters, toxigenic *E. coli* species generally owe their pathogenicity to the possession of two species, Ent and K. The introduction of Ent and K plasmids may be sufficient to convert a normal wild-type *E. coli* into a strain now capable of causing overt clinical disease. However, the introduction of these plasmids into *E. coli* K-12 sublines had no discernible effect on their ability to cause disease, although the K-12 strains could now better colonize calves. Despite the observation that

E. coli K-12 did not appear to offer a significant hazard as a potential enteric pathogen even when it possessed well-defined determinants of pathogenicity it was emphasized by Orskov, Freter and Falkow that *E. coli* K-12 strains carrying recombinant DNA molecules could still act as effective genetic donors *in vivo* and still posed a significant problem requiring control. E. Geldreich (U.S. Environmental Protection Agency, Cincinnati, Ohio) discussed the possible outcomes of the release of *E. coli* containing recombinant DNA molecules into the aquatic environment and concluded that total reliance cannot be placed on sewage treatment and the natural self-purification capacity of receiving waters to limit potential hazards. While these are realistic barriers to the dissemination of *E. coli* and associated fecal organisms via the water route, they are not infallible because of technological limitations, improper operational practices and system overloading. Finally, M. Starr (University of California, Davis) described the numerous genera of gram-negative bacteria found naturally occurring in the soil and on plants. He stated that most of these organisms do not appear to be a reasonable alternative to *E. coli* K-12 as a host for recombinant DNA molecules. Indeed, Starr pointed out that since genera as *Erwinia*, *Rhizobium* and *Agrobacterium* are known to conjugate with *E. coli*, the potential dissemination of recombinant DNA molecule includes a greater spectrum of microorganisms than just enteric species.

The fourth session of the workshop, chaired by R. Curtiss III (University of Alabama), was concerned with the construction of safer bacterial hosts for DNA cloning. The goals in constructing safer host strains enumerated at the beginning of the session included introduction of mutations that would: (a) preclude colonization in normal ecological niches; (b) preclude cell wall biosynthesis except in specially defined media; (c) cause degradation of genetic information in normal ecological niches; (d) cause vectors to be host-dependent; (e) minimize transmission of recombinant DNA to other strains in normal ecological niches; (f) increase usefulness for recombinant DNA molecule research; and (g) permit monitoring.

Most of the progress in developing safer hosts has been achieved with *E. coli* K-12, although F. Young described a *B. subtilis* strain with a deletion for sporulation genes which readily undergoes autolysis. The strain also has defects in genes for purine and TTP biosynthesis and a mutation conferring a D-alanine requirement can be introduced to cause cell wall biosynthesis to be defective. This strain may be defective in transformation, however, and therefore might be useful only with a phage vector which has yet to be developed and/or discovered.

A. I. Bukhari (Cold Spring Harbor Laboratory) described the use of the *dapD8* mutation in *E. coli* K-12 to block cell wall biosynthesis and another non-reverting mutation which causes sensitivity to bile salts and detergents. The *dapD8* allele is the most stable *dap* point mutation known, although it does revert at frequencies of 10^{-5} to 10^{-6} . The mutation conferring bile salts sensitivity was obtained after Mu-1 infection of an Hfr strain and, although exhibiting the theoretically useful properties of ease of DNA isolation and inability to survive in the intestinal tract, might be due to Mu insertion which would compromise its use for safe strain construction.

Curtiss reported on the work performed by him and his coworkers in constructing and testing numerous strains with different mutations. Survival of strains *in vivo* was tested by feeding rats 10^{10} cells in milk by stomach tube. *Δpur* mutations did not reduce strain titers in feces whereas *ΔthyA*; *ΔthyA drm*; and *ΔthyA dra* mutations gave 10^3 -fold, 10^4 -

fold and 10^5 -fold reductions, respectively, in strain titers in feces. Strains with *ΔthyA* mutations also exhibited thymineless death in *in vitro* tests. Since strains with the *dapD8* allele can revert to *Dap⁺* strains were constructed with both the *dapD8* and *ΔbioH-asd* mutations. These strains have not been observed to revert to *Dap⁺* but can survive passage through the rat intestine and in growth media lacking diaminopimelic acid but containing NaCl and 0.5% usable carbon sources. This survival was due to the production of the mucopolysaccharide, colanic acid, which permits many of the cells to grow and survive as spheroplasts. A *Δgal-chl^r* mutation (also deletes *lact*, *bio* and *uvrB* genes) was introduced which blocks colanic acid biosynthesis and leads to no detectable survivors in media lacking diaminopimelic acid or following passage through the rat intestine. The *dapD8 ΔbioH-asd Δgal-chl^r* strains are more readily lysed, transform at higher frequencies and are conjugation-defective in matings with donors possessing conjugative plasmids in the P, W and O incompatibility groups but *Con⁺* as recipients for F, I and T group plasmids when compared to the *dap⁺ gal⁺* parent strain. Strains with *endA* mutations were also observed to exhibit increased transformation frequencies. Attempts to introduce temperature-sensitive *polA* alleles into strains to block replication of ColEI cloning vectors at elevated temperatures and to cause DNA degradation at elevated temperatures in the presence of *recA* and *ΔthyA* alleles often do not have the same properties in the constructed strains as in the strains in which the allele was originally induced. Many mutations causing a *Con⁻* phenotype have been investigated, but many of these revert or do not exhibit a *Con⁻* phenotype in matings with donors possessing conjugative plasmids of the incompatibility groups commonly found in enteric microorganisms. Some *Con⁻* mutants exhibit increased sensitivity to bile salts; thus, the mutant described by Bukhari may also exhibit a *Con⁻* phenotype. All of the strains constructed by the Curtiss group are *SuII^r* and most have mutations abolishing restriction alone or both restriction and modification. Thus, sufficient information is now known to construct a usable safer *E. coli* K-12 host. Curtiss and collaborators are now introducing the *ΔthyA* and *dna* mutations into their *dapD8 Δbio-asd Δgal-chl^r-uvrB hsr nalA^r* (for use in monitoring) *Su⁺ λ^r 480^r* strain to accomplish this objective.

The final session involved a general discussion of some of the major points raised previously in the workshop. There was general agreement at this session that both plasmid-host and phage-host systems have been developed that should meet the criteria of an EK2 system specified by the National Institutes of Health guidelines for research on recombinant DNA molecules. Additional testing is required to confirm the EK2 properties of these available systems, but it is anticipated that these vector-host systems will meet these tests.

Dr. Donald R. Helinski, University of California, San Diego.

Dr. Stanley Falkow, University of Washington.

Dr. Roy Curtiss III, University of Alabama.

Dr. Wacław Szybalski, University of Wisconsin.

APPENDIX D.—SUPPLEMENTARY INFORMATION ON PHYSICAL CONTAINMENT

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XII. Outline of a Safety and Operation Manual for a P4 Facility.

References.

I. BIOLOGICAL SAFETY CABINETS

Biological Safety Cabinets suitable for confining operations involving recombinant DNA molecules are described below:

1. *Class I.* A ventilated cabinet for personnel protection only, with an unrecirculated inward flow of air away from the operator. The exhaust air from this cabinet may be filtered through a high-efficiency or high-efficiency particulate air (HEPA) filter before being discharged to the outside atmosphere. This cabinet is suitable for research work with the Center for Disease Control (CDC) classes of etiologic agents 1, 2 and 3 where no product protection is required. This cabinet may be used in three operational modes: (i) with an eight-inch high, full-width open front; (ii) with an installed front closure panel (having four, eight-inch diameter openings) without gloves; and (iii) with an installed front closure panel equipped with arm length rubber gloves. See Table I for ventilation requirements, agent use limitations, and minimum performance requirements.

2. *Class II.* A ventilated cabinet for personnel and product protection having an

open front with inward air flow for personnel protection, and HEPA-filtered recirculated mass air flow for product protection. The cabinet exhaust air is filtered through a HEPA filter. Two models of this cabinet are available, Type 1 and Type 2.

(i) *Type 1.* The Type 1 recirculates approximately 70% of the air. The exhaust air from this cabinet may discharge into the laboratory or be diverted out of the laboratory. This cabinet is suitable for CDC classes of etiologic agents 1, 2, and 3. Vapors or gases which are hazardous from a toxic, radioactive, or flammability standpoint should not be used in this cabinet because of the high quantity of recirculated air.

(ii) *Type 2.* The Type 2 cabinet recirculates approximately 30% of the air. The exhaust air from this cabinet is normally ducted out of the laboratory through a HEPA filter and, occasionally, an activated charcoal filter depending on the operation. The cabinet may be used with gases or vapors that are hazardous from a toxic, radioactive, or flammability standpoint. However, any consideration of use of such materials should be evaluated carefully from

the standpoint of build-up to dangerous levels and problems of decontamination of the cabinet. See Table I for ventilation requirements, agent use limitations, and minimum performance requirements.

3. *Class III.* A closed front ventilated cabinet of gas-tight construction providing total protection for personnel and product from contaminants exterior to the cabinet. The cabinet is operated under a negative pressure of at least 0.5 inches water gauge. All supply air is HEPA-filtered. Exhaust air is HEPA-filtered or incinerated to protect the environment. This cabinet, fitted with arm length rubber gloves, provides the highest containment of these three classes of cabinets and is utilized for all activities involving high risk agents (i.e., CDC etiologic agents, class 4). See Table I for ventilation requirements, agent use limitations, and minimum performance requirements.

The integrity of any cabinet depends on initial and periodic evaluation to meet established performance tests. Table I outlines the minimum performance required to assure that the cabinets will provide protection of personnel and the environment.

TABLE I.—Biological safety cabinets, safety performance requirements, and specifications, June 1976

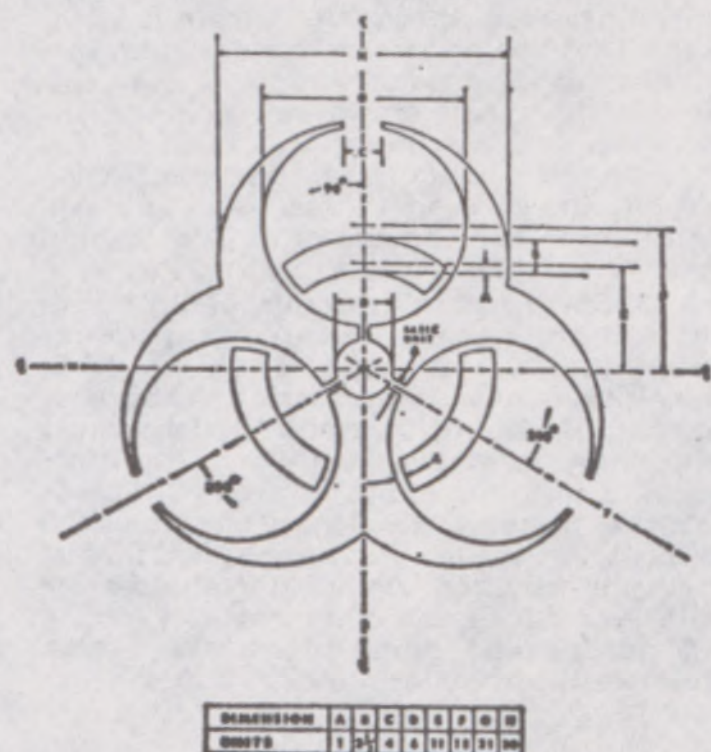
Cabinet	Use classification	Performance requirements					Exhaust filter efficiency (percent)
		Face velocity (linear feet per minute)	Exhaust air (cubic feet per minute)		Leak tightness		
			4-ft hood	6-ft hood			
Class I.....	P1-P3	1-3	75	200	300	Not applicable.....	99.97
Class II, type 1....	P1-P3	1-3	75	260	400	Gas tight; leak rate <1 by 10 ⁻³ cm ³ /s 2-in water gage pressure.	99.97
Class II, type 2....	P1-P3	1-3	100	250	360	Pressure tight; no air/soap bubble at 2-in water gage pressure.	99.97
Class III.....	P4	4	(³)	(⁴)	(⁴)	Gas tight; leak rate <1 by 10 ⁻³ cm ³ /s at 3-in water gage pressure.	99.97

¹ For work with recombinant DNA molecules.
² Center for Disease Control (U.S. Public Health Service).
³ Not applicable.
⁴ Based on 1 vol. of air change each 3 min, in the absence of unusual heat or moisture that would require more air changes.

II. UNIVERSAL BIOHAZARD WARNING SYMBOL (1)

The biological hazard warning symbol (biohazard symbol) specified herein shall be used to signify the actual or potential presence of a biohazard and to identify equipment, containers, rooms, materials, experimental animals or combinations thereof which contain or are contaminated with viable hazardous agents.

The biohazard symbol shall be designed and proportioned as illustrated here:



The symbol shall be as prominent as practical, and of a size consistent with the size of the equipment or material to which it is affixed, provided the proportions shown above are maintained, and, in any case, that the symbol can be easily seen from as many directions as possible.

Except when circumstances do not permit, the symbol shall be oriented with one of the three open circles pointed up and the other two forming a base.

The symbol color shall be a fluorescent orange or orange-red color.* Background color is optional as long as there is sufficient contrast for the symbol to be clearly defined.



Revised 9-9-66
 *May-Glo® Fire Orange of the Switzer Brothers, Inc. is cited as an example, not an endorsement.

The biohazard symbol shall be used or displayed only to signify the actual or potential presence of biological hazard.

Appropriate wording may be used in association with the symbol to indicate the nature or identity of the hazard, name of individual responsible for its control, precautionary information, etc., but never should this information be superimposed on the symbol.



ADMITTANCE TO AUTHORIZED PERSONNEL ONLY

Hazard identity: _____
 Responsible investigator: _____
 In case of emergency call:
 Daytime phone: _____ Home phone: _____
 Authorization for entrance must be obtained from the Responsible Investigator named above.

III. LABORATORY TECHNIQUES FOR BIOHAZARD CONTROL

A. Pipetting

1. No infectious or toxic materials should be pipetted by mouth (2, 3, 4).
2. No infectious mixtures should be prepared by bubbling expiratory air through a liquid with a pipette (2, 3, 4).
3. No infectious material should be blown out of pipettes (2, 3, 4).
4. Pipettes used for the pipetting of infectious or toxic materials should be plugged with cotton (2, 3, 4).
5. Contaminated pipettes should be placed horizontally in a pan containing enough suitable disinfectant to allow complete immersion (2, 4, 4). They should not be placed vertically in a cylinder.
6. The pan and pipettes should be autoclaved as a unit and replaced by a clean pan with fresh disinfectant (2, 3, 4).
7. Infectious material should not be mixed by alternate suction and expulsion through a pipette (2, 3, 4).
8. Mark-to-mark pipettes are preferable to other types, as they do not require expulsion of the last drop (5).
9. Discharge should be as close as possible to the fluid or agar level, or the contents should be allowed to run down the wall of the tube or bottle whenever possible—not dropped from a height (5).
10. A disinfectant-wetted towel over the immediate work surface is useful in some cases to minimize the splash from accidental droppage (9).

B. Syringes and Needles (9)

1. To lessen the chance of accidental infection, aerosol production or spills, avoid unnecessary use of the syringe and needle. For instance:
 - (i) Use the needle for parenteral injections but use a blunt needle or a cannula on the syringe for oral or intranasal inoculations.
 - (ii) Do not use a syringe and needle as a substitute for a pipette in making dilutions of dangerous fluids.
2. Use the syringe and needle in a Biological Safety Cabinet only and avoid quick and unnecessary movements of the hand holding the syringe.
3. Examine glass syringes for chips and cracks, and needles for barbs and plugs.

Note: This should be done prior to sterilization before use.

4. Use needle-locking (Luer-Lok® type) syringes only, and be sure that the needle is locked securely into the barrel. A disposable syringe-needle unit (where the needle is an integral part of the unit) is preferred.

5. Wear surgical or other type rubber gloves for all manipulations with needles and syringes.

6. Fill the syringe carefully to minimize air bubbles and frothing of the inoculum.

7. Expel excess air, liquid and bubbles from a syringe vertically into a cotton pledget moistened with the proper disinfectant, or into a small bottle of sterile cotton.

8. Do not use the syringe to expel forcefully a stream of infectious fluid into an open vial or tube for the purpose of mixing. Mixing with a syringe is condoned only if the tip of the needle is held below the surface of the fluid in the tube.

9. If syringes are filled from test tubes, take care not to contaminate the hub of the needle, as this may result in transfer of infectious material to the fingers.

10. When removing a syringe and needle from a rubber-stoppered bottle, wrap the needle and stopper in a cotton pledget moistened with the proper disinfectant. If there is danger of the disinfectant contaminating sensitive experiments, a sterile dry pledget may be used and discarded immediately into disinfectant solution.

11. Inoculate animals with the hand "behind" the needle to avoid punctures.

12. Be sure the animal is properly restrained prior to the inoculation, and be on the alert for any unexpected movements of the animal.

13. Before and after injection of an animal, swab the site of injection with a disinfectant.

14. Discard syringes into a pan of disinfectant without removing the needle. The syringe first may be filled with disinfectant by immersing the needle and slowly withdrawing the plunger, and finally removing the plunger and placing it separately into the disinfectant. The filling action clears the needle and dilutes the contents of the syringe. Autoclave syringes and needles in the pan of disinfectant.

15. Use separate pans of disinfectant for disposable and nondisposable syringes and needles to eliminate a sorting problem in the service area.

16. Do not discard syringes and needles into pans containing pipettes or other glassware that must be sorted out from the syringes and needles.

C. Opening Culture Plates, Tubes, Bottles, and Ampoules

1. Plates, tubes and bottles of fungi may release spores in large numbers when opened. Such cultures should be manipulated in a Biological Safety Cabinet (6, 15).

2. In the absence of definite accidents or obvious spillage, it is not certain that opening of plates, tubes and bottles of other microorganisms has caused laboratory infection. However, it is probable that among the highly infective agents, some infections have occurred by this means and are represented in the 80% for which no known act or accident is ascribable (3).

3. Water of syneresis in petri dish cultures is usually infected and forms a film between the rim and lid of the inverted plate. Aerosols are dispersed when this film is broken by opening the plate. Vented plastic petri dishes where the lid touches the rim at only three points are less likely to offer this hazard (8, 19).

4. The risk may also be minimized by using properly dried plates, but even these (when incubated anaerobically) are likely to be wet after removal from an anaerobic jar.

Filter papers fitted into the lids reduce, but do not prevent, dispersal. If plates are obviously wet they should be opened in the Biological Safety Cabinet (8).

5. Less obvious is the release of aerosols when screw-capped bottles or plugged tubes are opened. This happens when a film of infected liquid which may collect between the rim and the liner is broken during removal of the closure (8).

6. Dried, infected culture material may also collect at or near the rim or neck of culture tubes and may be dispersed into the air when disturbed (18). Containers of dry powdered hazardous materials (e.g., Class 3 fungal agents in the spore phase of growth) should be opened only in a Biological Safety Cabinet (6, 14).

7. When the neck of an ampoule containing liquid is broken after nicking with a file, the snapping action creates aerosols. The following methods have been recommended:

(i) After nicking the ampoule with a file, wrap the ampoule in disinfectant-wetted cotton before breaking. Wear gloves (2).

(ii) The bottom of the ampoule should be held in several layers of tissue paper to protect the hands, and a file mark made at the neck. A hot glass rod should be carefully applied to the mark. The glass will crack, allowing air to enter the ampoule and equalize the pressures. After a few seconds the ampoule should be wrapped in a few layers of tissue and broken along the crack. The tissues and ampoule neck can then be discarded into disinfectant, and the contents of the ampoule removed with a syringe. If the ampoule contains dried cultures, about 0.5 cm³ of broth should be added slowly to avoid blowing dried material out. The contents may then be mixed without bubbling and withdrawn into a culture tube (8).

(iii) The researcher uses an intense, but tiny, gas-oxygen flame and heats the tip of the hard glass ampoule until the expanding internal air pressure blows a bubble. After allowing this to cool, he breaks the bubble while holding it in a large low temperature flame; this immediately incinerates any infectious dust which may come from the ampoule when the glass is broken (16). Preliminary practice with a simulant ampoule of the same type actually in use is necessary to develop a technique that will not cause explosion of the ampoule.

(iv) A simple device has been recommended consisting of a sleeve of rubber tubing into which the ampoule is inserted before it is broken (17, 18).

D. Centrifuging

1. A safety centrifuge cabinet or safety centrifuge cup (3, 7, 8, 14, 22) may be used to house or safeguard all centrifuging of infectious substances. When bench type centrifuges are used in a Biological Safety Cabinet, the glove panel should be in place with the glove ports covered. The centrifuge operation creates air currents that may cause escape of agent from an open cabinet (2, 3, 4, 13).

2. In some situations, in the absence of O-ring cap sealed trunnion cups, specimens can be enclosed in sealed plastic bags before centrifugation (12).

3. Before centrifuging, inspect tubes for cracks, inspect the inside of the trunnion cup for rough walls caused by erosion or adhering matter, and carefully remove bits of glass from the rubber cushion (4, 10).

4. A germicidal solution should be added between the tube and trunnion cup to disinfect the materials in case of accidental breakage. This practice also provides an excellent cushion against shocks that might otherwise break the tube (4, 10).

5. Avoid decanting centrifuge tubes. If you must do so, afterwards wipe off the outer rim

with a disinfectant; otherwise the infectious fluid will spin off as an aerosol (4, 10).

6. Avoid filling the tube to the point that the rim, cap or cotton plug ever becomes wet with culture (4, 10).

7. Screw caps, or caps which fit over the rim outside the centrifuge tube are safer than plug-in closures. Some fluid usually collects between a plug-in closure and the rim of the tube. Even screw-capped bottles are not without risk, however; if the rim is soiled some fluid will escape down the outside of the tube. Screw-capped bottles may jam in the bucket, and removing them is hazardous. Propping such bottles higher in the bucket with additional rubber buffers is mechanically unsound (8).

8. Kitchen foil is often used to cap centrifuge tubes. This creates more risk than the screw cap. Foil caps often become detached in handling and centrifuging (8).

9. The balancing of buckets is often mismanaged. Care must be taken to ensure that matched sets of trunnions, buckets and plastic inserts do not become mixed. If the components are not inscribed with their weights by the manufacturer, colored stains can be applied to avoid confusion. When the tubes are balanced, the buckets, trunnions and inserts should be included in the procedure; and care must be taken to ensure that the centers of gravity of the tubes are equidistant from the axis of rotation. To illustrate the importance of this, two identical tubes containing 20 g of mercury and 20 g of water respectively will balance perfectly on the scales; but their performance in motion is totally different, leading to violent vibration with all its attendant hazards (5).

10. Fill and open centrifuge tubes or trunnion cups in a Biological Safety Cabinet (10).

E. High-Speed Centrifuges (22)

1. In high-speed centrifuges the bowl is connected to a vacuum pump. If there is a breakage or accidental dispersion of infected particles the pump and the oil in it will become contaminated. A high efficiency filter should be placed between the centrifuge and the pump (8).

2. High speed rotor heads are prone to metal fatigue, and where there is a chance that they may be used on more than one machine each rotor should be accompanied by its own log book indicating the number of hours run at top or de-rated speeds. Failure to observe this precaution can result in dangerous and expensive disintegration. Frequent inspection, cleaning and drying are important to ensure absence of corrosion or other traumata which may lead to creeping cracks. Rubber O-rings and tube closures must be examined for deterioration and be kept lubricated with the material recommended by the makers. Where tubes of different materials are provided (e.g., celluloid, polypropylene, stainless steel), care must be taken that the tube closures designed specifically for the type of tube in use are employed. These caps are often similar in appearance, but are prone to leakage if applied to tubes of the wrong material. When properly designed tubes and rotors are well maintained and handled, leaking should never occur (5).

3. Cleaning and disinfection of tubes, rotors and other components requires considerable care. It is unfortunate that no single process is suitable for all items, and the various manufacturers' recommendations must be followed meticulously if fatigue, distortion and corrosion are to be avoided. This is not the place to catalogue recommended methods, but one less well appreciated fact is worthy of mention. Celluloid (cellulose nitrate) centrifuge tubes are not only highly inflammable and prone to shrinkage with age and distortion on boiling, but can be

have as high explosive in an autoclave (5). Large-scale zonal centrifugation requires special attention (11).

F. Blenders, Ultrasonic Disintegrators, Colloid Mills, Ball Mills, Jet Mills, Grinders, Mortar and Pestle.

All these devices release considerable aerosols during their operation. For maximum protection to the operator during the blending of infectious materials, the following practices should be observed:

1. Operate blending and cell-disruption and grinding equipment in a Biological Safety Cabinet (9).

2. Use safety blenders designed to prevent leakage from the rotor bearing at the bottom of the bowl (9).

3. In the absence of a leak-proof rotor, inspect the rotor bearing at the bottom of the blender bowl for leakage prior to operation. Test it in a preliminary run with sterile saline or methylene blue solution prior to use with infected material (9).

4. Sterilize the device and residual infectious contents promptly after use. Use a towel moistened with disinfectant over the top of the blender (9).

5. Glass blender bowls are undesirable for use with infectious material because of potential breakage. If used, they should be covered with a polypropylene jar to prevent dispersal of glass (8).

6. A new machine, the Colworth Stomacher (England), in which material is homogenized in a plastic bag in a closed container, would appear to be safer than some of the other blenders (8).

7. A heat-sealed flexible plastic film enclosure for a grinder or blender can be used, but it must be opened in a Biological Safety Cabinet (7).

8. Blender bowls sometimes require supplemental cooling to prevent destruction of the bearings and to minimize thermal efforts on the product (7).

9. Before opening the safety blender bowl, permit the blender to rest for at least one minute to allow settling of the aerosol cloud.

10. Clinical or other laboratories handling human blood should be aware of the aerosols produced by the microhaematocrit centrifuge, the autoanalyzer stirrer, and the microtonometer, inasmuch as it seems that airborne transmission of infectious hepatitis may occur in the laboratory (20).

G. Miscellaneous Precautions and Recommendations

1. Water baths and Warburg baths used to inactivate, incubate, or test infectious substances should contain a disinfectant. For cold water baths, 70% propylene glycol is recommended (4, 10).

2. Deepfreeze, liquid nitrogen, and dry ice chests and refrigerators should be checked and cleaned out periodically to remove any broken ampoules, tubes, etc., containing infectious material, and decontaminated. Use rubber gloves and respiratory protection during this cleaning. All infectious or toxic material stored in refrigerators or deepfreezes should be properly labelled. Security measures should be commensurate with the hazards (4, 10, 21).

3. Freeze-dried culture ampoules should always be opened in a Biological Safety Cabinet. The ampoule should be wrapped in a disinfectant-soaked swab before breaking it open to minimize the risk of cutting the hands, and to a lesser extent of releasing aerosol of dried material. Whenever possible, ampoules should be filled with dry nitrogen after freeze-drying, thus avoiding implosion that may occur during the sealing as well as opening of evacuated ampoules. The whole process of freeze-drying itself should be per-

formed in a Biological Safety Cabinet. Filtration of the effluent air from the vacuum pump is desirable either up (preferably), or down stream of the pump (5).

4. Ensure that all virulent fluid cultures or viable powdered infectious materials in glass vessels are transported, incubated, and stored in easily handled, nonbreakable leak-proof containers that are large enough to contain all the fluid or powder in case of leakage or breakage of the glass vessel (4, 10).

5. All inoculated petri plates or other inoculated solid media should be transported and incubated in leak-proof pans or leak-proof containers (4, 10).

6. Care must be exercised in the use of membrane filters to obtain sterile filtrates of infectious materials. Because of the fragility of the membrane and other factors, such filtrates cannot be handled as noninfectious until culture or other tests have proved their sterility (4, 10).

7. Shaking machines should be examined carefully for potential breakage of flasks or other containers being shaken. Screw capped durable plastic or heavy walled glass flasks should be used. These should be securely fastened to the shaker platform. An additional precaution would be to enclose the flask in a plastic bag with or without an absorbent material.

8. No person should work alone on an extremely hazardous operation (4, 10).

IV. PERSONAL HYGIENE, HABITS, AND PRACTICES

Personal hygienic practices in the laboratory are directed, in most part, toward the prevention of occupationally acquired physical injury or disease. To a less obvious extent, they can raise the quality of the laboratory work by reducing the possibilities for contamination of experimental materials. The reasons for many of the recommended precautions and practices are obvious, but, in some instances, amplification will permit a better review of the applicability to any one specific laboratory.

Consequently, what might be forbidden in one laboratory might be only discouraged in another, and be permissible in a third. Nevertheless, adherence to safe practices that become habitual, even when seemingly not essential, provides a margin of safety in situations where the hazard is unrecognized. The history of occupational injury is replete with examples of hazards unrecognized until too late. The following guidelines, recommendations, and comments are presented with this in mind:

1. Food, candy, gum, and beverages for human consumption will be stored and consumed only outside the laboratory (5, 10).

2. Foot-operated drinking fountains should be the sole source of water for drinking by human occupants of the laboratory (27).

3. Smoking is not permitted in the laboratory or animal quarters. Cigarettes, pipes, and tobacco will be kept only in clean areas (5, 10, 26).

4. Shaving and brushing of teeth are not permitted in the laboratory. Razors, toothbrushes, toiletry supplies, and cosmetics are permissible only in clean change rooms or other clean areas, and should never be used until after showering or thorough washing of the face and hands (27).

5. A beard may be undesirable in the laboratory in the presence of actual or potential airborne contamination, because it retains particulate contamination more persistently than clean-shaven skin. A clean-shaven face is essential to the adequate facial fit of a face mask or respirator when the work requires respiratory protection (10, 27, 31).

6. Develop the habit of keeping hands away from mouth, nose, eyes, face, and hair. This may prevent self-inoculation (10, 27).

7. For product protection, persons with long hair should wear a suitable hair net or head cover that can be decontaminated. This has long been a requirements in hospital operating rooms and in the manufacture of biological pharmaceutical products. A head cover also will protect the hair from fluid splashes, from swinging into Bunsen flames and petri dishes, and will reduce facial contamination caused by habitual repetitive manual adjustment of the hair (5).

8. Long-flowing hair and loose-flapping clothing are dangerous in the presence of open flame or moving machinery. Rings and wrist watches also are a mechanical hazard during operation of some types of machines (5, 10).

9. Contact lenses do not provide eye protection. The capillary space between the contact lenses and the cornea may trap any material present on the surface of the eye. Caustic chemicals trapped in this space cannot be washed off the surface of the cornea. If the material in the eye is painful or the contact lens is displaced, muscle spasms will make it very difficult, if not impossible, to remove the lens. For this reason, contact lenses must not be worn by persons exposed to caustic chemicals unless safety glasses with side shields, goggles, or plastic face masks are also worn to provide full protection. It is the responsibility of supervisors to identify employees who wear contact lenses (25, 26).

10. Personal items, such as coats, hats, storm rubbers or overshoes, umbrellas, purses, etc., do not belong in the laboratory. These articles should be kept elsewhere (25).

11. Plants, cut flowers, an aquarium, and pets of any kind are undesirable sources of yeast, molds, and other potential microbial contaminants of biological experimental materials (25).

12. Books and journals returnable to the institutional library should be used only in the clean areas as much as possible (10, 27).

13. When change rooms with showers are provided, the employer should furnish skin lotion (27).

14. When employees are subject to potential occupational infection, the shower and/or face/hand-washing facilities should be provided with germicidal soap (8, 27).

15. Personal cloth handkerchiefs should not be used in the laboratory. Cleansing tissue should be available instead.

16. Hand washing for personal protection:

(i) This should be done promptly after removing protective gloves. Tests show it is not unusual for microbial or chemical contamination to be present despite use of gloves, due to unrecognized small holes, abrasions, tears, or entry at the wrist.

(ii) Throughout the day, at intervals dictated by the nature of the work, the hands should be washed. Presence of a wrist watch discourages adequate washing of the wrist (10, 25).

(iii) Hands should be washed after removing soiled protective clothing, before leaving laboratory area, before eating, and before smoking. The provision of hand cream by the employer encourages these practices (5, 8, 10).

(iv) A disinfectant wash or dip may be desirable in some cases, but its use must not be carried to the point of causing roughening, desiccation or sensitization of the skin.

17. Anyone with a fresh or healing cut, abrasion, or skin lesion should not work with infective material unless the injured area is completely protected (8, 25).

18. Persons vaccinated for smallpox may be shedders of vaccinia virus during the phase of cutaneous reaction. Therefore, vaccination requires permission of the appropriate supervisor, because two weeks' absence may be necessary before returning to work with

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normal cell cultures or with susceptible animals, especially the normal mouse colony (25).

19. The surgeon's mask of gauze or filter paper is of little value for personal respiratory protection (29). It is designed to prevent escape of droplets from the nose or mouth (23G). If biohazards demand respiratory protection, then nothing but a full face respirator or ventilated hood will suffice. A half-mask respirator does not protect the eyes, which are an unevaluated avenue of infection through the conjunctiva and the nasolacrimal duct (5, 8).

20. Nonspecific contamination by environmental organisms from humans, animals, equipment, containers for specimens or supplies, and outside air is a complication that may affect or invalidate the results of an experiment. The human sources of this contamination are evaluated as follows:

(i) Sneezing, coughing and talking (23A, 24A). Sneezing, variously reported to generate as many 32,000 or 1,000,000 droplets below 100 microns in diameter; coughing, which produces fewer and larger droplets; and talking, which has been reported to average only 250 droplets when speaking 100 words, show great differences between persons in regard to the number of microorganisms aerosolized. As a general rule, it may be said that these actions by normal healthy persons may play a less important role in transmission or airborne infection to humans or experimental materials than does liberation of microorganisms from human skin.

(ii) Dispersal of bacteria from human skin. There is a tremendous variation in the number of bacteria shed from the skin by a clothed subject. For instance, in one study, the number varied from 6,000 to 60,000 per minute (23C). These bacteria were released on skin scales which were of a size that could penetrate the coarse fabric used for the laboratory and surgical clothing in the test (23D). Dispersal of skin bacteria was several times greater from below the waist than from upper parts of the body (24D). Effective reduction is accomplished by use of closely-woven or impervious clothing fitted tightly at the neck, wrists, and ankles to prevent the clothing from acting as a bellows that disperses air carrying skin scales laden with bacteria (23B). Such clothing sometimes is too warm to work in. It was found that a significant reduction in dispersal of bacteria occurred with the wearing of close-fitting and closely-woven underpants beneath the usual laboratory clothing (23D). The purpose of this summary is to alert laboratory personnel to the existence of this source of contamination (9).

(iii) Prolific dispersal of bacteria occurs from infected abrasions, small pustules, boils, and skin disease (23F, 24B). Washing the lesions with germicidal soap will greatly decrease the number of organisms on the skin and dispersal into the air. Healthy nasal carriers who generate aerosolized staphylococci usually can be identified by the presence of heavy contamination of their fingers, face, and hair (23E). This point may be useful in investigating the source of staphylococcal contamination of cell lines.

(iv) Footwear. In moderate and high risk situations, shoes reserved for only laboratory use have been recommended as a precaution against transporting spilled infectious agents outside the laboratory. However, in experiments during which reduction of potential contamination of experimental materials is important, laboratory-only shoes can reduce the microbial load brought into the laboratory each day by street shoes. Shoes are efficient transporters. In one study, there were 4 to 850 times as many bacteria per square centimeter on the laboratory footwear as on the floor itself (30).

V. CARE AND USE OF LABORATORY ANIMALS (10,32-37)

A. Care and Handling

1. Special attention must be given to the humane treatment of all laboratory animals in accordance with the Animal Welfare Act of 1970. The implementing rules and regulations appear in the Code of Federal Regulations (CFR) Title 9, Chapter 1, Subchapter A, parts 1, 2, 3. Recommended provisions and practices that meet the requirements of the Act have been published by the U.S. Public Health Service (32).

2. There are specific minimum requirements (33) concerning the caging, feeding, watering, and sanitation for dogs, cats, guinea pigs, hamsters, rabbits, and non-human primates. To meet these requirements, the animal room supervisor must have a copy of 9 CFR Chapter 1, Subchapter A, Parts 1, 2, 3.

3. Each laboratory should establish procedures to ensure the use of animals that are free of disease prejudicial to the proposed experiments and free from carriers of disease or vectors, such as ectoparasites, which endanger other experimental animals or personnel (10).

B. Cages Housing Infected Animals (10)

1. Careful handling procedures should be employed to minimize the dissemination of dust from cage refuse and animals.

2. Cages should be sterilized by autoclaving. Refuse, bowls and watering devices should remain in the cage during sterilization.

3. All watering devices should be of the "non-drip" type.

4. Cages should be examined each morning and at each feeding time so that dead animals can be removed.

5. Heavy gloves should be worn when feeding, watering, handling, or removing infected animals. Bare hands should NEVER be placed in the cage to move any object therein.

6. When animals are to be injected with biohazardous material, the animal caretaker should wear protective gloves and the laboratory workers should wear surgeons gloves. Animals should be properly restrained to avoid accidents that might result in disseminating biohazardous material, as well as to prevent injury to the animal and to personnel.

7. Animals exposed to biohazardous aerosols should be housed in ventilated cages, in gas-tight cabinet systems, or in rooms designed for protection of personnel by use of ventilated suits.

8. Animals inoculated by means other than by aerosols should be housed in equipment suitable for the level of risk involved.

9. Infected animals to be transferred between buildings should be placed in ventilated cages or other aerosol-proof containers.

10. The oversize canine teeth of large monkeys present a particular biting hazard; these are important in the potential transmission of naturally-occurring, and very dangerous, monkey virus infections. Such teeth should be blunted or surgically removed by a veterinarian.

11. Presently available epidemiological evidence indicates that infectious hepatitis may be transmitted from nonhuman primates (typically chimpanzees) to man. Newly imported animals may be naturally infected with this disease, and persons in close contact with such animals may become infected. After six months residence in this country, chimpanzees apparently no longer transmit the disease. A record should be maintained for each newly imported animal. A sign should be posted at rooms housing these animals to warn that the animals are potentially infectious.

C. General Guidelines that Apply to Animal Room Maintenance (10)

1. Doors to animal rooms should be kept closed at all times except for necessary entrance and exit.

2. Unauthorized persons should not be permitted to enter animal rooms.

3. A container of disinfectant should be kept in each animal room for disinfecting gloves and hands, and for general decontamination, even though no infectious animals are present. Hands, floors, walls, and cage racks should be washed with an approved disinfectant at the recommended strength as frequently as the supervisor directs.

4. Floor drains in animal rooms, as well as floor drains throughout the building should be flooded with water or disinfectant periodically to prevent backup of sewer gases.

5. Shavings or other refuse on floors should not be washed down the floor drain because such refuse clogs the sewer lines.

6. An insect and rodent control program should be maintained in all animal rooms and in animal food storage areas.

7. Special care should be taken to prevent live animals, especially mice, from finding their way into disposable trash.

D. Necropsy Rules for Infected Animals (10)

1. Necropsy of infected animals should be carried out by trained personnel in Biological Safety Cabinets with the hinged glass panel down. The glove port panel with or without attached gloves, and a respirator should be used at the discretion of the supervisor.

2. Surgeons gowns should be worn over laboratory clothing during necropsies.

3. Rubber gloves should be worn when performing necropsies.

4. The fur of the animal should be wetted with a suitable disinfectant.

5. Small animals should be pinned down or fastened on wood or metal in a metal tray.

6. Upon completion of necropsy, all potentially biohazardous material should be placed in suitable containers and sterilized immediately.

7. Contaminated instruments should be placed in a horizontal bath containing a suitable disinfectant.

8. The inside of the Biological Safety Cabinets and other potentially contaminated surfaces should be disinfected with a suitable germicide.

9. Grossly contaminated rubber gloves should be cleaned in disinfectant before removal from the hands, preparatory to sterilization.

10. Dead animals should be placed in proper leak-proof containers, autoclaved and properly tagged before being placed outside for removal and incineration.

VI. DECONTAMINATION AND DISPOSAL (7, 10, 38-42)

A. Introduction

Available data on the efficacy of various decontaminants for etiologic agents indicate that no major surprises will be forthcoming regarding the susceptibility of organisms containing recombinant DNA molecules. In the absence of adequate information, tests to determine the efficacy of candidate decontaminants should be conducted with the specific agent of interest. The goal of decontamination is not only the protection of personnel and the environment from exposure to infectious agents, but also the prevention of contamination of experimental materials by a variable, persistent, and unwanted background of microorganisms. This additional factor should be considered in selecting decontamination materials and methods.

B. Decontamination Methods

Physical and chemical means of decontamination fall into four main categories: Heat; Liquid Decontaminants; Vapors and Gases; and UV Radiation.

1. *Heat.* The application of heat, either moist or dry, is recommended as the most effective method of sterilization. Steam at 121 C under pressure in the autoclave is the most convenient method of rapidly achieving sterility. Dry heat at 160 to 170 C for periods to 2 to 4 hours is suitable for destruction of viable agents on impermeable nonorganic material such as glass, but is not reliable in even shallow layers of organic or inorganic material that can act as insulation. Incineration is another use of heat in the decontamination of microorganisms and also serves as an efficient means for disposal.

2. *Liquid Decontaminants.* In general, the liquid decontaminants find their most practical use in surface decontamination and, at sufficient concentration, as decontaminants of liquid wastes for final disposal in sanitary sewer systems.

There are many misconceptions concerning the use of liquid decontaminants. This is due largely to a characteristic capacity of such liquids to perform dramatically in the test tube and to fail miserably in a practical situation. Such failures often occur because proper consideration was not given to such factors as temperature, time of contact, pH, concentration, and the presence and state of dispersion, penetrability and reactivity of organic material at the site of application. Small variations in the above factors may make large differences in effectiveness of decontamination. For this reason, even when used under highly favorable conditions, complete reliance should not be placed on liquid decontaminants when the end result must be sterility.

There are many liquid decontaminants available under a wide variety of trade names. In general, these can be categorized as halogens, acids or alkalies, heavy metal salts, quaternary ammonium compounds, phenolic compounds, aldehydes, ketones, alcohols and amines. Unfortunately, the more active the decontaminant the more likely it is that the decontaminant will possess undesirable characteristics, such as the possession of corrosive properties. None is equally useful or effective under all conditions.

3. *Vapors and Gases.* A variety of vapors and gases possess decontamination properties. The most useful of these are formaldehyde and ethylene oxide. When these can be employed in closed systems and under controlled conditions of temperature and humidity, excellent decontamination can result. Vapor and gas decontaminants are primarily useful in decontaminating: (i) Biological Safety Cabinets and associated effluent air-handling systems and air filters; (ii) bulky or stationary equipment that resists penetration by liquid surface decontaminants; (iii) instruments and optics that might be damaged by other decontamination methods; and (iv) rooms and buildings and associated air-handling systems.

4. *Radiation.* The usefulness of ultraviolet (UV) irradiation as a decontaminant is limited by its low penetrating power. No information is available regarding the effectiveness of UV irradiation for decontaminating microorganisms containing recombinant DNA molecules. Dependence on UV must be based on the results of experiments imitating particular anticipated environmental conditions and applications. Ultraviolet light is generally of limited application and is primarily useful in air locks and animal holding areas for controlling low levels of airborne contaminants.

No one procedure or material will solve all decontamination problems. The only

method of assuring the efficacy of selected methodologies is to critically examine the results obtained in practical tests with the microorganism(s) of interest.

C. Laboratory Spills

A troublesome problem that may occur in the laboratory is the decontamination of an overt biological spill. The occurrence of a spill poses less of a problem if it occurs in a Biological Safety Cabinet provided splattering to the outside of the cabinet does not occur. Direct application of concentrated liquid decontaminant and a thorough wipe down of the internal surfaces of such cabinetry will usually be effective for decontaminating the work zone but gaseous decontaminants would be required to rid the interior sections of the cabinet of contaminants. Each researcher must realize that in the event of an overt accident, research materials such as tissue cultures, media, and animals within such cabinets may well be lost to the experiment.

The greater problem arises if the incident occurs in the open laboratory. All laboratory protocols should be designed to prevent such occurrences. The first action in the event of an overt laboratory spill is evacuation of the affected area to minimize the exposure of personnel involved. Next, the spill area must be isolated to prevent exposure of personnel and experimental materials beyond those involved in the immediate area of the spill. The procedures adopted must be rapidly effective and must not create additional aerosol or foster mechanical transfer of materials to unaffected areas. Personnel carrying out the procedures must be provided with protective clothing and equipment, including respiratory protection. Consideration must be given to the safe disposal of all materials and liquids resulting from cleanup procedures. Reentry of personnel to the area should be avoided until it can be reasonably established that the area has been effectively decontaminated. Further specific details are provided in Section VIII.

D. Disposal

Decontamination and disposal in infectious disease laboratories are closely interrelated acts in which decontamination constitutes the introductory phase of disposal. All materials and equipment used in research on recombinant DNA molecules will ultimately be disposed of; however, in the sense of daily use, only a portion of these will require actual removal from the laboratory complex or on-site destruction. The remainder will be recycled for use either within the same laboratory or in other laboratories that may or may not engage in DNA recombinant research. Examples of the latter that immediately come to mind are: reusable laboratory glassware, instruments used in necropsy of infected animals, and laboratory clothing. Disposal should therefore be interpreted in the broadest sense of the word, rather than in the restrictive sense of dealing solely with a destructive process.

The principal questions to be answered prior to disposal of any objects or materials from laboratories dealing with potentially infectious microorganisms or animal tissues are:

1. Have the objects or materials been effectively decontaminated by an approved procedure?

2. If not, have the objects or materials been packaged in an approved manner for immediate on-site incineration or transfer to another laboratory?

3. Does disposal of the decontaminated objects or materials involve any additional potential hazards, biological or otherwise, to personnel either:

(i) Those carrying out the immediate disposal procedures or

(ii) Those who might come into contact with the objects or materials outside the laboratory complex?

Laboratory materials requiring disposal will normally occur as liquid, solid, and animal room wastes. The volume of these can become a major problem when there is the requirement that all wastes be decontaminated prior to disposal. It is most evident that a significant portion of this problem can be eliminated if the kinds of materials initially entering the laboratory are reduced. In any case, and wherever possible, materials not essential to the research should be retained in the nonresearch areas for disposal by conventional methods. Examples are the packaging materials in which goods are delivered, disposable carton-cages for transport of animals, and large carboys or tanks of fluids which can be left outside and drawn from as required. Reduction of this bulk will free autoclaves and other decontamination and disposal processes within the laboratory for the more rapid and efficient handling of materials known to be contaminated.

Inevitably, disposal of materials raises the question, "How can we be sure that the materials have been treated adequately to assure that their disposal does not constitute a hazard?" In the small laboratory, the problem is often solved by requiring that each investigator decontaminate all contaminated materials not of immediate use at the end of each day and place them in suitable containers for routine disposal. In larger laboratories where the mass of materials for disposal becomes much greater and sterilization and decontamination bottlenecks occur, materials handling and disposal will likely be the chore of personnel not engaged in the actual research. In either situation, a case can be made for establishing a positive method of designating the state of materials to be disposed of. This may consist of a tagging system stating that the materials are either sterile or contaminated.

Disposal of materials from the laboratory and animal holding areas will be required for research projects ranging in size from an individual researcher to those involving large numbers of researchers of many disciplines. Procedures and facilities to accomplish this will range from the simplest to the most elaborate. The primary consideration in any of these is to dispel the notion that laboratory wastes can be disposed of in the same manner and with as little thought as household wastes. Selection and enforcement of safe procedures for disposal of laboratory materials are of no less importance than the consideration given to any other methodology for the accomplishment of research objectives.

Materials of dissimilar nature will be common in laboratories studying recombinant DNA molecules. Examples are combinations of common flammable solvents, chemical carcinogens, radioactive isotopes, and concentrated viruses or nucleic acids. These may require input from a number of disciplines in arriving at the most practical approach for their decontamination.

E. Characteristics of Chemical Decontaminants in Common Use in Laboratory Operations

Every person actively working with viable microorganisms, no matter how remote the field of specialization, will, from time to time, find it necessary to decontaminate by chemical methods work areas and materials, equipment, and specialized instruments. Chemical decontamination is necessary because the use of pressurized steam, the most rapid and reliable method of sterilization, is not normally feasible for decontaminating large spaces, surfaces, and stationary equipment. Moreover, high temperatures and moisture often damage delicate instruments,

particularly those having complex optical and electronic components.

Chemicals with decontaminant properties are, for the most part, available as powders, crystals, and liquid concentrates. These may be added to tap water for application as surface decontaminants, and some, when added in sufficient quantity, find use as decontaminants of bulk liquid wastes. Chemical decontaminants that are gaseous at room temperatures are useful as space-penetrating decontaminants. Others become gases at reasonably elevated temperatures and can act as either aqueous surface or gaseous space-penetrating decontaminants.

Inactivation of microorganisms by chemical decontaminants may occur in one or more of the following ways:

1. Coagulation and denaturation of protein.
2. Lysis.
3. Binding to enzymes, or inactivation of an essential enzyme by either oxidation, binding, or destruction of enzyme substrate.

The relative resistance to the action of chemical decontaminants can be substantially altered by such factors as: concentration of active ingredient, duration of contact, pH, temperature, humidity, and presence of extrinsic organic matter. Depending upon how these factors are manipulated, the degree of success achieved with chemical decontaminants may range from minimal inactivation of target microorganisms to an indicated sterility within the limits of sensitivity of the assay systems employed.

There are dozens of decontaminants available under a wide variety of trade names. In general, these decontaminants can be classified as halogens, acids or alkalies, heavy metal salts, quaternary ammonium compounds, phenolic compounds, aldehydes, ketones, alcohols, and amines. Unfortunately, the more active the decontaminant the more likely it will possess undesirable characteristics. For example, peracetic acid is a fast-acting, universal decontaminant. However, in the concentrated state it is a hazardous compound that can readily decompose with explosive violence. When diluted for use, it has a short half-life, produces strong, pungent, irritating odors, and is extremely corrosive to metals. Nevertheless, it is such an outstanding decontaminant that it is commonly used in germ-free animal studies despite these undesirable characteristics.

The halogens are probably the second most active group of decontaminants. Chlorine, iodine, bromine, and fluorine will rapidly kill bacterial spores, viruses, rickettsiae, and fungi. These decontaminants are effective over a wide range of temperatures. In fact, chlorine has been shown to be effective at -40 F. (On the other hand, phenols and formaldehyde have high temperature coefficients). The halogens have several undesirable features. They readily combine with protein, so that an excess of the halogen must be used if proteins are present. Also, the halogens are relatively unstable so that fresh solutions must be prepared at frequent intervals. Finally, the halogens corrode metals. A number of manufacturers of decontaminants have treated the halogens to remove some of the undesirable features. For example, sodium hypochlorite reacts with p-toluenesulfonamide to form Chloramine T, and iodine reacts with certain surface-active agents to form the popular iodophors. These "tamed" halogens are stable, non-toxic, odorless, and relatively noncorrosive to metals. However, the halogens are highly reactive elements, and, because they are reactive they are good germicides. When a halogen acts as a decontaminant, free halogen is the effective agent. Raising the pH or combining the halogen with other compounds to decrease the corrosive effect will also decrease

the germicidal power. A trade-off situation occurs.

Ineffectiveness of a decontaminant is due primarily to the failure of the decontaminant to contact the microorganisms rather than failure of the decontaminant to act. If one places an item in a liquid decontaminant, one can see that the item is covered with tiny bubbles. Of course, the area under the bubbles is dry, and microorganisms in these dry areas will not be affected by the decontaminant. Also, if there are spots of grease, rust or dirt on the object, microorganisms under these protective coatings will not be contacted by the decontaminant. Scrubbing an item when immersed in a decontaminant is helpful, and a decontaminant should have, and most do have, incorporated surface-active agents.

F. Properties of Some Common Decontaminants

1. *Alcohol.* Ethyl or isopropyl alcohol in a concentration of 70-85% by weight is often used. Alcohols denature proteins and are somewhat slow in their germicidal action. However, they are effective decontaminants against lipid-containing viruses.

2. *Ether and Chloroform.* These compounds are not ordinarily used as decontaminants, but they do demonstrate the fact that lipid-containing viruses are inactivated by these organic solvents, whereas non-lipid-containing viruses are quite resistant.

3. *Formaldehyde.* Formaldehyde for use as a decontaminant is usually marketed as a solution of about 37% concentration referred to as formalin or as a solid polymerized compound called paraformaldehyde. Formaldehyde in a concentration of 5% active ingredient is an effective liquid decontaminant. It loses considerable activity at refrigeration temperatures and the pungent, irritating odors make formaldehyde solutions difficult to use in the laboratory. Formaldehyde vapor generated from formaldehyde solution is an effective space decontaminant for decontaminating rooms or buildings, but in the vapor state with water it tends to polymerize out on surfaces to form paraformaldehyde, which is persistent and unpleasant. Formaldehyde gas can be liberated by heating paraformaldehyde to depolymerize it. In the absence of high moisture content in the air, formaldehyde released in the gaseous state forms less polymerized residues on surfaces and less time is required to clear treated areas of fumes than formaldehyde released in the vapor state.

4. *Phenol.* Phenol itself is not often used as a decontaminant. The odor is somewhat unpleasant and a sticky, gummy residue remains on treated surfaces. This is especially true during steam sterilization. Although phenol itself may not be in widespread use, phenol homologs and phenolic compounds are basic to a number of popular decontaminants. The phenolic compounds are effective decontaminants against some viruses, rickettsiae, fungi and vegetative bacteria. The phenolics are not effective in ordinary usage against bacterial spores.

5. *Quaternary Ammonium Compounds or Quats.* After 30 years of testing and use, there is still a considerable controversy about the efficacy of the Quats as decontaminants. These cationic detergents are strongly surface-active and are effective against lipid-containing viruses. The Quats will attach to protein so that dilute solutions of Quats will quickly lose effectiveness in the presence of proteins. The Quats tend to clump microorganisms and are neutralized by anionic detergents, such as soap. The Quats have the advantages of being nontoxic, odorless, non-staining, noncorrosive to metals, stable, and inexpensive.

6. *Chlorine.* This halogen is a universal decontaminant active against all micro-

organisms, including bacterial spores. Chlorine combines with protein and rapidly decreases in concentration in its presence. Free, available chlorine is an active element. It is a strong oxidizing agent, corrosive to metals. Chlorine solutions will gradually lose strength so that fresh solutions must be prepared frequently. Sodium hypochlorite is usually used as a base for chlorine decontaminants. An excellent decontaminant can be prepared from household or laundry bleach. These bleaches usually contain 5.25 percent available chlorine or 52,500 ppm. If one dilutes them to 1 to 100, the solution will contain 525 ppm of available chlorine, and, if a nonionic detergent such as Naccanol is added in a concentration of about 0.7 percent, a very good decontaminant is created.

7. *Iodine.* The characteristics of chlorine and iodine are similar. One of the most popular groups of decontaminants used in the laboratory is the iodophors, and Wescodyne is perhaps the most popular. The range of dilution of Wescodyne recommended by the manufacturer is 1 oz. in 5 gal. of water giving 25 ppm of available iodine to 3 oz. in 5 gal. giving 775 ppm. At 75 ppm, the concentration of free iodine is .0075 percent. This small amount can be rapidly taken up by any extraneous protein present. Clean surfaces or clear water can be effectively treated by 75 ppm available iodine, but difficulties may be experienced if any appreciable amount of protein is present. For bacterial spores, a dilution of 1 to 40 giving 750 ppm is recommended by the manufacturer. For washing the hands, it is recommended that Wescodyne be diluted 1 to 10 or 10% in 50% ethyl alcohol (a reasonably good decontaminant itself) which will give 1,600 ppm of available iodine, at which concentration relatively rapid inactivation of any and all microorganisms will occur.

G. Vapors and Gases

The use of formaldehyde as a vapor or gas has already been discussed. Other chemical decontaminants which have been used this way included ethylene oxide, peracetic acid, beta-propiolactone (BPL), methyl bromide, and ethylene amine. When these can be used in closed systems and under controlled conditions of temperature and humidity, excellent decontamination can be obtained. Residues from ethylene oxide must be removed by aeration; but otherwise it is convenient to use, versatile, and noncorrosive. Peracetic acid is corrosive for metals and rubber. BPL in the vapor form acts rapidly against bacteria, rickettsiae, and viruses. It has a half-life of 3.5 hours when mixed with water, is easily neutralized with water, and lends itself to removal by aeration. The National Institutes of Health does not recommend BPL as a decontaminant because it has been identified as a suspect carcinogen.

H. Residual Action of Decontaminants

As noted in the preceding discussion of decontaminant properties, many of the chemical decontaminants often have residual properties that may be considered a desirable feature in terms of aiding in the control of background contamination. One is cautioned, however, to consider residual properties carefully. Ethylene oxide used to sterilize laboratory shoes can leave residues which cause skin irritation. Animal cell cultures, as well as viruses of interest, are also inhibited or inactivated by the decontaminants persisting after routine cleaning procedures. Therefore, reusable items that are routinely held in liquid decontaminant prior to autoclaving and cleaning should receive particular attention in rinse cycles. Similarly, during general area decontamination with gases or vapors, it may be necessary to protect new and used clean items by removing them from the area or by enclosing

them in gastight bags or by insuring adequate aeration following decontamination.

1. Selecting Chemical Decontaminants for Research on Recombinant DNA Molecules

No single chemical decontaminant or method will be effective or practical for all situations in which decontamination is required. Selection of chemical decontaminants and procedures must be preceded by practical consideration of the purposes for the decontamination and the interacting factors that will ultimately determine how that purpose is to be achieved. Selection of any given procedure will be influenced by the information derived from answers to the following questions:

1. What is the target microorganism(s)?
2. What decontaminants in what form are known to, or can be expected to, inactivate the target microorganism(s)?
3. What degree of inactivation is required?
4. In what menstruum is the microorganism suspended; i.e., simple or complex, on solid or porous surfaces, and/or airborne?
5. What is the highest concentration of cells anticipated to be encountered?
6. Can the decontaminant either as an aqueous solution, a vapor, or a gas reasonably be expected to contact the microorganisms, and can effective duration of contact be maintained?
7. What restrictions apply with respect to compatibility of materials?
8. Does the anticipated use situation require immediate availability of an effective concentration of the decontaminant or will sufficient time be available for preparation of the working concentration shortly before its anticipated use?

The primary target of decontamination in the infectious disease laboratory is the microorganism under active investigation. Laboratory preparations or infectious agents usually have titers grossly in excess of those

normally observed in nature. The decontamination of these high-titer materials presents certain problems. Maintenance systems for bacteria or viruses are specifically selected to preserve viability of the agent. Agar, proteinaceous nutrients, and cellular materials can be extremely effective in physically retarding or chemically binding active moieties of chemical decontaminants. Such interferences with the desired action of decontaminants may require the use of decontaminant concentrations and contact times in excess of those shown to be effective in the test tube. Similarly, a major portion of decontaminant contact time required to achieve a given level of agent inactivation may be expended in inactivating a relatively small number of the more resistant members of the population. The current state of the art provides little information on which to predict the probable virulence of these survivors. These problems are, however, common to all potentially pathogenic agents and must always be considered in selecting decontaminants and procedures for their use.

Microorganisms exhibit a range of resistance to chemical decontaminants. In terms of practical decontamination, most vegetative bacteria, fungi and lipid-containing viruses, are relatively susceptible to chemical decontamination. The non-lipid-containing viruses and bacteria with a waxy coating such as tubercle bacillus occupy a mid-range of resistance. Spore forms are the most resistant.

A decontaminant selected on the basis of its effectiveness against microorganisms on any range of the resistance scale will be effective against microorganisms lower on the scale. Therefore, if decontaminants that effectively control spore forms are selected for routine laboratory decontamination, it can be assumed that any other microorganisms generated by laboratory operations, even in high concentrations, would also be inactivated.

An additional area that must be considered and for which there is little definitive information available is the "inactivation" of nucleic acid. Nucleic acids often have better survival characteristics under adverse conditions than do the intact virions and cells from which they were derived. Strong oxidizers, strong acids and bases, and either gaseous or aqueous formaldehyde should react readily with nucleic acids. Their ability to destroy the nucleic acid being studied, however, should be confirmed in the experimenter's laboratory. Because of innate differences in the chemistry of RNA and DNA the effectiveness of a decontaminant for one cannot be extrapolated to the other. For example, RNA molecules are susceptible to mild alkaline hydrolysis by virtue of the free hydroxyl group in the 2' position, whereas DNA molecules are not susceptible to mild alkaline hydrolysis.

Table II summarizes pertinent characteristics and potential applications for several categories of chemical decontaminants most likely to be used in the biological laboratory. Practical concentrations and contact times that may differ markedly from the recommendations of manufacturers of proprietary products are suggested. It has been assumed that microorganisms will be afforded a high degree of potential protection by organic menstruums. It has not been assumed that a sterile state will result from application of the indicated concentrations and contact times. It should be emphasized that these data are only indicative of efficacy under artificial test conditions. The efficacy of any of the decontaminants should be conclusively determined by individual investigators. It is readily evident that each of the decontaminants has a range of advantages and disadvantages as well as a range of potential for inactivation of a diverse microflora. Equally evident is the need for compromise as an alternative to maintaining a veritable "drug store" of decontaminants.

TABLE II
SUMMARY OF PRACTICAL DECONTAMINANTS FOR USE IN THE LABORATORY

DECONTAMINANTS		PRACTICAL REQUIREMENTS				INACTIVATES				IMPORTANT CHARACTERISTICS										POTENTIAL APPLICATION										PROPRIETARY ORGANISMS/EXAMPLES		
		CONCENTRATION ACTIVE INGREDIENT	CONTACT TIME (minutes)	LIPO. VIRUS ONLY	BROAD SPECTRUM	VEG. BACT.	LIPO. VIRUS	HYDROPHILIC VIRUS	BACT. SPORES	EFFECTIVE ONLY LIFE = 1 CELL	COMBUSTIBLE	FLAMMABLE	EXPLOSION POTENTIAL	RESIDUE	INACTIVATED BY ORGANIC MATTER	LIPO. COMPATIBLE	ELECTROLYSIS COMPATIBLE	SALT INHIBITANT	EYE INHIBITANT	RESPIRATORY INHIBITANT	TOXIC	WORK SURFACES	DIRTY GLASSWARE	LARGE AREA DECON.	AIR HANDLING SYSTEMS	PORTABLE EQUIP. SURFACE DECON.	PORTABLE EQUIP. PENETRATING DECON.	STATIONARY EQUIP. SURFACE DECON.	STATIONARY EQUIP. PENETRATING DECON.	LEAKAGE & ELECTRONIC INSTRUMENTS	LIQUIDS FOR DISCARD	BODIES, PAPERS
LIQUID	Quat. Ammon. CPB	2%	10	N.E.		+	+		+					+	+			+	+	+		/	/		/		/					A-13, CQ, DND-BAC, RI-100, MICRO-QUIK
	Phenolic CPB	2%	10	N.E.		+	+	1	+	+				+	+			+	+	+		/	/		/		/					RI-100, MICRO-QUIK, D-400
	Chlorine CPB	2%	10	30		+	+	+	+	+				+	+			+	+	+		/	/		/		/					CHLORAMINE T, CLOXON, FUMEX
	Indophor	2%	10	30		+	+	+	+	+				+	+			+	+	+		/	/		/		/					RI-100, IOPRO, KEROSENE, MICRO-QUIK
	Alcohol, Ethyl	95%	10	N.E.		+	+	1	+	+								+	+	+		/	/		/		/					
	Alcohol, Isopropyl	95%	10	N.E.		+	+	1	+	+								+	+	+		/	/		/		/					
	Formaldehyde	2%	10	30		+	+	+	+	+				+	+			+	+	+		/	/		/		/					HYDRO-QUIK
	Glutaraldehyde	2%	10	30		+	+	+	+	+				+	+			+	+	+		/	/		/		/					
GAS	Ethylene Oxide	10g/l	60	60	30	30	+	+	+	+	N.E.	+	+			+	+	+	+	+		/	/		/		/					CIDEX
	Peracetic Acid	10g/l	60	60	23	60	+	+	+	+	N.E.	+	+			+	+	+	+	+		/	/		/		/					QUADRON, CHLOROX, HYDRO-QUIK
	Hydrogen Peroxide	10g/l	60	60	30	30	+	+	+	+	N.E.	+	+			+	+	+	+	+		/	/		/		/					

- N.E. = Not applicable - N.E. = Not effective
1. Variable results dependent on virus.
 2. Neither flammable or explosive in 95% CPB or flammable hydrocarbon use form.
 3. At concentrations of 7 to 7.5% by volume in air, solid-exposure to open flame.
 4. Protected from light and air.
 5. By skin or mouth or both - refer to manufacturer's literature and/or MSDS (MSDS).
 6. Spore limitations preclude listing all products available. Individual listings (or omissions) do not imply endorsement or rejection of any product by the FDA.
 7. Refer to micrographs and camera lenses.

VII. HOUSEKEEPING

A. Introduction

Well-defined housekeeping procedures and schedules are essential in reducing the risks of working with etiologic agents and in protecting the integrity of the research program. This is particularly true in the biological laboratory operating under less than total containment concepts and in all areas used

for the housing of animals, whether or not they have been intentionally infected. A well-conceived and well-executed housekeeping program limits physical clutter that could distract the attention and interfere with the activities of laboratory personnel at a critical moment in a potentially hazardous procedure, provides a work area that will not in itself be a source of physical injury or contamination, and provides an area that pro-

motes the efficient use of decontaminants in the event of the inadvertent release of a harmful agent. Less immediately evident are the benefits of establishing, among personnel of widely varying levels of education, an appreciation of the nature and sources of biological contamination.

Housekeeping is an omnibus term that can be interpreted as broadly or as narrowly as one chooses. It can be seen that many of the

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procedures found under special headings, such as decontamination, disposal, and animal care, are, in reality, specific instructions for safely accomplishing otherwise routine housekeeping chores. In these safety suggestions for research on recombinant DNA molecules, it has been elected to address specifically only tasks of a janitorial nature under the subject of housekeeping.

The objectives of housekeeping in the biological laboratory are to:

1. Provide an orderly work area conducive to the accomplishment of the research program.
2. Provide work areas devoid of physical hazards.
3. Provide a clean work area with background contamination ideally held to a zero level but more realistically to a level such that extraordinary measures in sterile techniques are not required to maintain integrity of the biological systems being researched.
4. Prevent the accumulation of materials from current and past experiments that constitute a hazard to laboratory personnel.
5. Prevent the creation of aerosols of hazardous materials as a result of the housekeeping procedures used.

Procedures developed in the area of housekeeping should be based on the highest level of risk to which the personnel and integrity of the experiments will be subject. Such an approach avoids the confusion of multiple practices and retraining of personnel. The primary function, then, of routine housekeeping procedures is to prevent the accumulation of organic debris that (i) may harbor microorganisms that are a potential threat to the integrity of the biological systems under investigation, (ii) may enhance the survival of microorganisms inadvertently released in experimental procedures, (iii) may retard penetration of decontaminants, (iv) may be transferable from one area to another on clothing and shoes, (v) may, with sufficient buildup, become a biohazard as a consequence of secondary aerosolization by personnel and air movement, and (vi) may cause allergenic sensitization of personnel, e.g., to animal danders.

Housekeeping in animal care units has the same primary function as that stated for the laboratory and should, in addition, be as meticulously carried out in quarantine and conditioning areas as in areas used to house experimentally infected animals. No other areas in the laboratory have the constant potential for creation of significant quantities of contaminated organic debris than do animal care facilities.

In all laboratories, efforts to achieve total decontamination and to conduct a major cleanup of the biological complex are normally undertaken at relatively long time intervals. Routine housekeeping must be relied on to provide a work area free of significant sources of background contamination. The provision of such a work area is not simply a matter of indicating in a general way what has to be done, who will do it, and how often. The supervisor must view each task critically in terms of the potential biohazard involved, decide on a detailed procedure for its accomplishment, and provide instructions to laboratory personnel in a manner that minimizes the opportunity for misunderstanding.

The following checklist outlines a portion of the items requiring critical review by the laboratory supervisor. It is not intended to be complete but is presented as an example of the detailed manner in which housekeeping in the biological laboratory complex must be viewed.

Administration Areas
Aisles
Animal Food Storage
Animal Bedding Storage

Biological Safety Cabinets
Bench Tops and Other Work Surfaces
Ceilings
Change Rooms
Cleaning Solution Disposal
Cages and Cage Racks
Dry Ice Chests
Deep Freeze Chests
Entry and Exit Ways
Equipment Storage
Floors
Glassware
General Laboratory Equipment Cleanup
Hallways
Incubators
Instruments
Insect and Rodent Control
Light Fixtures
Mechanical Equipment Areas
Mops
Pipes—Wall and Ceiling Hung
Refrigerators
Showers
Supply Storage
UV Lamps
Vacuum Cleaners
Waste Accumulations
Waste Water Disposal
Others

Housekeeping in the laboratory is one of the avenues that leads to accomplishing the research program safely. It is important that housekeeping tasks be assigned to personnel who are knowledgeable of the research program and special hazards of the research environment. The recommended approach to housekeeping is the assignment of housekeeping tasks to the research teams on an individual basis for their immediate work areas and on a cooperative basis for areas of common usage. Similarly, animal caretaker personnel should be responsible for housekeeping in animal care areas. The laboratory supervisor must determine the frequency with which the individual and cooperative housekeeping chores need be accomplished. He should provide schedules and perform frequent inspection to assure compliance. This approach assures that research work flow patterns will not be interrupted by an alien cleanup crew, delicate laboratory equipment will be handled only by those most knowledgeable of its particular requirements, and the location of concentrated biological preparations and contaminated equipment used in their preparation and application will be known.

B. Floor Care

Avoidance of dry sweeping and dusting will reduce the formation of nonspecific environmental aerosols. Wet mopping or vacuum cleaning with a high-efficiency particulate air (HEPA) filter on the exhaust is recommended.

Careful consideration must be given to design and quality in the selection of cleaning equipment and materials and in their use to prevent the substitution of one hazard for another.

In the absence of overt hazardous spills, the cleaning process commonly will consist of an initial vacuuming to remove all gross particulate matter and a follow-up wet mopping with a solution of chemical decontaminant containing a detergent. Depending on the nature of the surfaces to be cleaned and availability of floor drains, removal of residual cleaning solutions can be accomplished by a number of methods. Among these are: pickup with a partially dry mop, pickup with a wet vacuum that has an adequately filtered exhaust, or removal to a convenient floor drain by use of a floor squeegee.

After cleaning up a spill of infected material, the residual solution should not be discharged to a sanitary sewer until it has

been autoclaved or given further chemical treatment, such as by the addition of sodium hypochlorite sufficient to provide a final concentration of 500 ppm chlorine. Most household bleaches are marketed with a chlorine content of 5.25%. These in a final dilution of 1:100, yield 525 ppm of available chlorine. After allowing a contact time of 15 minutes, these solutions may be flushed down any available drain. Chlorine solutions in these high concentrations may be too corrosive for general application to floors and equipment. In any event, if solutions are used in this way, after the contact time the area should be rinsed with water.

C. Dry Sweeping

While it is recommended that dry sweeping be minimized, this may be the only method available or practicable under certain circumstances. In such cases, sweeping compounds used with push brooms and dry-dust mop heads treated to suppress aerosolization of dust should be used.

Sweeping compounds available from the usual janitorial supply firms fall in three categories:

Wax-based compounds used on vinyl floors and waxed floor coverings.

Oil-based compounds for concrete floors.

Oil-based compounds with abrasives (such as sand) to achieve a dry scouring action where much soil is present.

Dry-dust mop heads can be purchased as treated disposable units or as reusable, washable heads that must be treated with appropriate sprays or by other means to improve their dust-capturing property.

D. Vacuum Cleaning

In the absence of a HEPA filter on the exhaust, the usual wet and dry industrial-type vacuum cleaner is a potent aerosol generator. The HEPA-filtered exhaust used in conjunction with a well-sealed vacuum unit, however, can negate this factor because of its ability to pass large volumes of exhaust air while retaining particles with a minimum efficiency of 99.97%. Wet and dry units incorporating a HEPA filter on the exhaust are available from a number of manufacturers.

There are no particular requirements with respect to the manner in which the dry vacuuming is accomplished other than to emphasize that the objective is to remove all debris and particulate matter. The manufacturer's directions adequately detail the frequency of bag changes, filter changes, and mechanical adjustments.

Dry material vacuum-collected during these floor-cleaning activities is potentially contaminated, but the nature of the risk is probably greater to the experimenter than to the experimenter. It is wise to effect bag and filter changes and to clean out collection tanks in a manner that will avoid or minimize aerosolizing the contents of the vacuum cleaner.

A vacuum machine that collects debris in a disposable bag is preferable to machines that collect the major debris in a tank and on an exposed primary filter. Even though it may serve as a primary filter, the disposable bag must be removed with caution. A bellows effect may pump dust out of the bag if its intake opening is not sealed before moving it to a plastic bag for transfer out of the area. In any event, the outer surface of the disposable bag will probably bear some dust contamination, which also may occur on inner surfaces of the machine.

To avoid contaminating experimental materials, the emptying of vacuum collection tanks and changing of bags and filters are best done away from the immediate laboratory area, for example, in a small area that can be easily cleaned afterwards. The use of heavy rubber gloves is recommended when

removing wastes from tanks in case broken glass is present. After making the filter changes, all external surfaces of the immediate work area and the equipment should be wiped with a cloth moistened in decontaminant. The operator might plan for a change of laboratory clothing afterwards so as to minimize carrying contamination into other areas of the laboratory.

Avoid use of dry vacuum cleaning equipment in work with high risk agents in the open laboratory. Should it be necessary to use it, it is recommended that gaseous sterilization be used to minimize aerosolization of microorganisms before waste is emptied from the vacuum container. Because complete penetration of sterilizing gases into the collected dry dust may be a problem, all wastes should be placed in a plastic bag, which then is tightly closed and incinerated or disposed of in an approved manner.

When dry vacuum cleaning equipment has been used within a gastight safety cabinet system, it can be treated in an attached double-door carboxyclave (an autoclave equipped with an ethylene oxide gas sterilization system) to allow for removal and emptying of the collection tank.

If a wet vacuum is to be used for pickup of the detergent-germicide solution from the floor, the manufacturer's recommendations on filter life should be followed. In addition, the operation of the vacuum should be closely observed for evidence of operating changing indicating restricted airflow or, conversely, increased flow indicating filter failure. Liquids collected in the vacuum cleaner after floor mopping will contain decontaminant material. These liquids may be poured down a convenient floor drain, except in the case of cleanup wastes from an overt spill. The collected liquid should then be autoclaved or treated with chlorine solution before disposal.

Provisions should be made for regular decontamination of the entire vacuum cleaner with formaldehyde gas or vapor, or ethylene oxide. This should be done after use if the vacuum is used in any manner for cleanup of overt spills of infectious material.

E. Selection of a Cleaning Solution

The selection of a detergent-decontaminant combination for routine cleaning of the laboratory complex should be based on the requirements of the area of greatest potential for contamination by the widest spectrum of microorganisms. With rare exception, this will be identified as the animal holding area and the expected microorganisms. With rare exception, this will be identified as the animal holding area and the expected microorganisms may well include fungi, viruses, and the vegetative and spore forms of bacteria. A decontaminating solution for such a range of microorganisms would, however, be expensive and excessively corrosive for routine use. Except in those rare instances where it can be assumed that pathogenic spores are being shed by laboratory animals, the risks from the spores are more likely to affect the experiments than the personnel. The spores tend to be associated with organic debris from bedding and food, thus offering potential for removal or at least a large initial reduction in their numbers by vacuum cleaning. A wide range of cleaning solutions that are mildly sporicidal, reasonably residual, and are not destructive to the physical plant are available. Phenol derivatives in combination with a detergent have these characteristics and have been selected for routine use in a number of research facilities. There are numerous detergent-phenolic combinations available on the market. The phenols are one type of a broad spectrum of biocidal substances that

includes the mercurials, quaternary ammonium compounds, chloride compounds, iodophores, alcohols, formaldehyde, glutaraldehyde, and combinations of alcohol with either iodine or formaldehyde. These have been discussed in Section VI.

The laboratory supervisor should make a selection from those types most readily available which meet the general criteria of effectiveness, residual properties, and low corrosiveness.

F. Wet Mopping—Two-Bucket Method

Wet mopping of floors in laboratory and animal care areas is, from a safety standpoint, most conveniently and efficiently accomplished using a two-bucket system. The principal feature of such a system is that fresh detergent-decontaminant solution is always applied to the floor from one bucket, while all spent cleaning solution wrung from the mop is collected in the second bucket. Compact dolly-mounted double-bucket units with foot-operated wringers are available from most janitorial supply houses. A freshly laundered mop head of the cotton string type should be used daily. This requires that a mop with removable head be provided as opposed to a fixed-head type. In practice, the mop is saturated with fresh solution, very lightly wrung into the second bucket and applied to the floor using a figure eight motion of the mop head. After every four or five strokes, the mop head is turned over and the process continued until an area of approximately 100 ft² has been covered. After allowing a contact time of five minutes, the solution is removed with either a wet vacuum cleaner with HEPA-filtered exhaust or with the wrung-out mop. The mopping is continued in 100 ft² increments until the total floor area has been covered. Floor-cleaning procedures are most effectively completed after the majority of the work force has departed and should progress from areas of least potential contamination to those of greatest potential. Before a mop head is sent to a laundry, it should be autoclaved. Spent cleaning fluids are disposed of by flushing down the drain.

If the cleanup follows an overt spill of infectious material, the spent cleaning solution, after removal from the floor, should be autoclaved or treated with chlorine solution. Chlorine (as household bleach) should be added to give 500 ppm and held for a contact time of 15 minutes before dumping in the sanitary sewer.

G. Alternative Floor Cleaning Method for Animal Care Areas and Areas with Monolithic Floors

The absence of permanently placed laboratory benches and fixed equipment, coupled with the mobility of modern cage racks, makes possible alternate floor-cleaning procedures in animal care facilities. As in all considerations of methodologies in biomedical laboratory facilities, it is necessary to assess the compatibility of procedures and facilities from the hazard point of view. The alternative floor-cleaning procedure to be discussed requires that floors are completely sealed or of monolithic construction so that liquid leakage to adjacent areas does not occur and that floor drains or wet vacuum cleaners are available.

Subsequent to the removal of all debris by dry vacuum, move the cage racks to one side of the room. Cover the floor of the remaining cleared portion of the room with detergent-decontaminant solution applied at a rate of approximately one gallon per 144 ft² from a one-gallon tank sprayer, using a setting of the nozzle which will cause the solution to flow on and not create a spray. The nozzle is placed close to the floor. Allow a fifteen-minute contact period; then push the clean-

ing solution to the floor drain with a large floor squeegee or pick it up with a wet vacuum. Allow the flow to air dry; move the cage racks into the cleaned area, and repeat the process for the remaining floor area. Floor drains in these areas should be rim-flush, at least six inches in diameter, and fitted with a screen or porous trap bucket to catch large debris that escapes the initial dry cleaning. Such screens and baskets should be emptied after treatment with a decontaminant. If space utilization does not require frequent floor washdown, pour a half-gallon of detergent-decontaminant solution into the drain each week to keep the trap in the waste line filled against backup of sewer gases.

VIII. CLEAN-UP OF BIOHAZARDOUS SPILLS (8, 9, 10)

A. Biohazards Spill in a Biological Safety Cabinet

Chemical decontamination procedures should be initiated at once while the cabinet continues to operate to prevent escape of contaminants from the cabinet.

1. Spray or wipe walls, work surfaces, and equipment with a 2% solution of an iodophor-decontaminant (Wescodyne or equivalent). A decontaminant detergent has the advantage of detergent activity, which is important because extraneous organic substances frequently interfere with the reaction between the microorganisms and the active agent of the decontaminant. Operator should wear gloves during this procedure.

2. Flood the top work surface tray, and, if a Class II cabinet, the drain pans and catch basins below the work surface, with a decontaminant and allow to stand 10-15 minutes.

3. Remove excess decontaminant from the tray by wiping with a sponge or cloth soaked in a decontaminant. For Class II cabinets, drain the tray into the cabinet base, lift out tray and removable exhaust grille work, and wipe off top and bottom (underside) surfaces with a sponge or cloth soaked in a decontaminant. Then replace in position and drain decontaminant from cabinet base into appropriate container and autoclave according to standard procedures. Gloves, cloth or sponge should be discarded in an autoclave pan and autoclaved.

B. Biohazard Spill Outside a Biological Safety Cabinet

1. Hold your breath, leave the room immediately, and close the door.

2. Warn others not to enter the contaminated area.

3. Remove and put into a container contaminated garments for autoclaving and thoroughly wash hands and face.

4. Wait 30 minutes to allow dissipation of aerosols created by the spill.

5. Put on a long-sleeve gown, mask, and rubber gloves before reentering the room. For a high risk agent, a jumpsuit with tight-fitting wrists and use of a respirator should be considered.

6. Pour a decontaminant solution (5% iodophor or 5% hypochlorite are recommended) around the spill and allow to flow into the spill. Paper towels soaked with the decontaminant may be used to cover the area. To minimize aerosolization, avoid pouring the decontaminant solution directly onto the spill.

7. Let stand 20 minutes to allow an adequate contact time.

8. Using an autoclavable dust pan and squeegee, transfer all contaminated materials (paper towels, glass, liquid, gloves, etc.) into a deep autoclave pan. Cover the pan with aluminum foil or other suitable cover and autoclave according to standard directions.

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9. The dust pan and squeegee should be placed in an autoclavable bag and autoclaved according to standard directions. Contact of reusable items with non autoclavable plastic bags should be avoided—separation of the plastic after autoclaving can be very difficult.

C. Radioactive Biohazard Spill Outside a Biological Safety Cabinet

In the event that a biohazardous spill also involves a radiation hazard, the clean-up procedure may have to be modified, depending on an evaluation of the risk assessment of relative biological and radiological hazard.

Laboratories handling radioactive substances must have the services of a designated radiation protection officer available for consultation.

The following procedure indicates suggested variations from the biohazard spill procedure (above) that should be considered when a radioactive biohazard spill occurs outside a Biological Safety Cabinet.*

1. Holding your breath, leave the room immediately and close the door.

2. Warn others not to enter the contaminated area.

3. Remove and put in a container contaminated garments for autoclaving and thoroughly wash hands and face.

4. Wait thirty-minutes to allow dissipation of aerosols created by the spill.

*Before clean-up procedures begin, a radiation protection officer should survey the spill for external radiation hazard to determine the relative degree of risk.

5. Put on a long-sleeve gown, mask, and rubber gloves before reentering the room. (For a high risk agent, a jumpsuit with tight-fitting sleeves and a respirator should be considered).

6. Pour a decontaminant solution (5% iodophor or 5% hypochlorite are recommended) around the spill and allow to flow into the spill. Paper towels soaked with the decontaminant may be used to cover the area. To minimize aerosolization, avoid pouring the decontaminant solution directly onto the spill.

7. Let stand 20 minutes to allow adequate disinfectant contact time.

8. *In most cases, the spill will involve ¹⁴C or ³H, which present no external hazard. However, if more energetic beta or gamma emitters are involved, care must be taken to prevent hand and body radiation exposure. The radiation protection officer must make this determination before the clean-up operation is begun.

If the radiation protection officer approves, the biohazard-handling procedure may begin: Using an autoclavable dust pan and squeegee, transfer all contaminated materials (paper towels, glass, liquid, gloves, etc.) into a deep autoclave pan. Cover the pan with aluminum foil or other suitable cover and autoclave according to standard directions.

*If the radiation protection officer determines that radioactive vapors may be released and thereby contaminate the autoclave, the material must not be autoclaved. In that case, sufficient decontaminant solution to immerse the contents should be added to the waste container. The cover should be sealed with waterproof tape, and the container stored and handled for disposal as radioactive

waste. Radioactive and biohazard warning symbols should be affixed to the waste container. As a general rule, autoclaving should be avoided.

9. If autoclaving has been approved, the dust pan and squeegee should be placed in an autoclavable bag and autoclaved according to standard directions. Contact of reusable items with plastic bags should be avoided—separation of the plastic after autoclaving can be very difficult.

*A final radioactive survey should be made of the spill area, dust pan, and squeegee with a Geiger counter, or a smear should be taken and counted in a liquid scintillation counter.

IX. A SECONDARY RESERVOIR AND FILTRATION APPARATUS FOR VACUUM SYSTEMS

The aspiration of tissue culture media from monolayer cultures and of supernatants from centrifuged samples into collection vessels or reservoirs is a common procedure in many laboratories. To prevent the accidental contamination by aerosols or fluids of house vacuum systems or laboratory pumps, some investigators have installed side arm flasks containing cotton, sulfuric acid or decontaminant between the reservoir and the vacuum line. Cotton is not completely effective as a filtering agent, sulfuric acid will corrode pipes, and decontaminants may lose their inactivating ability upon standing. The introduction of a cartridge-type filter that is moisture resistant and has a rated capacity to remove particles 350 nm (0.35u) or larger in size provides an effective barrier to virus aerosols.

The secondary reservoir and filtration apparatus can be assembled from readily available units as shown in Figure 1. A length of plastic tubing 1/4 inch I.D. x 1/8 inch wall is attached at one end of the reservoir and at the other end to the lower arm of a filtration and media storage flask. These flasks vary in capacity from 250 to 4000 ml, the choice of flask depending on available space and amount of fluid that could be accidentally aspirated. A second tube of the same dimensions is attached from the upper arm of the flask to the inlet port of the disposable filter assembly. The third tube is attached from the filter assembly to a vacuum source. The tubes are securely held to the filter by fittings supplied with the filter and the other tubing connections can be secured by worm drive hose clamps.

Ideally the flask should be placed higher than the reservoir of collection vessel. If fluid is accidentally drawn into the flask, the liquid can drain back into the reservoir by gravity if the connection at the vacuum line is broken. This prevents the loss of fluid which the investigator needs to retain.

Should the flask be used only for the recovery and storage of waste fluids, then the addition of a few grams of Dow Corning Antifoam A to the flask will reduce violent foaming of fluids aspirated into it. Such fluids can be decontaminated by introducing into the reservoir a final 5% concentration of an iodophor or other appropriate decontaminant, holding for 30 minutes and draining as above.

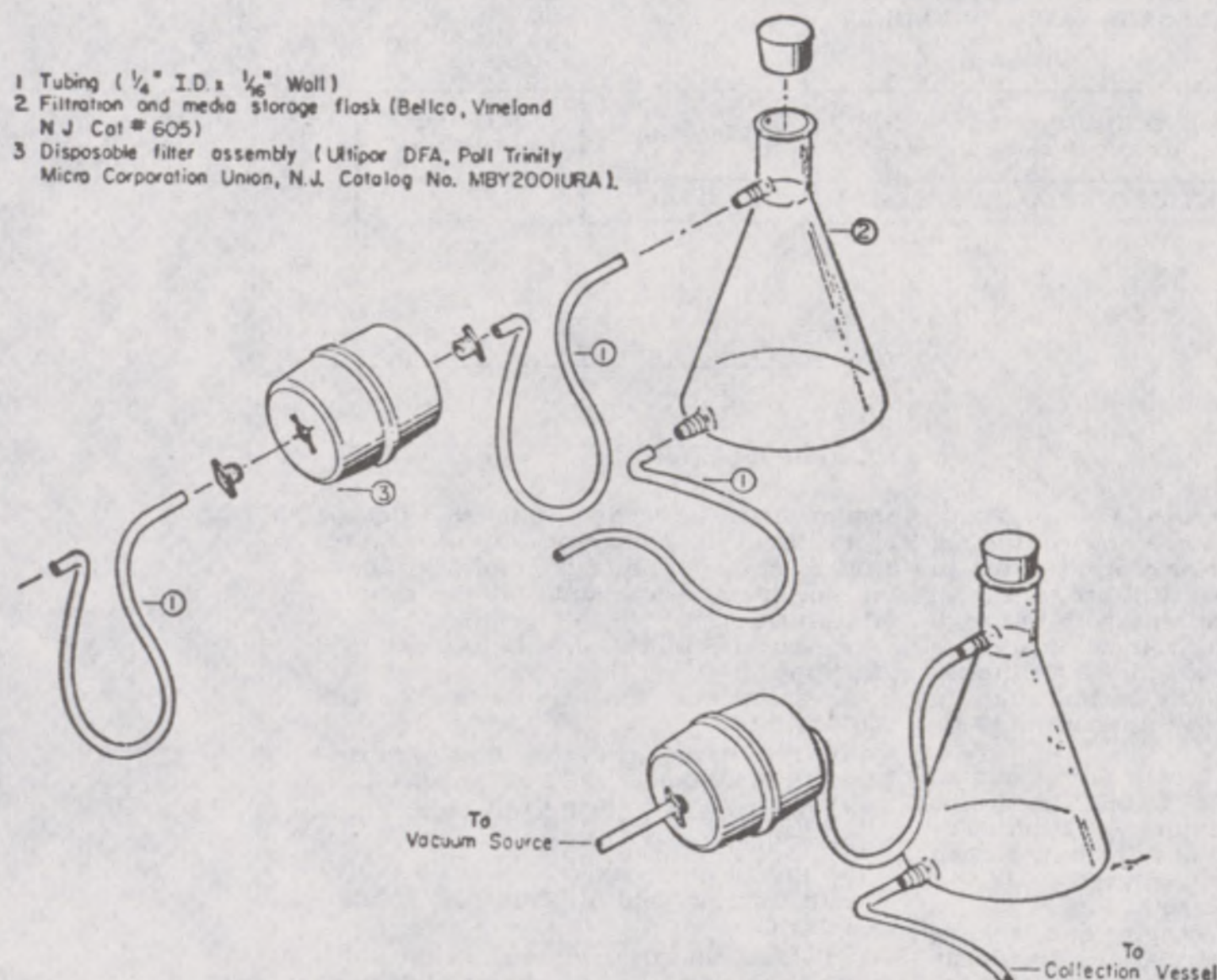
If the filter becomes contaminated or requires changing, the filter and flask can be safely removed by clamping the line between filter and vacuum source. The filter and flask should be autoclaved before the filter is discarded. A new filter can then be installed and the assembly replaced.

*Changes in procedures have been starred and underlined.

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Figure 1
A SECONDARY RESERVOIR AND FILTRATION APPARATUS



X. PACKAGING AND SHIPPING

A. Introduction

Federal regulations and carrier tariffs have been promulgated to ensure the safe transport of hazardous biological materials. The NIH Guidelines specify that all DNA recombinant materials will be packaged and shipped in containers that meet the requirements of these regulations and carrier tariffs. In addition when any portion of the recombinant DNA material is derived from an etiologic agent listed in paragraph (c) of 42 CFR 72.25 (which is included at the end of this section, page D-85) the labeling requirements in these regulations and carrier tariffs shall apply.

B. Packaging of Recombinant DNA Materials

1. Volume less than 50 ml.

Material shall be placed in a securely closed, watertight container [primary container (test tube, vial, etc.)] which shall be enclosed in a second, durable watertight container (secondary container). Several primary containers may be enclosed in a single secondary container, if the total volume of all the primary containers so enclosed does not exceed 50 ml. The space at the top, bottom, and sides between the primary and secondary containers shall contain sufficient non-particulate absorbent material to absorb the entire contents of the primary container(s) in case of breakage or leakage. Each set of

primary and secondary containers shall then be enclosed in an outer shipping container constructed of corrugated fiberboard, cardboard, wood, or other material of equivalent strength.

If dry ice is used as a refrigerant, it must be placed outside the secondary container(s). Descriptions of this packaging method are given in Table III.

2. Volumes of 50 ml. or Greater.

Material shall be placed in a securely closed, watertight container (primary container) which shall be enclosed in a second, durable watertight container (secondary container). Single primary containers shall not contain more than 500 ml. of material. However, two or more primary containers whose combined volumes do not exceed 500 ml. may be placed in a single secondary container. The space at the top, bottom, and sides between the primary and secondary containers shall contain sufficient non-particulate absorbent material to absorb the entire contents of the primary container(s) in case of breakage or leakage. Each set of primary and secondary containers shall then be enclosed in an outer shipping container constructed of corrugated fiberboard, cardboard, wood, or other material of equivalent strength. A shock absorbent material, in volume at least equal to that of the absorbent material between the primary and secondary containers, shall be placed at the top, bottom, and sides between the secondary con-

tainer and the outer shipping container. Not more than eight secondary shipping containers may be enclosed in a single outer shipping container. (The maximum amount of materials which may be enclosed within a single outer shipping container should not exceed 4,000 ml.).

If dry ice is used as a refrigerant, it must be placed outside the secondary container(s). If dry ice is used between the secondary container and the outer shipping container, the shock absorbent material shall be placed so that the secondary container does not become loose inside the outer shipping container as the dry ice sublimates.

Descriptions of packages which comply with the regulations of the Department of Transportation (DOT) are given in Table IV.

C. Labeling of Packages Containing Recombinant DNA Materials

1. Materials which do not contain any portion of an etiologic agent listed in paragraph (c) of 42 CFR 72.25.

Material data forms, letters, and other information identifying or describing the material should be placed around the outside of the secondary container. Place only the address label on the outer shipping container. DO NOT USE THE LABEL FOR ETIOLOGIC AGENTS/BIOMEDICAL MATERIAL.

2. Materials which contain any portion of an etiologic agent listed in paragraph (c) of 42 CFR 72.25.

Material data forms, letters, and other information identifying or describing the material should be placed around the outside of the secondary container. In addition to the address label, the label for Etiologic Agents/Biomedical Material must be affixed to the outer shipping container. This label is described in paragraph (c) (4) of 42 CFR 72.25.

3. Materials which contain any portion of a plant pest (plant pathogens) which are so defined by the Department of Agriculture (USDA).

Material data forms, letters, and other information identifying or describing the material should be placed around the outside of the secondary container. In addition to the address label, the shipping labels furnished by the USDA as part of the General, Courtesy, or Special Permits required for research with and shipment of such agents shall be affixed to the outer shipping container.

D. Additional Shipping Requirements and Limitations for Recombinant DNA Materials

1. Domestic Transportation.

Civil Aeronautics Board Rule No. 82 (Air Transport Association Restricted Articles Tariff 6-D) requires that a Shipper's Certificate, depicted below, be completed and affixed to all shipments which bear the ETIOLOGIC AGENT/BIOMEDICAL MATERIALS label required under the provisions of the Interstate Quarantine regulations [42 CFR Section 72.25(c)]. The Certificate must be completed in duplicate and affixed to the outer shipping container.

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This is to certify that the contents of this consignment are properly classified, described by proper shipping name and are packed, marked and labelled and are in proper condition for carriage by air according to all applicable carrier and government regulations. (For international shipments add "and to the IATA Restricted Articles Regulations".) This consignment is within the limitations prescribed for: PASSENGER AIRCRAFT/CARGO ONLY (cross out nonapplicable).

Number of Packages	Specify Each Article Separately (Proper Shipping Name)	Classification	Net Quantity per Package
	ETIOLOGIC AGENT, n.o.s.	ETIO. AG.	

Shipper:

Date _____

(Signature of Shipper)

Shipments of recombinant DNA Materials exceeding 50 ml in volume and containing any portion of an etiologic agent listed in paragraph (c) of 42 CFR 72.25 are restricted, by DOT regulations, to transport by cargo only aircraft. When the volume of a single primary container exceeds the 50 ml limitation, this restriction must be indicated on the Shipper's Certificate by crossing out "Passenger Aircraft".

When dry ice is used as a refrigerant an "ORA-Group A-DRY ICE LABEL" should be affixed to the outer shipping container. The amount of dry ice used and the date packed should be designated on the label.

2. International Transportation.

In addition to the packaging and labeling requirements of the regulations previously cited, international shipments of recombinant DNA materials in which any portion of

the material is derived from an etiologic agent listed in paragraph (c) of 42 CFR 72.25 must have one or more of the following documents—depending on the country of destination:

(1) Parcel Post Customs Declaration (PS 2966) tag.

(2) Parcel Post Customs Declaration (PS 2966-A) label.

(3) International Parcel Post—Instructions Given by Sender (POD 2922) label.

(4) Dispatch note (POD 2972) tag.

(5) "Violet Label".

(6) Shipper's Certificate specified in the current International Air Transport Association Tariff.

Individual country requirements are listed in "International Postage Rates and Fees" (USPO Publication 51).

TABLE III.—Description of packages for material in volume less than 50 ml.

Volume (milliliter)	Primary container	Packing	Secondary container	Packing	Outer shipping container ¹
15 maximum..	Sealed vial(s) or small glass test tube, screw cap or stopper, taped. ²	Nonparticulate absorbent material at top, bottom, and sides that will completely absorb contents of the primary container(s).	Metal can 1-in diameter by 7-in outside dimensions metal screw cap.	None required	Fiberbody; metal screw cap, top and bottom; 1½-in diameter by 7-to 7½-in outside dimensions.
50 or less.....	One 20 by 150 mm test tube, taped stopper or multiple small vials. ²	do.....	Metal can 2½-in diameter by 6½-in high outside dimensions screw cap.	do.....	Fiberbody; metal screw cap, top and bottom; 3¼-in diameter by 7-to 7½ in outside dimensions.
Do.....	Plastic screw cap bottle or Pyrex glass with skirt rubber stopper. ²	do.....	do.....	do.....	Do.
Do.....	Multiple watertight vials or tubes, taped stoppers. ²	do.....	1 or more friction-seal tin cans 306 by 400 or larger. ²	None required, but with the 306 by 400 cans or larger cans use sufficient non-particulate shock-absorbent material to prevent rattling.	Fiberboard box.

¹ If materials are to be refrigerated, it is recommended that an overpack be used to contain the refrigerant and the secured (original) outer shipping container. A leak-proof outer container must be used for water ice. If dry ice is used the outer container must permit release of carbon dioxide. Interior supports must be provided to hold the container(s) in the original position(s) after wet or dry ice has dissipated.

² The flexibility of the plastic bottle requires that a stopper or screw cap be secured in place by adhesive tape. The usual equivalent-size glass flat-sided prescription

bottle is too fragile for use. For air transport, all stoppers, corks, and caps on primary containers must be secured in place with wire, tape, or other means, and all screw-capped containers of unfrozen liquid must be placed in 5- or 6-mil polyvinyl tubing, heat sealed at both ends to prevent atmospheric decompression that may result in leakage past the screw cap.

³ 610 by 708 and 804 by 908 are trade designations for outside dimensions of 6¼-in diameter by 7¾-in height, and 8¼-in by 9¾-in.

TABLE IV.—Description of packages for material in volumes of 50 ml or greater

Volume (milliliter)	Primary container	Packing	Secondary container		Packing		Outer shipping container	
			Secondary container		Packing		Outer shipping container	
			With refrigerant	Without refrigerant	With refrigerant	Without refrigerant	With refrigerant	Without refrigerant
51 to 100.....	Plastic or Pyrex glass screw cap bottle; rubber or skirt rubber stopper, taped. ¹	Nonparticulate absorbent material at top, bottom, and sides that will completely absorb contents of the primary container(s).	Consists of metal container and outer container specified in table III.		Shock absorbent material, in volume at least equal to that between the primary and secondary container(s), at the top, bottom, and sides between the secondary container and the outer shipping container. The shock absorbent material shall be so placed that the secondary container(s) does not become loose inside the outer shipping container as the water ice or dry ice is dissipated.		Fiberboard box closely fitting the styrofoam box, taped shut.	Corrugated fiberboard or cardboard box, taped shut.
100 maximum....	1 100-ml plastic screw cap narrow neck bottle or Pyrex glass, taped. ¹	do.....	No. 3 crimp seal tin can No. 4 by 700 or a 1-gal friction-seal tin can, 610 by 708, top soldered or clipped at 4 points. ²		do.....	do.....	do.....	V3C cardboard box PS3 type, 9 ³ / ₁₆ in by 9 ³ / ₁₆ in by 11 ¹ / ₄ in high outside dimensions, taped shut with 3 in type PS3 tape.
200 maximum....	2 100-ml plastic screw cap bottles or Pyrex glass, taped. ¹	do.....	do.....		do.....	do.....	do.....	Do.
250 maximum....	1 250-ml plastic narrow mouth screw cap bottle or Pyrex glass skirted rubber stopper, taped. ¹	do.....	do.....		do.....	do.....	do.....	Do.
500 maximum....	2 250-ml plastic screw cap bottles or Pyrex glass bottles, taped. ¹	do.....	2-gal friction-seal tin can, 804 by 908, top soldered or clipped at 4 points. ²		do.....	do.....	do.....	V3C cardboard box 12 ¹ / ₄ in by 12 ¹ / ₄ in by 10 ¹ / ₁₆ in high outside dimensions, taped shut with 3-in wide PS3 tape.
Do.....	500-ml Pyrex glass bottle, rubber-skirt stopper, taped, or 500-ml plastic bottle, narrow or wide mouth, screw cap, taped. ¹	do.....	No. 12 crimp seal tin can 603 by 810 2-gal friction-seal tin can, 804 by 908, top soldered or clipped at 4 points. ²		do.....	do.....	do.....	V3C cardboard box 12 ¹ / ₄ in by 12 ¹ / ₄ in by 10 ¹ / ₁₆ in high outside dimensions, taped shut with 3 in wide PS3 tape. For the No. 12 can a cardboard box is OK taped shut.

¹ The flexibility of the plastic bottle requires that a stopper or screw cap be secured in place by adhesive tape. The usual equivalent-size glass flat-sided prescription bottle is too fragile for use. For air transport, all stoppers, corks, and caps on primary containers must be secured in place with wire, tape, or other means, and all screw-capped containers of unfrozen liquid must be placed in 5 or 6 mil polyvinyl tubing heat-sealed at both ends to prevent atmospheric decompression that may result in leakage past the screw cap.

² 610 by 708 and 804 by 908 are trade designations for outside dimensions of 6⁹/₁₆ in diameter by 7³/₁₆ in height, and 8⁵/₁₆ in by 9⁵/₁₆ in.

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE; PUBLIC HEALTH SERVICE; CENTER FOR DISEASE CONTROL; ATLANTA, GEORGIA 30333; TELEPHONE: (404) 633-3311, EXT. 3883

TITLE 42—PUBLIC HEALTH; CHAPTER I—PUBLIC HEALTH SERVICE, DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE; SUBCHAPTER F—QUARANTINE, INSPECTION, LICENSING; PART 72—INTERSTATE QUARANTINE; SUBPART C—SHIPMENT OF CERTAIN THINGS

Section 72.25 of Part 72, Title 42, Code of Federal Regulations, is amended to read as follows:

§ 72.25 Etiologic agents.¹

(a) Definitions. As used in this section:

(1) An "etiologic agent" means a viable microorganism or its toxin which causes, or may cause, human disease.

(2) "diagnostic specimen" means any human or animal material including, but not limited to, excreta, secretions, blood and its components, tissue, and tissue fluids being shipped for purposes of diagnosis.

(3) A "biological product" means a biological product prepared and manufactured in accordance with the provisions of 9 CFR Part 10, Licensed Veterinary Biological Products, 42 CFR Part 73, Licensed Human Biological Products, 21 CFR 130.3, *New drugs for investigational use in humans*, 9 CFR Part 103, Biological Products for Experimental Treatment of Animals, or 21 CFR 130.3(a), *New drugs for investigational use in animals*, and which, in accordance with such provisions may be shipped in interstate traffic.

(b) Transportation; etiologic agent minimum packaging requirements. No person may knowingly transport or cause to be transported in interstate traffic, directly or indirectly, any material, including but not limited to, diagnostic specimens and biological products, containing, or reasonably believed by such person to contain an etiologic agent unless such material is packaged to withstand leakage of contents, shocks, pressure changes, and other conditions incident to ordinary handling in transportation.

(c) Transportation; etiologic agents subject to additional requirements. No person may knowingly transport or cause to be transported in interstate traffic, directly or indirectly, any material, other than diagnostic specimens and biological products, containing, or reasonably believed by such person to contain, one or more of the following etiologic agents unless such material is packaged in accordance with the requirements specified in paragraph (b) of this section, and unless, in addition, such material is packaged and shipped in accordance with the requirements specified in subparagraphs (1)–(6) of this paragraph:

¹ The requirements of this section are in addition to and not in lieu of any other packaging or other requirements for the transportation of etiologic agents in interstate traffic prescribed by the Department of Transportation and other agencies of the Federal Government.

BACTERIAL AGENTS

Actinobacillus—all species.
Arizona hinshawii—all serotypes.
Bacillus anthracis.
Bartonella—all species.
Bordetella—all species.
Borrelia recurrentis, *B. vincenti*.
Brucella—all species.
Clostridium botulinum, *Cl. chauvoei*, *Cl. haemolyticum*, *Cl. histolyticum*, *Cl. novyi*, *Cl. septicum*, *Cl. tetani*.
Corynebacterium diphtheriae *C. equi*, *C. haemolyticum*, *C. pseudotuberculosis*, *C. pyogenes*, *C. renale*.
Diplococcus (Streptococcus) pneumoniae.
Erysipelothrix insidiosa.
Escherichia coli, all enteropathogenic serotypes.
Francisella (Pasteurella) tularensis.
Haemophilus ducreyi, *H. influenzae*.
Herellea vaginicola.
Klebsiella—all species and all serotypes.
Leptospira interrogans—all serotypes.
Listeria—all species.
Mima polymorpha.
Moraxella—all species.
Mycobacterium—all species.
Mycoplasma—all species.
Neisseria gonorrhoeae, *N. meningitidis*.
Pasteurella—all species.
Pseudomonas pseudomallei.
Salmonella—all species and all serotypes.
Shigella—all species and all serotypes.
Sphaerophorus necrophorus.
Staphylococcus aureus.
Streptobacillus moniliformis.
Streptococcus pyogenes.
Treponema carereum, *T. pallidum*, and *T. pertenue*.
Vibrio fetus, *V. comma*, including biotype El Tor, and *V. parahemolyticus*.
Yersinia (Pasteurella) pestis.

FUNGAL AGENTS

Actinomyces (including *Nocardia species*, *Actinomyces species* and *Arachnia propionica*).
Blastomyces dermatitidis.
Coccidioides immitis.
Cryptococcus neoformans.
Histoplasma capsulatum.
Paracoccidioides brasiliensis.

VIRAL, RICKETTSIAL, AND CHLAMYDIAL AGENTS

Adenoviruses—human—all types.
Arboviruses.
Coxiella burnetii.
Coxsackie A and B viruses—all types.
Cytomegaloviruses.
Dengue virus.
Echoviruses—all types.
Encephalomyocarditis virus.
Hemorrhagic fever agents, including *Crimean hemorrhagic fever (Congo)*, *Junin*, and *Machupo viruses*, and others as yet undefined.
Hepatitis-associated antigen.
Herpesvirus—all members.
Infectious bronchitis-like virus.
Influenza viruses—all types.
Lassa virus.
Lymphocytic choriomeningitis virus.
Marburg virus.
Measles virus.

Mumps virus.

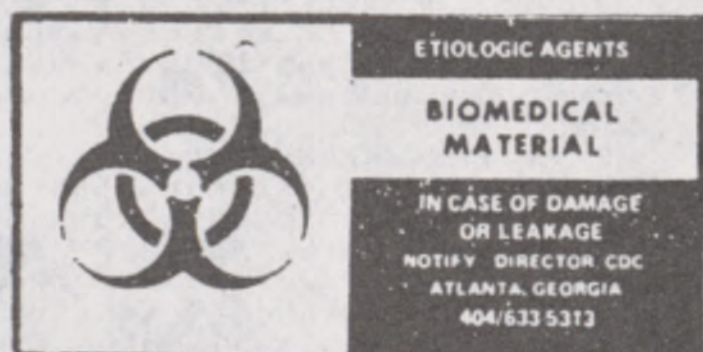
Parainfluenza viruses—all types.
Poliomyelitis viruses—all types.
Poxviruses—all members.
Psittacosis-Ornithosis-Trachoma-Lymphogranuloma group of agents.
Rabies virus—all strains.
Reoviruses—all types.
Respiratory syncytial virus.
Rhinoviruses—all types.
Rickettsia—all species.
Rubella virus.
Simian viruses—all types.
Tick-borne encephalitis virus complex, including *Russian spring-summer encephalitis*, *Kyasanur forest disease*, *Omsk hemorrhagic fever*, and *Central European encephalitis viruses*.
Vaccinia virus.
Varicella virus.
Variola major and *Variola minor viruses*.
Vesicular stomatitis virus.
Yellow fever virus.

(1) Volume less than 50 ml. Material shall be placed in a securely closed, watertight container (primary container (test tube, vial, etc.)) which shall be enclosed in a second, durable watertight container (secondary container). Several primary containers may be enclosed in a single secondary container, if the total volume of all the primary containers so enclosed does not exceed 50 ml. The space at the top, bottom, and sides between the primary and secondary containers shall contain sufficient nonparticulate absorbent material to absorb the entire contents of the primary container(s) in case of breakage or leakage. Each set of primary and secondary containers shall then be enclosed in an outer shipping container constructed of corrugated fiberboard, cardboard, wood, or other material of equivalent strength.

(2) Volume 50 ml. or greater. Packaging of material in volumes of 50 ml. or more shall include, in addition, a shock absorbent material, in volume at least equal to that of the absorbent material between the primary and secondary containers at the top, bottom, and sides between the secondary container and the outer shipping container. Single primary containers shall not contain more than 500 ml. of material. However, two or more primary containers whose combined volumes do not exceed 500 ml. may be placed in a single, secondary container. Not more than eight secondary shipping containers may be enclosed in a single outer shipping container. (The maximum amount of etiologic agent which may be enclosed within a single outer shipping container shall not exceed 4,000 ml.)

(3) Dry ice. If dry ice is used as a refrigerant, it must be placed outside the secondary container(s). If dry ice is used between the secondary container and the outer shipping container, the shock absorbent material shall be so placed that the secondary container does not become loose inside the outer shipping container as the dry ice sublimates.

(4) Labels. The label for Etiologic Agents/Biomedical Material, except for size and color, must be shown:



(i) The color of material on which the label is printed must be white and the symbol and printing in red.

(ii) The label must be a rectangle measuring 51 mm. (2 inches) high by 102.5 mm. (4 inches) long.

(iii) The red symbol measuring 38 mm. (1½ inches) in diameter must be centered in a white square measuring 51 mm. (2 inches) on each side.

(iv) Type size of the letters of label shall be as follows:

ETIOLOGIC AGENT.....	10 pt. rev.
BIOMEDICAL MATERIAL.....	14 pt.
IN CASE OF DAMAGE OR LEAKAGE.....	10 pt. rev.
NOTIFY DIRECTOR CDC AT- LANTA, GA.....	8 pt. rev.
404 633 5313.....	10 pt. rev.

(5) *Damaged packages.* Carriers shall promptly, upon discovery of damage to the package that indicates damage to the primary container, isolate the package and notify the Director, Center for Disease Control, 1600 Clifton Road NE., Atlanta, GA 30333 (telephone (404) 633-5313), and the sender.

(6) *Registered mail or equivalent system.* Transportation of the following etiologic agents shall be by registered mail or an equivalent system which requires or provides for sending notification to the shipper immediately upon delivery:

Actinobacillus mallei.
Coccidioides immitis.
Francisella (Pasteurella) tularensis.
Hemorrhagic fever agents, including, but not limited to, Crimean hemorrhagic fever (Congo), Junin, Machupo viruses.
Herpesvirus simiae (B virus).
Histoplasma capsulatum.
Lassa virus.
Marburg virus.
Pseudomonas pseudomallei.
Tick-borne encephalitis virus complex. Including, but not limited to, *Russian spring-summer encephalitis, Kyasanur forest disease, Omsk hemorrhagic fever, and Central European encephalitis viruses. Variola minor and Variola major.*
Yersenia (Pasteurella) pestis.

(d) *Notice of delivery; failure to receive.* When notice of delivery of agents containing, or suspected of containing, etiologic agents listed in paragraph (c) (6) of this section is not received by the sender within 5 days following anticipated delivery of the package, the shipper shall notify the Director, Center for Disease Control, 1600 Clifton Road NE., Atlanta, GA 30333 (telephone (404) 633-5313).

(e) *Requirements; variations.* The Administrator may approve variations from the requirements of this section if, upon review and evaluation, he finds that such variations provide protection at least equivalent to that provided by compliance with the requirements specified in this section and makes such findings a matter of official record.

(Sec. 361, 58 Stat. 703; 42 U.S.C. 264)

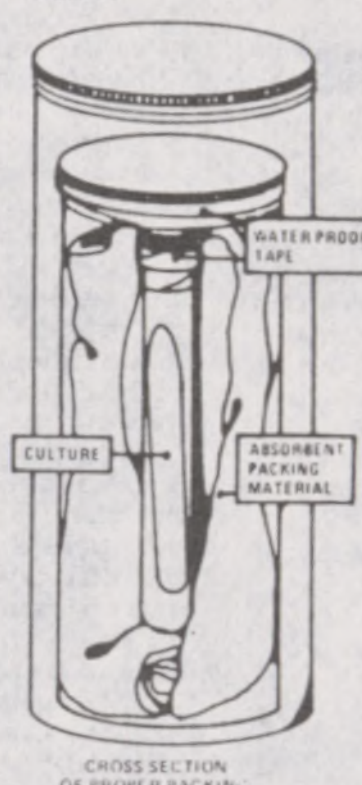
[FR Doc.72-9887 Filed 6-29-72; 8:45 am]

Effective July 30, 1972



PACKAGING AND LABELING OF ETIOLOGIC AGENTS

FIGURE 2



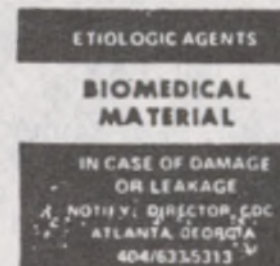
The Interstate Quarantine Regulations (42 CFR, Part 72.25, Etiologic Agents) was revised July 31, 1972 to provide for packaging and labeling requirements for etiologic agents and certain other materials shipped in interstate traffic.

Figures 1 and 2 diagram the packaging and labeling of etiologic agents in volumes of less than 50 ml. in accordance with the provisions of subparagraph (C) (1) of the cited regulation. Figure 3 illustrates the color and size of the label, described in subparagraph (C) (4) of the regulations, which shall be affixed to all shipments of etiologic agents.

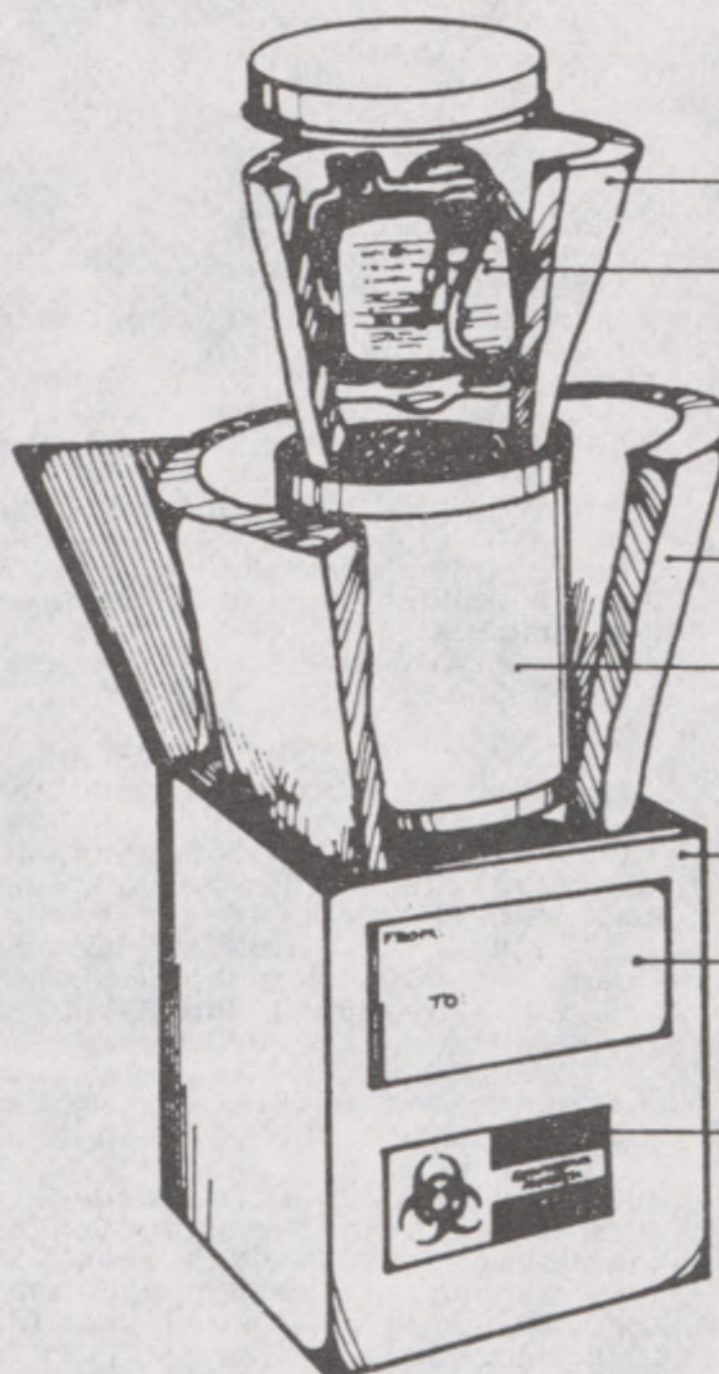
For further information on any provision of this regulation contact:

Center for Disease Control
 Attn: Biohazards Control Office
 1600 Clifton Road
 Atlanta, Georgia 30333
 Telephone: 404 633 3311

FIGURE 3



PACKAGING AND LABELING OF ETIOLOGIC AGENTS



ABSORBENT PACKING MATERIAL

PRIMARY CONTAINER (Bottle, blood bag, etc.)*

*NOTE: Single primary containers may not exceed 500 ml. of material. Two or more primary containers whose combined volumes do not exceed 500 ml. may be enclosed in a single, secondary container. The maximum volume of etiologic agent which may be enclosed in a single outer shipping container shall not exceed 4000 ml.

SHOCK ABSORBENT MATERIAL

SECONDARY CONTAINER (Gasketed screwcap with waterproof tape or hermetically sealed can)

OUTER SHIPPING CONTAINER

MAILING LABEL

ETIOLOGIC AGENT LABEL

The Interstate Quarantine Regulations (42 CFR, Part 72.25, Etiologic Agents) was revised July 31, 1972, to provide for packaging and labeling requirements for etiologic agents and certain other materials shipped in interstate traffic. The illustration shows acceptable packaging and labeling of etiologic agents in accordance with subparagraphs (c) (2) and (4) of the cited regulation.

For further information on any provision of this regulation contact:

Center for Disease Control
 Attn: Biohazards Control Office
 1600 Clifton Road
 Atlanta, Georgia 30333
 Telephone: 404-633-3311

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XI. TRAINING AIDS, MATERIALS AND COURSES

A. Slide-Tape Cassettes

1. Assessment of Risk in the Cancer Virus Laboratory (\$10).
2. Effective Use of The Laminar Flow Biological Safety Cabinet (\$10).
3. Formaldehyde Decontamination of Laminar Flow Biological Safety Cabinets (\$10).
4. Certification of Class II (Laminar Flow) Biological Safety Cabinets (\$13).
5. Hazard Control in the Animal Laboratory (\$10).
6. Basic Principles of Contamination Control (In preparation).
7. Selection of a Biological Safety Cabinet (In preparation). These slide tape cassettes are available for purchase from the National Audiovisual Center. The price for each is given above after the title. Send your order prepaid with a check or money order made payable to National Archives Trust Fund and mail to: Sales Branch, National Audiovisual Center (GSA), Washington, D.C. 20409.
8. Research Laboratory Safety. This slide tape cassette, stock number 176.79, is available for \$75 from the National Safety Council, 425 North Michigan Avenue, Chicago, Illinois 60611.

B. Films

1. Air Sampling for Microbiological Particulates (M-926).
 2. Handling the Laboratory Guinea Pig (T2618-X).
 3. Handling the Laboratory Mouse (T2617-X).
 4. Infectious Hazards of Bacteriological Techniques (M-382).
 5. Laboratory Design for Microbiological Safety (M-1091).
 6. Plastic Isolators: New Tools for Medical Research (M-599).
 7. Safe Handling of Laboratory Animals (M-455).
 8. Surface Sampling for Microorganisms (Rodac Method) (M-924).
 9. Surface Sampling for Microorganisms (Swab Method) (M-925).
- These films are available on loan without charge from: Media Resources Branch, National Medical Audiovisual Center (Annex), Station K, Atlanta, Georgia 30324.
- The same films (except 2 and 3) can be rented or bought from: National Audiovisual Center (GSA) (Rental Branch) = (Sales Branch), Washington, D.C. 20409.

C. Courses

1. Biohazard and Injury Control in the Biomedical Laboratory. Presented by the University of Minnesota, School of Public Health and the National Cancer Institute, Office of Research Safety. Direct inquiries to Dr. Donald Vesley, University of Minnesota, School of Public Health, 1325 Mayo Memorial Building, Minneapolis, Minnesota 55455. June 22-24, 1976, Los Angeles, CA; October 26-28, 1976, Boston, MA; December 7-9, 1976, Bethesda, MD.
2. Biohazard Containment and Control for Recombinant DNA Molecules. Presented by the University of Minnesota, School of Public Health and the National Cancer Institute, Office of Research Safety. Direct inquiries as above. September 8-9, 1976, Stanford, CA; September 21-23, 1976; Cold Spring Harbor, NY.
3. Safety in Laboratory. Presented by National Institute of Occupational Safety and Health, Division of Training and Manpower Development, by special arrangement. Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, Ohio 45226.
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 James F. Sullivan, National Animal Disease Laboratories.
 Arnold G. Wedum, Frederick Cancer Research Center.

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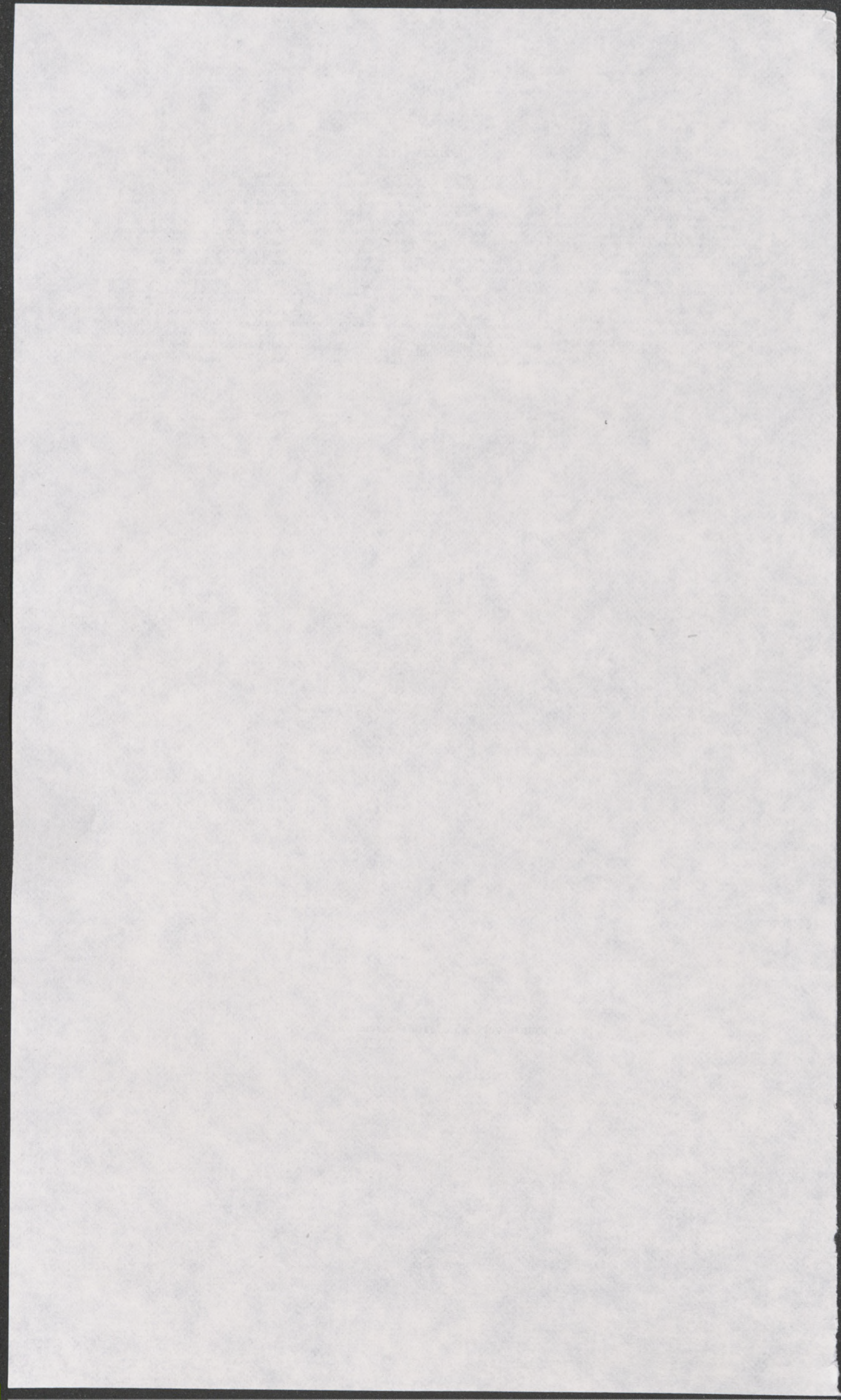
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CLASSIFICATION OF ETIOLOGIC AGENTS

ON THE BASIS OF HAZARD

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE



**CLASSIFICATION OF
ETIOLOGIC AGENTS
ON THE
BASIS OF HAZARD**

4th Edition, July 1974
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**U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
CENTER FOR DISEASE CONTROL
OFFICE OF BIOSAFETY
ATLANTA, GEORGIA 30333**

Prepared by the U.S. Public Health Service *Ad Hoc*
Committee on the Safe Shipment and Handling of Etiologic
Agents, with assistance from the staff of the Center for
Disease Control.

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I. INTRODUCTION

This document provides a standard for evaluating the hazards associated with various etiologic agents and defines minimal safety conditions for their management without restricting or hampering bona fide microbiological investigations. Human etiologic agents are placed in four classes of increasing hazard. A fifth class, composed of animal agents excluded from the United States by law and United States Department of Agriculture (USDA) administrative policy, is described on page 2. The degree of hazard depends on the etiologic agent and the nature and kind of study in which it is being used. Aerosol studies, passage in animals, and infection of arthropod vectors markedly increase the hazard, whereas strict adherence to *in vitro* experiments decreases the hazard.

Other important factors must be considered when planning experiments with etiologic agents, particularly with those in Classes 3 and 4. These factors obviously vary from situation to situation, and it would be impossible to list all of them. Therefore, each investigator must use scientific judgment in interpreting the classification. For example, the public health risk accompanying animal infection or transmission experiments with yellow fever in southeastern states where the mosquito vector of the disease is prevalent would make them highly inadvisable except under the most rigidly controlled conditions, although a similar experiment in northern states, where natural vectors are lacking, could be conducted with far less risk.

Another factor that must be considered is whether the agent to be used naturally exists in the United States. This distinction is especially important when planning work with disease agents in

Classes 3 and 4 such as smallpox, which has been eradicated in this country. Experiments with such agents should be undertaken only when valid scientific consideration requires the use of the particular agents and no less hazardous agent can be substituted for it.

Anyone planning to work with etiologic agents should be aware of the animal agents in Class 5 which are excluded from the United States by law (virus of foot and mouth disease) and USDA administrative policy (African horse sickness virus, African swine fever virus, *Besnoitia besnoiti*, Borna disease virus, bovine infectious petechial fever, camel pox virus, ephemeral fever virus, fowl plague virus, goat pox virus, hog cholera virus, louping ill virus, lumpy skin disease virus, Nairobi sheep disease virus, Newcastle disease virus (Asiatic strains), *Mycoplasma mycoides* (contagious bovine pleuropneumonia), *Mycoplasma agalactiae* (contagious agalactia of sheep), *Rickettsia ruminantium* (heart water), Rift valley fever virus, rinderpest virus, sheep pox virus, swine vesicular disease virus, Teschen disease virus, *Trypanosoma vivax* (Nagana), *Trypanosoma evansi*, *Theileria parva* (East Coast fever), *Theileria annulata*, *Theileria lawrencei*, *Theileria bovis*, *Theileria hirci*, vesicular exanthema virus, Wesselsbron disease virus, *Zyoonema farciminosum* (pseudofarcy)).

II. PRINCIPLES OF CLASSIFICATION

Members from those offices of the Public Health Service (PHS) and the USDA which have regulatory responsibility for quarantine and interstate shipment of etiologic agents participated in the development of the "Basis for Agent Classifications" which begins on page 3. Therefore, the principles expressed in the "Basis for Agent Classifications" are equally applicable to human and animal pathogens, although the specific list of agents, with the few exceptions noted, includes only human pathogens.

The least hazardous agents are in Class 1, and those requiring the greatest restrictions are in Class 4. Since the number of relatively or completely nonpathogenic agents is very large, listing all of

them in Class 1 would be impractical. Therefore, all agents which are not listed in Classes 2 through 4 belong in Class 1. Three special viruses in Class 1 are listed because the PHS *Ad Hoc* Committee on the Safe Shipment and Handling of Etiologic Agents considered them suitable for science experiments at a junior level. Newly recognized agents will be classified in later editions.

Basis for Agent Classifications

CLASS 1

Agents of no or minimal hazard under ordinary conditions of handling.

CLASS 2

Agents of ordinary potential hazard. This class includes agents which may produce disease of varying degrees of severity from accidental inoculation or injection or other means of cutaneous penetration but which are contained by ordinary laboratory techniques.

CLASS 3

Agents involving special hazard or agents derived from outside the United States which require a federal permit for importation unless they are specified for higher classification. This class includes pathogens which require special conditions for containment.

CLASS 4

Agents that require the most stringent conditions for their containment because they are extremely hazardous to laboratory personnel or may cause serious epidemic disease. This class includes Class 3 agents from outside the United States when they are employed in entomological experiments or when other entomological experiments are conducted in the same laboratory area.

CLASS 5

Foreign animal pathogens that are excluded from the United States by law or whose entry is restricted by USDA administrative policy. (These agents are listed on page 2.)

Note: Federally licensed vaccines containing live bacteria or viruses are not subject to these classifications. These classifications are applicable, however, to cultures of the strains used for vaccine production, or further passages of the vaccine strains.

III. CLASSIFICATION OF AGENTS^{1,2}**A. Classification of Bacterial Agents****CLASS 1**

All bacterial agents not included in higher classes according to "Basis for Agent Classifications."

CLASS 2

Actinobacillus — all species except *A. mallei*, which is in Class 3

Arizona hinshawii — all serotypes

Bacillus anthracis

Bordetella — all species

Borrelia recurrentis, *B. vincenti*

Clostridium botulinum,

Cl. chauvoei, *Cl. haemolyticum*,

Cl. histolyticum, *Cl. novyi*,

Cl. septicum, *Cl. tetani*

Corynebacterium diphtheriae,

C. equi, *C. haemolyticum*,

C. pseudotuberculosis,

C. pyogenes, *C. renale*

Diplococcus (Streptococcus) pneumoniae

1. This classification does not include strictly animal pathogens.

2. A PHS permit is required to import any agent or to transfer within the United States any agent imported under permit.

Erysipelothrix insidiosa
Escherichia coli — all enteropathogenic serotypes
Haemophilus ducreyi, *H. influenzae*
Herellea vaginicola
Klebsiella — all species and all serotypes
Leptospira interrogans — all serotypes
Listeria — all species
Mima polymorpha
Moraxella — all species
Mycobacteria — all species except those listed in
 Class 3
Mycoplasma — all species except *Mycoplasma*
 mycoides and *Mycoplasma agalactiae*,
 which are in Class 5 (page 2)
Neisseria gonorrhoeae, *N. meningitidis*
Pasteurella — all species except those listed in Class
 3
Salmonella — all species and all serotypes
Shigella — all species and all serotypes
Sphaerophorus necrophorus
Staphylococcus aureus
Streptobacillus moniliformis
Streptococcus pyogenes
Treponema carateum, *T. pallidum*, and *T. pertenue*
Vibrio fetus, *V. comma*, including biotype E1 Tor,
 and *V. parahemolyticus*

CLASS 3

*Actinobacillus mallei**
Bartonella — all species
Brucella — all species
Francisella tularensis
Mycobacterium avium, *M. bovis*, *M. tuberculosis*
Pasteurella multocida type B ("buffalo" and other
 foreign virulent strains*)
*Pseudomonas pseudomallei**
Yersenia pestis

*USDA permit also required for import or interstate transport.

B. Classification of Fungal Agents

CLASS 1

All fungal agents not included in higher classes
according to "Basis for Agent Classifications"

CLASS 2

Actinomyces (including *Nocardia* species and
Actinomyces species and *Arachnia propionica*)
Blastomyces dermatitidis
Cryptococcus neoformans
Paracoccidioides brasiliensis

CLASS 3

Coccidioides immitis
Histoplasma capsulatum
Histoplasma capsulatum var. *duboisii*

C. Classification of Parasitic Agents

CLASS 1

All parasitic agents not included in higher classes
according to "Basis for Agent Classification."

CLASS 2

Endamoeba histolytica
Leishmania sp.
Naegleria gruberi
Toxoplasma gondii
Toxocara canis
Trichinella spiralis
Trypanosoma cruzi

CLASS 3

Schistosoma mansoni

D. Classification of Viral, Rickettsial, and Chlamydial Agents

CLASS 1

Class 1 includes all viral, rickettsial, and chlamydial agents not included in higher classes according to "Basis for Agent Classification." Specifically listed are:

Influenza virus A/PR8/34

Newcastle virus — strains licensed for vaccine use in U.S.

Parainfluenza virus 3, SF4 Strain

(These viruses are included because the Committee agreed that they are suitable for science experiments at a junior level.)

CLASS 2

Adenoviruses — human — all types

Cache Valley virus

Coxsackie A and B viruses

Cytomegaloviruses

Echoviruses — all types

Encephalomyocarditis virus (EMC)

Flanders virus

Hart Park virus

Hepatitis-associated antigen material

Herpes viruses — except *Herpesvirus simiae* (Monkey B virus) which is in Class 4

Corona viruses

Influenza viruses — all types except A/PR8/34, which is in Class 1

Langat virus

Lymphogranuloma venereum agent

Measles virus

Mumps virus

Parainfluenza viruses — all types except Parainfluenza virus 3, SF4 strain, which is in Class 1

Polioviruses — all types, wild and attenuated

Poxviruses — all types except *Alastrim*, *Smallpox*, *Monkey pox*, and *Whitepox*, which, depending on experiments, are in Class 3 or Class 4

Rabies virus — all strains except *Rabies street virus*, which should be classified in Class 3 when inoculated into carnivores

Reoviruses — all types

Respiratory syncytial virus

Rhinoviruses — all types

Rubella virus

Simian viruses — all types except *Herpesvirus simiae* (*Monkey B virus*) and *Marburg virus*, which are in Class 4

Sindbis virus

Tensaw virus

Turlock virus

Vaccinia virus

Varicella virus

Vole rickettsia

Yellow fever virus, 17D vaccine strain

CLASS 3

Alastrim, *Smallpox*, *Monkey pox*, and *Whitepox*, when used *in vitro*

Arboviruses — all strains except those in Class 2 and 4 (*Arboviruses* indigenous to the United States are in Class 3, except those listed in Class 2. *West Nile* and *Semliki Forest* viruses may be classified up or down, depending on the conditions of use and geographical location of the laboratory.)

Dengue virus, when used for transmission or animal inoculation experiments

Lymphocytic choriomeningitis virus (LCM)

Psittacosis-Ornithosis-Trachoma group of agents

Rabies street virus, when used in inoculations of carnivores (See Class 2.)

Rickettsia — all species except *Vole rickettsia* when used for transmission or animal inoculation experiments

*Vesicular stomatitis virus**

Yellow fever virus — wild, when used *in vitro*

CLASS 4

Alastrim, Smallpox, Monkey pox, and Whitepox, when used for transmission or animal inoculation experiments

Hemorrhagic fever agents, including *Crimean hemorrhagic fever (Congo)*, *Junin*, and *Machupo* viruses, and others as yet undefined

Herpesvirus simiae (Monkey B virus)

Lassa virus

Marburg virus

Tick-borne encephalitis virus complex, including *Russian spring-summer encephalitis*, *Kyasanur forest disease*, *Omsk hemorrhagic fever*, and *Central European encephalitis viruses*

Venezuelan equine encephalitis virus, epidemic strains, when used for transmission or animal inoculation experiments

Yellow fever virus — wild, when used for transmission or animal inoculation experiments

IV. LEVEL OF COMPETENCE AND PHYSICAL CONTAINMENT RECOMMENDED FOR EACH CLASS

The following recommendations describe the level of competence and physical containment suggested for working with agents of each Class.

*USDA permit also required for import or interstate transport.

CLASS 1

Distribution to all users; no special competence or containment required.

CLASS 2

Distribution to laboratories whose staffs have levels of competency equal to or greater than one would expect in a college department of microbiology. Requests for agents in Class 2 are placed on institutional letterhead.

CLASS 3

Distribution to laboratories whose staffs have levels of competency equal to or greater than one would expect in a college department of microbiology and who have had special training in handling dangerous agents and are supervised by competent scientists. For aerosol studies, passage in animals, and infection of arthropod vectors, the laboratory should be located in a geographical area in which the chance of accidental establishment of the agent in a susceptible ecologic focus is minimal. Requests for agents in Class 3 are signed by the chairman of the department or the head of the laboratory or research institute where the work will be carried out. Conditions for containment include:

1. A controlled access facility: suite or room separated from the activities of individuals not engaged in handling Class 3 agents and from the general traffic pattern of the rest of the building or laboratory.
2. Negative air pressure is maintained at the site of work in a preparation cubicle or under a hood. Air is recirculated only after it has been adequately decontaminated through high efficiency filters.
3. Animal experiments, including cage sterilization, refuse handling, disposal of animals, etc., are conducted with a level of precaution equivalent to conditions required for laboratory experiments.
4. Personnel at risk are immunized against agents for which immune prophylaxis is available.

CLASS 4

Distribution to laboratories whose staffs have levels of competency equal to or greater than one would expect in a college department of microbiology and who have had special training in handling dangerous pathogens and are supervised by competent scientists. For aerosol studies, passage in animals and infection of arthropod vectors, the laboratory should be located in a geographic area in which the risk of accidental establishment of the agent in a susceptible ecologic focus is minimal. Requests for agents in Class 4 are signed by the director of the institute or laboratory where the work is to be carried out. Conditions for containment include all those required for Class 3 agents and the following:

1. Work areas are in a facility which is in effect a separate building, or they are separated from other work areas by effective airlocks.
2. If the work area is not in a separate building, the entire area used for Class 4 agents has a separate air exhaust and negative pressure with respect to other areas of the building. Exhaust air is decontaminated by filtration through high efficiency filters or by some other suitable process. Class 4 agents are manipulated only in safety cabinets equipped with absolute filters.
3. Access to work areas is restricted to individuals immunized or otherwise under specific control.
4. Protective clothing is worn, and it is decontaminated before being removed from the laboratory area.
5. When an agent is used in entomological experiments, the windows, walls, floor, ceiling, and airlock of the work area are insect-proof, and pure pyrethrum insecticide or a suitable insect killing device is available in the airlock.

V. GENERAL SAFETY

The best way to maintain laboratory safety is to practice correct and careful laboratory techniques, including effective decon-

tamination and sterilization procedures, at all times. The laboratory's isolation and containment requirements are to supplement, not to supplant, good laboratory practice and sound scientific judgment. However, in an adequately isolated and properly equipped laboratory with correctly directed airflow, a scientifically and technically competent investigator can confidently work even with the most hazardous agents, provided the safety cabinets are selected to meet the requirements of the work. Of the several available cabinet types, the investigator should select the one which meets requirements for the maximum risk he expects to encounter.

The Office of Biosafety of the Center for Disease Control, 1600 Clifton Road, N.E., Atlanta, Georgia 30333, is available for consultation on the handling of etiologic agents.

VI. FEDERAL REGULATIONS COVERING ETIOLOGIC AGENTS

Several Federal agencies have regulations which cover the importation, interstate shipment, and safe packaging of etiologic agents. Even though the requirements of the agencies differ somewhat, the same safety principles should apply to all shipments. The investigator who wishes to import etiologic agents from abroad or to forward imported agents to other laboratories should be aware of and observe the restrictions, thus avoiding delays, unpleasant situations and embarrassment.

The principal agencies concerned with the transportation of etiologic agents are the USDA and the PHS. The following should be consulted for current regulations and requirements:

1. For importation or interstate transportation of agents which are animal pathogens:

Chief Staff Veterinarian
Organisms and Vectors
Veterinary Services, APHIS, USDA
Federal Building
Hyattsville, Maryland 20782

2. For importation and interstate movement of agents that cause human disease:**

Center for Disease Control
Attn: Office of Biosafety
Atlanta, Georgia 30333

**In the case of zoonotic agents, both the USDA and the PHS should be consulted.

APPENDIX 10

THURSDAY, SEPTEMBER 9, 1976



PART III:

**DEPARTMENT OF
HEALTH,
EDUCATION, AND
WELFARE**

National Institutes of Health



**RECOMBINANT DNA
RESEARCH GUIDELINES**

Draft Environmental Impact Statement

38426

NOTICES

DEPARTMENT OF HEALTH,
EDUCATION, AND WELFARE

National Institutes of Health

RECOMBINANT DNA RESEARCH
GUIDELINES

Draft Environmental Impact Statement

On Wednesday, June 23, 1976, the Director of the National Institutes of Health, with the concurrence of the Secretary of Health, Education, and Welfare and the Assistant Secretary for Health, issued Guidelines that will govern the conduct of NIH-supported research on recombinant DNA molecules.

The decision by the NIH Director to release the Guidelines was reached after extensive scientific and public airing of the issues. The issues were discussed at public meetings of the Recombinant DNA Molecule Program Advisory Committee (Recombinant Advisory Committee) and the Advisory Committee to the NIH Director. The Recombinant Advisory Committee debated three different versions of the Guidelines during this period, and made detailed recommendations to the NIH Director on how this line of research could proceed effectively with maximum protection of workers and the environment against possible hazards.

The Advisory Committee to the NIH Director, augmented with consultants representing law, ethics, consumer affairs, and the environment, was asked to advise on whether the proposed Guidelines balanced responsibility to protect the public with the potential benefits through the pursuit of new knowledge. The many points of view expressed at an open meeting of the Committee on February 9 and 10, 1976, and in subsequent correspondence, were taken into consideration in the Director's decision.

A number of public commentators urged NIH to consider preparing an environmental impact statement on recombinant DNA research activity. They evoked the possibility that organisms containing recombinant DNA molecules might escape and affect the environment in potentially harmful ways. It should be noted that the development of the guidelines was in large part tantamount to conducting an environmental impact assessment. For example, the objectives of recombinant DNA research were considered and the potential hazards and risks analyzed. Possible alternative approaches to the objectives were thoroughly explored, to maximize safety and minimize potential risks. And an elaborate review structure to ensure safety has been created.

The Guidelines are premised on physical and biological containment to prevent the release or propagation of DNA recombinants outside the laboratory. Deliberate release of organisms into the environment is prohibited. The stipulated physical and biological containment ensures that this research will proceed with a high degree of safety and precaution.

With a view to promoting public understanding of its issuance of the Guidelines, NIH conducted an environmental impact assessment and prepared the

present draft environmental impact statement in accordance with the National Environmental Policy Act of 1969. Notice of the availability of this document appeared in the FEDERAL REGISTER of September 2.

In order to extend the opportunity for public comment and consideration, the present draft environmental impact statement is offered for general comment. Please address any comments on this draft statement to the Director, National Institutes of Health, 9000 Rockville Pike, Bethesda, Maryland 20014. All comments should be submitted by October 18, 1976.

Additional copies of this draft are available from Dr. Rudolf G. Wanner, Associate Director for Environmental Health and Safety, Building 12A, Room 4051, National Institutes of Health, 9000 Rockville Pike, Bethesda, Maryland 20014.

Dated: August 26, 1976.

DONALD S. FREDRICKSON,
Director,
National Institutes of Health.

DRAFT ENVIRONMENTAL IMPACT STATEMENT
GUIDELINES FOR RESEARCH INVOLVING RE-
COMBINANT DNA MOLECULES

NATIONAL INSTITUTES OF HEALTH
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GUIDELINES FOR RESEARCH INVOLVING
RECOMBINANT DNA MOLECULES

National Institutes of Health, Public Health
Service, DHEW, Bethesda, Maryland

(X) Draft () Final Environmental
Impact Statement.

Name of Action

(X) Administrative () Legislative
Action.

Additional Information

Additional information on the proposed action, including technical documents pertinent to this statement may be obtained from:

Dr. Donald S. Fredrickson, Director, National Institutes of Health, 9000 Rockville Pike, Bethesda, Maryland 20014, Telephone: (301) 496-2433.

A copy of the "Guidelines for Research Involving Recombinant DNA Molecules" is attached. (Appendix D)

COMMENTS

The Department, in issuing this draft, is requesting comments on the accuracy of the factual information (including the absence of relevant material) and projections contained therein. Comments shall be submitted by October 18, 1976, the Council on Environmental Quality weekly notice in the FEDERAL REGISTER. Address comments to Dr. Donald S. Fredrickson.

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FOREWORD

Recent developments in molecular genetics, particularly in the last 4 years, open avenues to science that were previously inaccessible. In the "recombinant DNA" experiments considered here, genes—deoxyribonucleic acid (DNA) molecules—from virtually any living organism can be transferred to cells of certain completely unrelated organisms. For example, the genes from one species of bacteria have been transferred to bacteria of another species. And genes from toads and from fruit flies have been introduced into the bacterium *Escherichia coli*.

If the recipient bacterium is then allowed to multiply, it will propagate these newly acquired genes as part of its own genetic complement. It appears likely that any kind of gene from any kind of organism could be introduced into *E. coli* and certain other organisms.

This ability to join together genetic material from two different sources and to propagate these hybrid elements in bacterial and animal cells has resulted in a profound and qualitative change in the field of genetics. Now, for the first time, there is a methodology for crossing very large evolutionary boundaries, and for moving genes between organisms that are believed to have previously had little genetic contact.

The promise of recombinant DNA research for better understanding and improved treatment of human disease is great. There is also a possible risk that microorganisms with foreign genes might cause disease or alter the environment should they escape from the laboratory and infect human beings, animals, or plants. However, in the absence of further experimental data neither the benefits nor the risks can be precisely identified or assessed.

On June 23, 1976, the Director of the National Institutes of Health released Guidelines governing the conduct of NIH-supported research on recombinant DNA molecules (See Appendix D). Promulgation of these Guidelines followed 2 years of intensive discussion and debate within the scientific community and NIH itself, with public participation, concerning the possible hazards of such research and the best means for averting them, although the possible hazards remain speculative. The Guidelines prohibit certain kinds of recombinant DNA experiments and, for those experiments that are permitted, they specify safety precautions and conditions designed to protect the health of laboratory workers, the general public, and the environment should the putative hazards prove real.

The issuance of Guidelines establishing conditions and precautions with respect to such experiments is viewed by NIH as a Federal action that may significantly affect the quality of the human environment, and NIH Director Dr. Donald S. Fredrickson ordered the preparation of this statement pursuant to the National Environmental Policy Act.

Although NEPA assumes that such Federal actions will not be taken until the NEPA procedures are completed, the Director of NIH concluded that the public interest required immediate issuance of the Guidelines, rather than deferral for the months that would be required for completion of the NEPA process. This was because the escape of potentially hazardous organisms was more likely in the absence of NIH action. Further, prompt issuance of the Guidelines was believed necessary in order to promote their acceptance by scientists in the United States and abroad who do not come under the purview of NIH.

Issuance of and compliance with the Guidelines is, in itself, expected to decrease the chance of any detrimental environmental impact. However, since there has been little actual experience to date with recombinant DNA experiments, the indicated confidence in the Guidelines rests essentially upon the judgment of scientists. Their confidence is based on two premises. First, it is believed that the containment measures specified in the Guidelines make the escape of potentially harmful recombinant organisms into the environment highly improbable. Second, it is believed that, even if an experiment performed in accordance with the Guidelines does result in accidental release of recombinant organisms, adverse effects will either not occur or not be serious.

In the absence of an adequate base of data derived from either experiments or experience, it must be recognized that future events may not conform to these judgments. There is some statistical probability that recombinant organisms will find their way into the environment either from experiments under NIH auspices or from the activities of others. It is not difficult to construct scenarios in which injury could result. Although the possibility of significant environmental consequences is entirely speculative, the chance of an event that could cause severe injury, however low the probability, must be treated as an environmental impact.

The NIH Guidelines, in addition to ensuring the safety of NIH-supported researchers, the general public and the environment, are serving as a model for other laboratories throughout the world, thereby promoting environmental protection beyond that achievable through other actions available to the Federal Government. And the experiments themselves may be expected ultimately to lead to an increase of knowledge and the advancement of medicine and other sciences.

Although the action in question—that is, issuance of the Guidelines—has already been taken, the Director of NIH believes that the NEPA review will further enlighten the public and focus attention on the important issues involved, in the interest of gaining the understanding and views of the broadest possible segment of the American people. In issuing the Guidelines, the NIH Director pointed out that they will be subject to continuous review and modification in the light of changing circumstances. Constructive modification could result from information received during the NEPA process.

II. AUTHORITY

The Federal action discussed in this document is taken under the authority of Title III of the Public Health Service Act—General Powers and Duties of Public Health Service; Part A—Research and Investigation; sections 301 and 307 (42 U.S.C. 241 and 242l).

III. OBJECTIVE OF THE NIH ACTION

The objective of the proposed action—release of the NIH Guidelines—is the protection of laboratory workers, the general public, and the environment from infection by possibly hazardous agents that may result from recombinant DNA research. The Guidelines are meant to ensure that experiments involving recombinant DNA molecules and which are supported by NIH, are carried out under conditions and safeguards that minimize the possibility of the harmful exposure of any human being or other component of the environment to these possibly hazardous agents.

It is NIH policy that all work supported by NIH, either in its own laboratories or through grants or contracts to various organizations, must be carried out according to the Guidelines. As part

of this objective, the Guidelines describe procedures that will be used to ensure implementation. A further objective of establishing the Guidelines is to influence, to the extent possible, other Federal, non-Federal, and foreign organizations in their efforts to assure that recombinant DNA experiments will be carried out with minimal risk to laboratory workers, the general public, and the environment.

IV. BACKGROUND

A. DESCRIPTION OF THE RECOMBINANT DNA EXPERIMENTAL PROCESS

All living things, from subcellular particles to higher organisms, require specific information for their reproduction and functions. The basic source of this information is deoxyribonucleic acid (DNA), which is the principal substance of the genes, the units of heredity (1). Each cell of an organism is composed of various organized structures, several of which contain DNA. Figure IV-1 illustrates a typical cell.



FIGURE IV-1

DNA plays two roles: (1) Provides information for the reproduction, growth, and functions of the cell, and (2) preserves and directs replication of this information and transfers it to the offspring. These two roles of DNA are common to animals, plants, single-cell organisms, and many viruses. The DNA of cells is mainly found in organized structures called chromosomes.

Intracellular DNA also occurs outside of the chromosomes as separately replicating molecules. Such DNA molecules include the plasmids, found in bacteria; the DNA of chloroplasts, common to green plants; and the DNA of mitochondria, the energy-producing units of the cells of complex organisms. These DNAs, while not strictly part of the inherent genetic make-up of a cell, help define the cell's functional capability. Another type of DNA commonly found in cells is the DNA of infecting viruses.

In the past 30 years the structure of the DNA molecule has been studied in-

tensively, and it can now be described in much detail. The molecule may be compared to a very long, but twisted step-ladder with thousands to millions of rungs (shown in Figure IV-2). The sides of the ladder are formed of sugar molecules (deoxyribose) attached end to end through phosphate groups. At right angles to each sugar molecule is one of four possible bases—adenine, guanine, thymine, and cytosine. The precise sequence of these bases, the rungs of the ladder, codes the information content. The "reading" of the code contained in the sequence of bases results in the formation of proteins which in turn permit the essential functions of the cell.

A gene is a portion of the DNA molecule which codes for the manufacture of a single protein. In higher organisms, much of the DNA may not serve as genes in this sense, but may regulate the activity of nearby genes. It is possible to break open cells and isolate DNA, free of other cellular constituents.

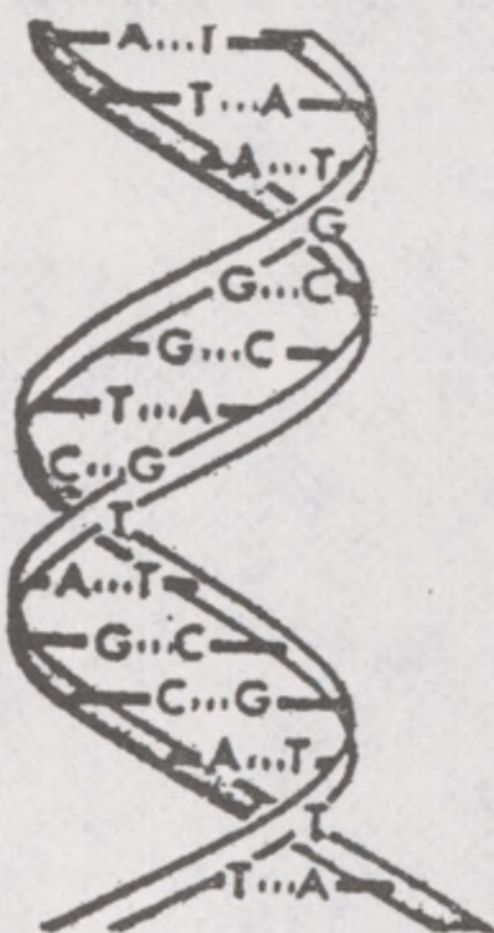


FIGURE IV-2

In recombinant DNA experiments, DNA is first isolated from two different cell types. Each DNA is then broken into segments. Each segment may contain one or more genes, or it may contain a portion of the DNA that lacks functional genes. The breaking is accomplished by means of bacterial enzymes (restriction endonucleases), which cut the DNA in such a way that the chemical structure at the ends of the segments permits interchangeable rejoining when the two different DNAs are mixed. In this way single DNA molecules containing portions of the two different DNAs are constructed. The DNA recombined in these experiments can be derived from widely divergent sources. The DNA from one of the sources serves as a carrier, or vector, for the insertion of the recombined DNA into a cell, or host. The vector may be DNA from a virus or a plasmid, usually derived from the same species as will serve as the host of the recombinant DNA. From a growth culture of the host cells, those containing the DNA fragment of particular interest are selected

and allowed to multiply. The resulting population of identical cells is called a "clone." In some experiments the DNA will be extracted from the cells for study; in others, the properties of the cells themselves will be investigated.

In the experiments discussed in the Guidelines, the host cells are generally single-cell microorganisms such as bacteria, or animal or plant cells that were originally obtained from living tissue but are grown as single cells under special laboratory conditions.

The process of producing recombinant DNA molecules and introducing them into cells is illustrated in Figure IV-3.

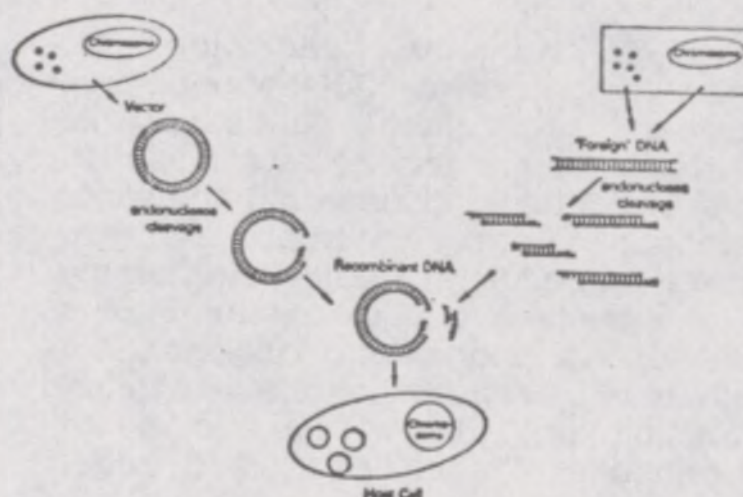


FIGURE IV-3

The cell represented at the upper left contains chromosomal DNA and several separately replicating DNA molecules. The non-chromosomal DNA molecules can be isolated from the cell and manipulated to serve as vectors (carriers) for DNA from a foreign cell. Most DNA molecules used as vectors are circular. They can be cleaved, as shown, by enzymes (restriction endonucleases) to yield linear molecules with rejoinable ends.

At the upper right is another cell, represented here as a rectangle. It serves as the source of the foreign DNA to be inserted in the vector. This DNA can also be cleaved by enzymes. The rectangular cell could be derived from any living species, and the foreign DNA might contain chromosomal or non-chromosomal DNA, or both.

In the next steps, the foreign DNA fragment is mixed and combined with the vector DNA, and the recombinant DNA is reinserted into a host cell. In most experiments this host cell will be of the same species as the source of the vector. The recipient cells are then placed under conditions where they grow and multiply by division. Each new cell will contain recombinant DNA.

B. EVENTS LEADING TO DEVELOPMENT OF GUIDELINES

On June 23, 1976, the Director, NIH, released "National Institutes of Health Guidelines for Research Involving Recombinant DNA Molecules" (see Appendix D). This action was approved by the Secretary of Health, Education, and Welfare and the Assistant Secretary for Health. The Guidelines established carefully controlled conditions for the conduct of experiments involving the insertion of recombinant genes into organisms, such as bacteria. The chronology leading to the present Guidelines and the decision to release them are outlined below.

It was some of the scientists engaged in recombinant DNA research who called for a moratorium on certain kinds of experiments in order to assess the risks and devise appropriate guidelines. The capability to perform DNA recombina-

tions, and the potential hazards, had become apparent at the Gordon Research Conference on Nucleic Acids in July 1973. Those in attendance voted to send an open letter to Dr. Philip Handler, President of the National Academy of Sciences, and to Dr. John R. Hogness, President of the Institute of Medicine, NAS. The letter, appearing in "Science" (2), suggested that the Academy "establish a study committee to consider this problem and to recommend specific actions or guidelines, should that seem appropriate."

In response, NAS formed a committee, and its members published another letter in "Science" in July of 1974 (3). Under the title "Potential Biohazards of Recombinant DNA Molecules," the letter proposed:

First, and most important, that until the potential hazards of such recombinant DNA molecules have been better evaluated or until adequate methods are developed for preventing their spread, scientists throughout the world join with the members of this committee in voluntarily deferring . . . [certain] experiments . . .

Second, plans to link fragments of animal DNAs to bacterial plasmid DNA or bacteriophage DNA should be carefully weighed . . .

Third, the Director of the National Institutes of Health is requested to give immediate consideration to establishing an advisory committee charged with (i) overseeing an experimental program to evaluate the potential biological and ecological hazards of the above types of recombinant DNA molecules; (ii) developing procedures which will minimize the spread of such molecules within human and other populations; and (iii) devising guidelines to be followed by investigators working with potentially hazardous recombinant DNA molecules.

Fourth, an international meeting of involved scientists from all over the world should be convened early in the coming year to review scientific progress in this area and to further discuss appropriate ways to deal with the potential biohazards of recombinant DNA molecules.

On October 7, 1974, the NIH Recombinant DNA Molecule Program Advisory Committee (hereafter "Recombinant Advisory Committee") was established to advise the Secretary of HEW, the Assistant Secretary for Health, and the Director of NIH concerning a program for developing procedures which will minimize the spread of such molecules within human and other populations, and for devising guidelines to be followed by investigators working with potentially hazardous recombinants."

The international meeting proposed in the "Science" article (2) was held in February 1975 at the Asilomar Conference Center, Pacific Grove, California. It was sponsored by the National Academy of Sciences and supported by the National Institutes of Health and the National Science Foundation. One hundred and fifty people attended, including 52 foreign scientists from 15 countries, 16 representatives of the press, and 4 attorneys.

The conference reviewed progress in research on recombinant DNA molecules and discussed ways to deal with the potential biohazards of the work. Participants felt that experiments on con-

struction of recombinant DNA molecules should proceed: *Provided*, that appropriate containment is utilized. The conference made recommendations for matching levels of containment with levels of possible hazard for various types of experiments. Certain experiments were judged to pose such serious potential dangers that the conference recommended against their being conducted at the present time.

A report on the conference was submitted to the Assembly of Life Sciences, National Research Council, NAS, and approved by its Executive Committee on May 20, 1975. A summary statement of the report (4) was published in "Science, Nature," and the "Proceedings of the National Academy of Sciences." The report noted that "in many countries steps are already being taken by national bodies to formulate codes of practice for the conduct of experiments with known or potential biohazards. Until these are established, we urge individual scientists to use the proposals in this document as a guide."

The NIH Recombinant Advisory Committee held its first meeting in San Francisco immediately after the Asilomar conference. It proposed that NIH use the recommendations of the Asilomar conference as guidelines for research until the committee had an opportunity to elaborate more specific guidelines, and that NIH establish a newsletter for informal distribution of information. NIH accepted these recommendations.

At the second meeting, held on May 12-13, 1975, in Bethesda, Maryland, the committee received a report on biohazard-containment facilities in the United States and reviewed a proposed NIH contract program for the construction and testing of microorganisms that would have very limited ability to survive in natural environments and would thereby limit any possible hazards. A subcommittee chaired by Dr. David Hogness was appointed to draft guidelines for research involving recombinant DNA molecules, to be discussed at the next meeting.

The NIH committee, beginning with the draft guidelines prepared by the Hogness subcommittee, prepared proposed guidelines for research with recombinant DNA molecules at its third meeting, held on July 18-19, 1975, in Woods Hole, Massachusetts.

Following this meeting, many letters were received which were critical of the guidelines. The majority of critics felt that they were too lax, others that they were too strict. The committee reviewed all letters, and a new subcommittee, chaired by Dr. Elizabeth Kutter, was appointed to revise the guidelines.

A fourth committee meeting was held on December 4-5, 1975, in La Jolla, California. For this meeting a "variorum edition" had been prepared, comparing line-for-line the Hogness, Woods Hole, and Kutter guidelines. The committee reviewed these, voting item-by-item for their preference among the three variations and, in many cases, adding new material. The result was the "Proposed Guidelines for Research Involving Re-

combinant DNA Molecules," which were referred to the Director, NIH, for a final decision in December 1975.

The Director of the National Institutes of Health called a special meeting of the Advisory Committee to the Director to review these proposed guidelines. The meeting was held at NIH, Bethesda, on February 9-10, 1976. The Advisory Committee is charged to advise the Director, NIH, on matters relating to the broad setting—scientific, technological, and socioeconomic—in which the continuing development of the biomedical sciences, education for the health professions, and biomedical communications must take place, and to advise on their implications for NIH policy, program development, resource allocation, and administration. The members of the committee are knowledgeable in the fields of basic and clinical biomedical sciences, the social sciences, physical sciences, research, education, and communications. In addition to current members of the committee, the Director, NIH, invited a number of former committee members as well as other scientific and public representatives to participate in the special February session.

The purpose of the meeting was to seek the committee's advice on the guidelines proposed by the Recombinant Advisory Committee. The Advisory Committee to the Director was asked whether, in their judgment, the guidelines balanced scientific responsibility to the public with scientific freedom to pursue new knowledge.

Public responsibility weighs heavily in this genetic research area. The scientific community must have the public's confidence that the goals of this profoundly important research accord respect to important ethical, legal, and social values of our society. A key element in achieving and maintaining this public trust is for the scientific community to ensure an openness and candor in its proceedings. Representatives of the international press were invited to the Asilomar conference, and the proceedings received extensive coverage. The meetings of the Director's Advisory Committee and the Recombinant Advisory Committee have also reflected the intent of science to be an open community in considering the conduct of recombinant DNA experiments. Notification of all the meetings was published in the *FEDERAL REGISTER* and all the meetings were attended and reported by representatives of the press. At the Director's Advisory Committee meeting, there was ample opportunity for comment and an airing of the issues, not only by the committee members but by public witnesses as well. All major points of view were broadly represented.

The guidelines were reviewed in light of the comments and suggestions made by participants at that meeting, as well as the written comments received afterward. As part of that review the Recombinant Advisory Committee was asked to consider at its meeting of April 1-2, 1976, a number of selected issues raised by the commentators. Those issues and the response of the Recombinant Ad-

visory Committee were taken into account in arriving at the final decision on the Guidelines.

The history of the events and discussions leading to the development of the Guidelines are described in greater detail in the "Decision of the Director, NIH," published as a preamble to the Guidelines in the *FEDERAL REGISTER*, Part II, July 7, 1976 (See Appendix D).

C. DESCRIPTION OF ISSUES RAISED BY RECOMBINANT DNA RESEARCH

1. *Possible hazardous situations.* The stable insertion of DNA derived from a different species into a cell or virus (and therefore the progeny thereof) may change certain properties of the host. The changes may be advantageous, detrimental, or neutral with regard to (a) the survival of the recipient species, (b) other forms of life that come in contact with the recipient and (c) aspects of the nonliving environment. Current knowledge does not permit accurate assessment of whether such changes will be advantageous, detrimental or neutral, and to what degree, when considering a particular recombinant DNA experiment. At present it is only possible to speculate on ways in which the presence of recombinant DNA in a cell or virus could bring about these effects. It should be emphasized that there is no known instance in which a hazardous agent has been created by recombinant DNA technology. The following discussion is speculative and consider ways in which hazardous agents might be produced.

a. *The effect of foreign DNA on the survival of recipient species (host cells or viruses).* The effect of foreign DNA on the survival of recipient species is important to the discussion of possible hazards of recombinant DNA experiments because although a recipient species may acquire a potential for harmful effects as a result of the foreign DNA, the possibility that the harmful effect will occur will depend on the survival of the recipient and its ability to multiply. If acquisition of foreign DNA increases the probability of survival and multiplication the possibility of harmful effects will increase. Similarly, if acquisition of foreign DNA decreases the probability of survival or multiplication, the possibility of harmful effects will decrease. It is important to recognize, in evaluating the potential for harmful effects, that significant infections of animals and plants by bacteria or viruses may require contact with either a large or small number of the infectious agent, depending on the agent.

There are various indications that bacteria and viruses containing inserted foreign DNA are less likely to survive and multiply than are the original organisms. Natural evolution results in the survival of well-balanced and efficient organisms. Essential functions are carefully controlled, and can be switched on and off as needed. It is unlikely that uncontrolled, nonessential properties such as might be introduced by foreign genes would result in any advantage to the survival and multiplication of an other-

wise well-balanced organisms. It is more likely that the new properties accompanying insertion of foreign genes will confer some relative disability to the recipient organisms. Therefore it is likely that bacterial cells containing inserted foreign DNA will multiply more slowly than the same cells without foreign DNA. Thus, in a natural competitive environment, bacteria containing recombinant DNA would generally be expected to disappear. The rate of disappearance will depend on the relative rate of growth compared to other, competing bacteria. The following calculation demonstrates this point.

Assume that a new organism constitutes 90 percent of a population, but grows 10 percent less rapidly than its natural counterpart. The new organism will drop from a concentration of 90 percent to a concentration of 0.0001 percent (1 part in 1,000,000) in 207 generations. If the generation time of the natural organism is one hour, this amounts to about 8½ days.

One example of a situation in which the capability of recipient bacterial host cells to survive may be significantly increased as the result of the presence of a foreign DNA is the case of resistance to antibiotics and drugs. It is well known that such resistance is often genetically determined and genes specifying resistance have been described. Furthermore it is well known that such genes may be transferred, by natural DNA recombination, from one species of microorganism to another. Such natural events are in fact responsible for the rapid and wide spread of resistance to clinically important drugs that has been observed during the last 20 years.

The ability of recipient bacterial host cells to survive and multiply might also be enhanced by acquisition and expression of a foreign gene conferring the ability to metabolize particular nutrients. In an environmental niche containing the metabolite, such a recombinant might compete successfully against organisms native to the niche. This could result in destruction of an environmental component—that is, the metabolite. Also, if the native organisms were performing beneficial functions, those functions could be lost upon the successful establishment of the recombinant in the niche.

b. *The effect of bacteria and viruses containing recombined DNA on other forms of life.* The analysis leading to the Guidelines centered on the possibility of deleterious effects, since the concern was the health and safety of living organisms, including humans, and the environment. Agents constructed by recombinant DNA technology could prove hazardous to other forms of life by becoming pathogenic (disease-producing) or toxigenic (toxin-producing), or by becoming more pathogenic or toxigenic than the original agent.

There are two basic mechanisms by which a recipient microorganism might be altered with regard to its pathogenicity or toxicity as a result of a resident recombinant:

(1) *The recombinant DNA may result in formation of a protein that has un-*

desirable effects. The case in which bacterial cells are used as carriers of foreign DNA is discussed first. A foreign protein, specified by the foreign DNA, might act after being liberated from the microorganism, or it could function within the microorganism and alter, secondarily, normal microbial cell function in such a way that the cell is rendered harmful to other living things. Either means depends on the expression of the foreign genes; that is, the information in the foreign genes must be used by the recipient bacterium to produce a foreign protein. Examples of protein that might prove harmful to other organisms are hormones, enzymes and toxins.

The weight of present evidence suggests that foreign DNA from bacteria of one species, when inserted into bacteria of another species, may be expressed in the recipient. For example, if the donor of the foreign DNA produces a toxic substance, then the recipient cell may produce such a substance if the gene for the toxic substance is present in the recombinant. The recipient may or may not be more hazardous than the original donor organism, depending on the relative ability of the two organisms to grow and infect an animal or plant species at risk.

The evidence available at present is insufficient to predict whether or not foreign genes derived from a complex organism (animals, plants, yeasts, and fungi) will be expressed in a bacterium in any particular instance. It may be that specific manipulations will be required to permit bacteria to express information of a foreign DNA efficiently. Faithful expression of a gene requires accurate functioning of the complex bacterial machinery involved in protein synthesis. At each step, specific signals originating in the foreign gene must be recognized by the bacterial machinery. Evolutionary divergence has resulted in different signals in bacteria and complex organisms.

Attempts to translate animal virus and animal cell genes into protein, using cell-free systems containing the protein-synthesizing machinery isolated from bacteria such as *E. coli* yield some protein-like products. The protein products characterized to date were not faithful products of the information in the genes.

In a few cases, intact bacteria containing recombined genes from complex organisms have been tested for evidence of expression of the inserted gene. By and large, accurate expression of the genes has not yet been demonstrated, although it may occur at a low frequency. In some instances, a new protein has been found, replacing one encoded by a bacterial gene. This result is expected if a bacterial gene is interrupted by insertion of the new DNA sequence within it, and does not necessarily indicate expression of the foreign gene. DNA fragments from yeast have been inserted into a strain of the bacterium *E. coli* which cannot manufacture the amino acid histidine (5). (Histidine is a component of most proteins and therefore is required for the growth of all organisms.) After insertion, some cells no longer required histidine; thus, the presence of the yeast DNA over-

came the requirement for histidine. This is the first suggestion that a foreign gene from an organism more complex than bacteria may actually function in a bacterial cell. (Although yeast is a single-cell organism, it contains an organized nucleus like cells of higher organisms.) However, the detailed mechanism explaining this observation is unknown.

Analogous issues must be considered for the case in which animal viruses are the carriers of foreign DNA. Many viruses are simply described as DNA molecules enclosed and protected by coats of protein molecules. The protein coat protects the DNA from environmental effects, thus increasing the ability of the viral DNA to infect a cell. If viral DNAs are recombined with foreign DNAs in such a way that necessary viral genes remain intact, then the recombinant DNA may in turn be able to produce, and be packaged in, the coat of the virus. Inadvertent dispersal of such a viral particle outside of the laboratory might then result in entry of the recombinant DNA into cells of living organisms. The foreign genes may be expressed, resulting in the formation of a protein foreign to the infected cell, or the uncontrolled synthesis of a normal protein. The likelihood of expression of the foreign genes will probably depend on the degree of relatedness between its source and the infected organism as well as its location in the viral DNA used as vector. Currently, few if any relevant experimental data are available so that estimates of the probability of expression are, in these instances, impossible.

(2) *The recombined DNA may itself cause pathogenic or toxic effects.* Foreign DNA inserted in a bacterial gene, might so alter the microbial cell's properties that it becomes harmful to other organisms. This might happen, for example, through a change in the growth rate and competitive advantage of the recipient microbial cell, resulting in increased virulence of a mildly pathogenic bacteria. In general, one would expect the inserted DNA to result in a reduced growth rate and a selective disadvantage to the organism, as discussed in "a" above. Similar issues arise where animal viruses serve as carriers of foreign DNA.

It is also necessary to consider situations in which DNA molecules themselves may escape from the laboratory or from the experimental host cell and enter cells of living organisms with which they come in contact. Although free DNA molecules are themselves relatively fragile (and the probability that they would survive, in a significant form or for a significant time, in air, water, or any other medium, is considered remote), they can be protected in nature in a variety of ways and be released either into, or close to, a living cell.

When a cell or virus dies, or comes close to or invades the tissue of another living organism, the recombinant DNA may effectively enter a new cell. A hazardous situation similar to that described above might ensue if foreign proteins were manufactured in this "secondary" recipient. The recombinant DNA might survive as an independent cellular component, or it could recombine by natural

process with the DNA of the secondary recipient. Various possible deleterious consequences of such a recombination may be considered.

If the secondary recipient is another microorganism, the same considerations described in IV-C-1-a apply. If the secondary recipient is one of the cells of an animal or plant, different considerations apply. The latter include alterations of normal cellular control mechanisms, synthesis of a foreign protein (such as a hormone), and insertion of genes involved in cancer production (if, for example, the foreign DNA were derived from a cancer-producing virus).

It should be pointed out that the likelihood of causing inheritable changes in the offspring of complex organisms by such a mechanism is extremely low in animals because of the protection afforded germ-line cells (eggs and sperm) by their location. Thus, the possibility that recombined foreign DNA would reach germ line cells at a time in the life of such cells when secondary recombination can occur is extremely remote. With one-celled organisms, plants, or simple multicellular organisms, the probability of causing heritable change by secondary recombination may be higher.

What is the probability of secondary recombination between prokaryotes and eukaryotes in nature? It is generally held that recombination in nature is more likely if similar or identical sequences of bases (rungs in the DNA ladder) occur in the two recombining DNAs. The greater the degree of similar sequences, the more likely is recombination. In general, the more closely two species are related, the more likely it is that similar sequences will be found in their DNAs. Thus, DNA from primates has more DNA sequences in common with human DNA than does DNA from mice, or fish, or plants. Recombination may also occur between DNAs not sharing sequences but at lower frequencies.

It is possible that the capacity for interspecies recombination between distantly related species exists in nature. For example, bacteria in animal intestines are constantly exposed to fragments of animal DNA released from dead intestinal cells. Significant recombination requires the uptake of intact segments of animal DNA and their subsequent incorporation into the bacterial DNA. The frequency of such events is unknown.

There are very few available data permitting assessment of the reverse process—namely, the incorporation of bacterial DNA into the cells, or DNA, of more complex organisms. Although there are reports of experiments in which bacterial DNA was inserted into animal and plant species and production of the bacterial protein followed, the process is very inefficient and many investigators have been unable to repeat these experiments (6-8).

There are certain well-documented instances in which the DNAs of different living things become more or less permanently recombined in nature. These instances involve recombination between the DNAs of nonchromosomal genes, such

as those of viruses or plasmids, or recombination between the DNAs of viruses or plasmids and chromosomal genes. The former instance, for example, is the mechanism behind the rapid spread of resistance to antibiotics among different bacterial species (9, 10). This spread accompanied the prevalent use of antibiotics in medicine and agriculture. Some viral DNAs recombine into and persist in chromosomal DNA of cells of receptive organisms (11, 12). Some viral DNAs acquire, in stable form, DNA sequences derived from their host cells (13, 14). There is also strong evidence for recombination of the DNA form of RNA tumor virus genes with chromosomal genes (15-17).

2. *Expected benefits of DNA recombinant research.* Benefits may be divided into two broad categories: An increased understanding of basic biological processes, and practical applications for medicine, agriculture, and industry.

At this time the practical applications are, of course, speculative. It is important to stress that the most significant results of this work, as with any truly innovative endeavor, are likely to arise in unexpected ways and will almost certainly not follow a predictable path.

a. *Increased understanding of basic biological processes.* There are many important fundamental biomedical questions that can be answered or approached by DNA recombinant research. In order to advance against diseases in inheritance, we need to understand the structure of genes and how they work. The DNA recombinant methodology provides a simple and inexpensive way to prepare large quantities of specific genetic information in pure form. This should permit elucidation of the organization and function of the genetic information in higher organisms. For example, current estimates of the fraction of this information that codes for proteins are simply educated guesses. There are almost no clues about the function of the portions of DNA that do not code for proteins, although these DNA sequences are suspected of being involved in the regulation of gene expression.

The existing state of ignorance is largely attributable to our previous inability to isolate discrete segments of the DNA in a form that permits detailed molecular analysis. Recombinant DNA methodology remove this barrier. Furthermore, ancillary techniques have been developed whereby pure DNA segments that contain particular sequences of interest can be identified and selected. Of particular interest is the isolation of pure DNA segments that contain the genes for the variable and constant portions of the immunoglobulin proteins. The analyses of such segments obtained from both germline and somatic cells should be of inestimable value in determining the mechanism of immunologic diversity.

A major problem in understanding the mechanism by which certain viruses cause cancer is how and where the infecting or endogenous viral genomes are integrated into the cell's chromosome. This bears on the question of how the expression of the integrated viral genes

affects cellular regulation, thus leading to the abnormal growth characteristics of cancer cells. With the recombinant DNA techniques for isolation and purification of specific genes, this research problem is reduced to manageable proportions. It is possible to isolate the desired DNA segment in pure form. Large quantities can be obtained for detailed study by simply extracting a culture of the bacteria carrying the viral DNA segment in a plasmid.

b. *Potential practical applications for medicine, agriculture and industry.* Certain of the potential applications will only be realized if the reproduction of the recombined foreign DNA in a recipient-host cell is followed by expression of the genetic information contained in the DNA in the form of synthesis of proteins. Since the efficient translation of eukaryote genes in bacterial (prokaryote) hosts has yet to be proved, these potential applications are speculative at this time. Applications that depend on the expression of foreign prokaryotic genes in prokaryotic recipient cells are presently more certain.

(1) *Synthesis of medically important proteins and other substances.* It has been suggested that genes coding for medically important substances be attached to bacterial vectors, and that the bacteria then be used to produce large quantities of the desired material. A number of costly and/or rare substances would be prime candidates for such synthesis:

Human insulin (a future shortage of currently used animal insulin appears to be likely);

Human growth hormone (presently available only from human cadavers and in short supply);

Clothing factor VIII (for treatment of hemophilia);

Specific antibodies and antigens (for preventing and treating infectious, allergic, and autoimmune disease, and perhaps even cancer);

Certain enzymes, such as fibrinolysin and urokinase (promising agents in the treatment of embolism) and lysosomal enzymes.

(2) *Endowment of plants with new synthesis capabilities.* Whole plants may be generated from a single cell, and thus insertion of recombinant DNA into such cells might make it possible to endow plant species with the capability of—

Improved photosynthetic fixation of carbon dioxide;

Nitrogen fixation by presently inept species (thereby reducing the need for costly chemical fertilizers that cause pollution—e.g., eutrophication);

Producing a higher quality or quantity of food protein.

(3) *Some industrial applications.* A number of industrial processes utilize microorganisms containing enzymes (which are proteins) to produce important chemicals (e.g., steroid hormones or other drugs, vitamins) or foodstuffs (e.g., cheese). Such processes could be improved through innovations effected by DNA recombinant research. Completely new biosynthetic reactions may thereby become available, permitting the synthesis of large amounts of complex and

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valuable compounds with ease and at low cost.

Some highly speculative applications relate to the area of energy production and neutralization of pollutants—e.g., as in oil spills. Genetic modification through DNA recombination might it possible to devise microorganisms tailor-made for such important purposes.

3. *Long-range implications.* The experimental situations treated in the Guidelines are those that appear feasible either currently or in the near future. The experiments primarily involve insertion of recombinant DNA into bacteria or into single cells derived from more complex organisms and maintained under special laboratory conditions. It is only in the case of plants that the Guidelines cover experiments involving insertion of DNA into cells capable of developing into complex, multicellular organisms. The Guidelines and the discussions leading to their development have focused on problems of safety.

It is possible that techniques similar to or derived from current recombinant DNA methodology may, in the future, be applicable to the deliberate modification of complex animals, including humans. Such modification might have as its aim correction of an inherited defect in an individual, or alteration of heritable characteristics in the offspring of individuals of a given species. The latter type of alteration has been successfully achieved in agriculture for centuries, by classical breeding techniques. It may be that recombinant DNA methods, should they develop in appropriate ways, may offer new opportunities for specificity and accuracy in animal breeding.

The deliberate application of such methods for the correction of individual genetic defects or the alteration of heritable characteristics in man raises complex and difficult problems. In addition to philosophical, moral, and ethical questions of concern to individuals, serious societal issues are involved. Broad discussion of these problems in a variety of forums will be required to inform both private and public decision-making.

4. *Possible deliberate misuse.* In the event that recombinant DNA technology can yield hazardous agents, such agents might be considered for deliberate perpetration of harm to animals (including humans), plants or the environment. The possibilities include biological warfare or sabotage. Because it is not known whether recombinant DNA technology can yield such agents, discussion of these problems such as theft by saboteurs is hypothetical and difficult. With regard to biological warfare, a July 3, 1975 letter to Dr. David Baltimore from James L. Malone, General Counsel of the United States Arms Control and Disarmament Agency says, "you raise the question as to whether the Biological Weapons Convention prohibits production of recombinant DNA molecules for purposes of constructing biological weapons. In our opinion the answer is in the affirmative. The use of recombinant DNA molecules for such purposes clearly falls within the scope of the Convention's provisions."

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V. DESCRIPTION OF THE PROPOSED ACTION

The Director, National Institutes of Health, has issued Guidelines that will govern the conduct of NIH-supported research on recombinant DNA molecules. The Guidelines will apply to all NIH-supported research on such molecules—that is, molecules which are made by combining segments of DNA from different organisms in a cell free-system and which can be inserted into some living cell, there to replicate. The objective of

the Guidelines is the protection of the laboratory worker, the general public, and the environment from infection by possibly hazardous agents that may result from this research. The complete text of the Guidelines is found in the FEDERAL REGISTER, Part II, for Wednesday, July 7, 1976. As an integral part of this Draft Environmental Impact Statement the Guidelines are found in Appendix D.

The mechanisms by which the NIH will implement the application of the Guidelines are outlined in the Guidelines themselves and are specified in greater detail in Appendix C. Noncompliance with the Guidelines will result in termination of funding of research grants and contracts.

The Guidelines describe (1) safeguards that protect the laboratory worker, the general public, and the environment, (2) the criteria for assessing the possible dangers from experiments involving recombinant DNA molecules, (3) the criteria for matching the assessed possible dangers of individual experiments with the appropriate safeguards, and (4) the roles and responsibilities of principal investigators, their institutions, and NIH for ensuring the implementation of the requirements specified in these Guidelines. The emphasis on protection of laboratory workers from infection reflects the fact that laboratory workers are the persons at the greatest risk of infection and that the most likely route of escape of possibly hazardous agents from the laboratory is the laboratory worker.

The physical safeguards have been grouped into four levels providing increasing capability for containment. The four levels approximate those recommended by the Center for Disease Control for the control of known infectious agents that have been determined to be of (1) no or minimal, (2) ordinary, (3) special, or (4) extreme hazard to man and other living things. These correspond to the terms Minimal, Low, Moderate, and High risk, respectively, as used in the NIH Guidelines. The safeguards include usual and special microbiological safety practices, primary physical barriers that isolate the experiment from the laboratory worker, and facility installations that either markedly reduce or eliminate the potential for accidental dissemination of recombinant DNA molecules to the environment. The four levels, designated P1 to P4, provide increasing protection against contact with or accidental release of microorganisms containing recombinant DNA molecules.

Additional safeguards are provided by the use of host cells and vectors with demonstrably limited ability to survive in other than specially designed laboratory environments. This concept is called "biological containment" in the Guidelines. In the case of bacterial host cells and vectors, this means that particular strains of cells and vectors with genetically determined and fastidious survival requirements must be used. For those experiments judged to be of potentially moderate or high risk, the properties of the bacterial strains to be used

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must be certified by the NIH Recombinant Advisory Committee prior to initiation of experiments. In the case of a vector derived from an animal virus, the virus itself must be a low risk agent (CDC or National Cancer Institute), and a strain of the virus that is defective in infection must serve as the source of the vector DNA.

The selection of containment (safety) levels is dependent on the assessed possible dangers of the experiment. The Guidelines provide standards for evaluating the conceivable dangers of particular experiments involving recombinant DNA molecules. In the absence of evidence of any hazard actually occurring, these standards are based on relevant current knowledge. Permissible experiments are placed into four classes of increasing possible danger which correspond to the four levels of increasing containment capability (safety). Certain experiments, judged to have the potential for extreme hazard, should they prove dangerous, are prohibited.

The possibility for danger depends on—

- (1) The biohazard associated with the DNA of the cell or microorganism that serves as the DNA source (e.g., genes for toxin production),
- (2) The degree to which the DNA segment has been purified away from other genes and shown to be free of harmful characteristics,
- (3) The biohazard associated with the vector that serves to transmit the source DNA to a recipient host cell,
- (4) The ability of the vector to survive in natural environments or habitats,
- (5) The kinds and number of different organisms that are susceptible to infection by the recipient or vector,
- (6) The biohazard of the recipient host cell that serves to replicate the recombinant DNA molecule,
- (7) The ability of the recipient cell to survive in natural environments or habitats,
- (8) The ability of the recipient cell to transmit the recombinant DNA molecule to other cells capable of surviving in natural environments or habitats,
- (9) The potential of the recipient cell to obtain the source DNA by natural means, and
- (10) The evolutionary relatedness of the DNA source to humans.

The Guidelines prohibit a number of types of experiments, including those in which an organism contributing DNA is itself a biohazard of greater than low risk as determined by conventional methods of risk assessment (low risk corresponds to class 2 agents as defined by the Center for Disease Control). The host cells and vectors are required to be of no or minimal risk. The potential dangers are considered to increase as the organism providing the source DNA approaches humans phylogenetically. Thus, source DNA from primate cells is considered to have greater potential dangers than source DNA from lower eukaryotes. In general, greater possible dangers are assigned to recombinants than are present in the most hazardous component used to construct the DNA.

The risk-assessment standards are specified in detail for one prokaryote

host-vector system employing a variant of *E. coli* called strain K12, which is, by itself, of no or minimal risk. Eukaryote host-vector systems using defective viral vectors are also described. The descriptions of these systems provide principles by which the potential dangers of recombinant DNA experiments with other host-vector systems can be assessed.

The Guidelines also establish an administrative framework for assigning the responsibility for ensuring safety in recombinant DNA research supported by NIH. This responsibility is shared among the principal investigators, their institutions, and NIH. The principal investigators have the primary responsibility for hazard assessment and for implementation of appropriate safeguards. The institutions are responsible for ensuring that the principal investigators have the capabilities for meeting the requirements stipulated in the Guidelines. NIH is responsible for securing an independent assessment of the potential dangers of this research and for ensuring that no research is supported unless it conforms to the requirements stipulated in the Guidelines.

The Guidelines require that the institutions establish biohazard committees to carry out the institutional responsibility, and stipulate the qualifications and expertise of the committee membership. NIH responsibilities are detailed in the Guidelines and are divided among (1) NIH Initial Review Groups, (2) the NIH Recombinant DNA Molecule Program Advisory Committee, and (3) the NIH staff.

Physical containment requirements

The safeguards in the Guidelines require the use of procedures and physical containment systems to protect laboratory workers and the environment from exposure to potentially harmful organisms. The requirements include procedures and equipment in which work is to be done and special laboratory room and building features, as well as appropriate training of workers. The systems are grouped into four levels of containment—P1, P2, P3, and P4—each providing a level of containment greater than the one preceding it. The level of containment that must be provided by a laboratory in which an experiment is to be done is based on an assessment of the degree of hazard involved.

The following description of the physical containment levels is presented to outline these requirements. A complete description may be found in the Guidelines (Appendix B).

P1 Level (Minimal). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P1 level is shown in Figure V-1. Such a laboratory possesses no special engineering design features. Work in this laboratory is generally conducted on open bench tops. Special containment equipment is neither required nor generally available. The laboratory is not separated from the general traffic patterns of the building, and public access is permitted. Control of biohazards

is provided by standard microbiological practices.

P2 Level (Low). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P2 level (see Figure V-2) is similar in construction and design to the P1 laboratory. The P2 laboratory must have access to an autoclave within the building, and it may have a biological safety cabinet. Work that does not produce a considerable aerosol is conducted on the open bench. However, when excessive aerosols may be produced, low-risk experiments must be conducted in special cabinets (biological safety cabinets) that provide physical barriers against possible release of organisms. Although this laboratory is not separated from the general traffic patterns of the building, access to it is limited when experiments requiring P2-level physical containment are being conducted.

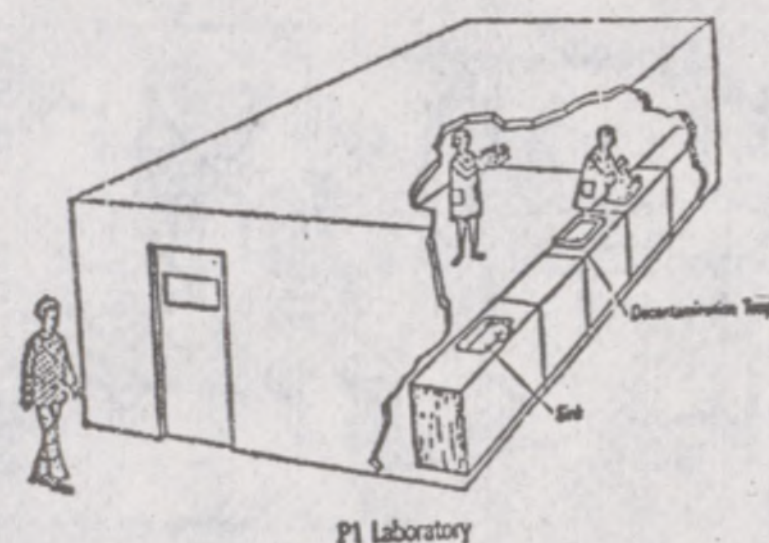


FIGURE V-1

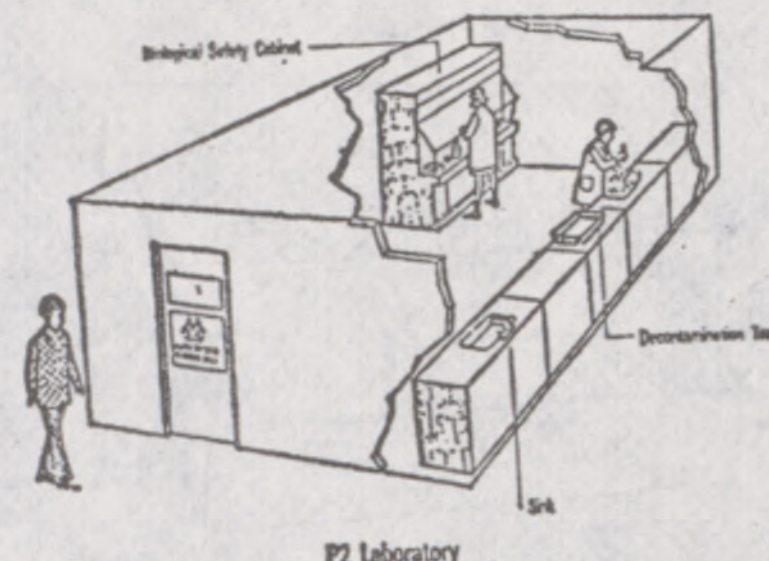


FIGURE V-2

P3 Level (Moderate). As shown in Figure V-3, a laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P3 level has special engineering design features and physical containment equipment. The laboratory is separated from areas that are open to the general public. Separation is generally achieved by controlled access corridors and air locks, locker rooms, or other double-doored facilities not available for use by the general public. Access to the laboratory is controlled. Biological safety cabinets are available within the controlled laboratory area. An autoclave shall be available within the building and preferably within the controlled laboratory area. Environmental protection is provided by waste sterilization techniques. The surfaces of walls, floors,

P4 Level (High). As shown in Figure V-4, experiments involving recombinant DNA molecules requiring physical containment at the P4 level shall be confined to work areas in a maximum-security facility of the type designed to contain microorganisms that are extremely hazardous to man or may cause serious epidemic disease. The facility is either a separate building or a controlled interior area completely isolated from all other areas of a building. Access to the facility is under strict control. Class III biological safety cabinets are available.

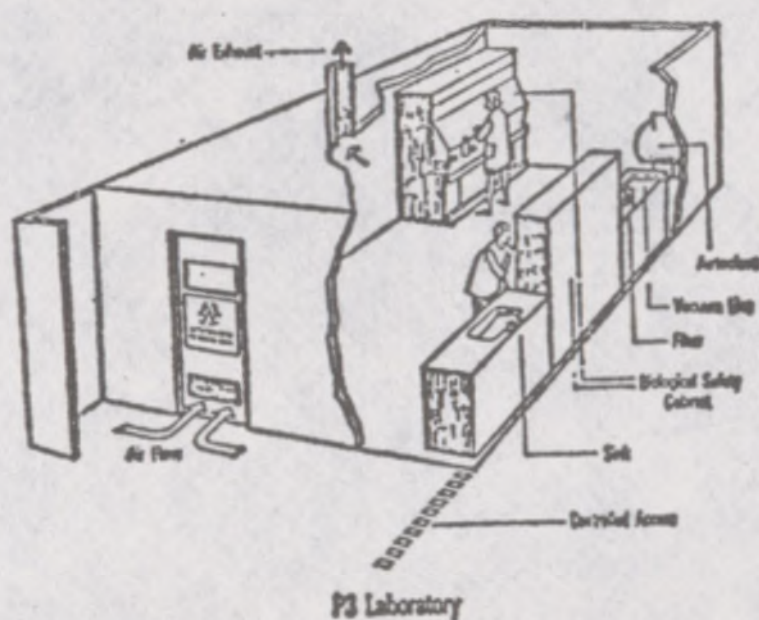


FIGURE V-3

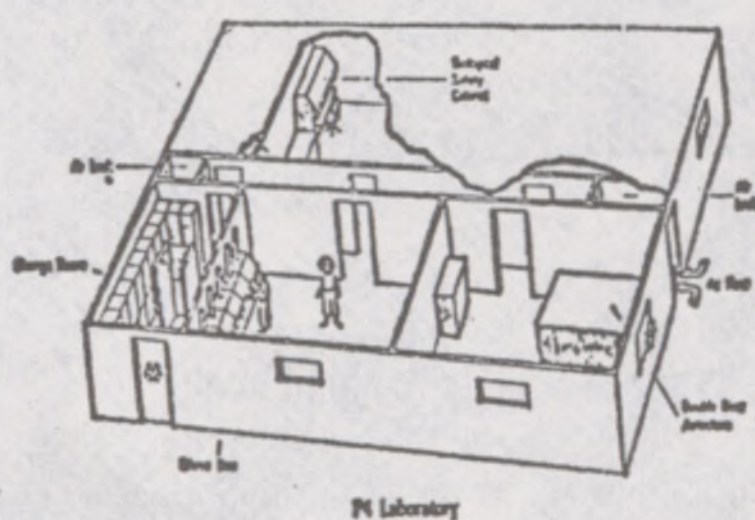


FIGURE V-4

A blowaste treatment system to sterilize liquid effluents if facility drains are installed.

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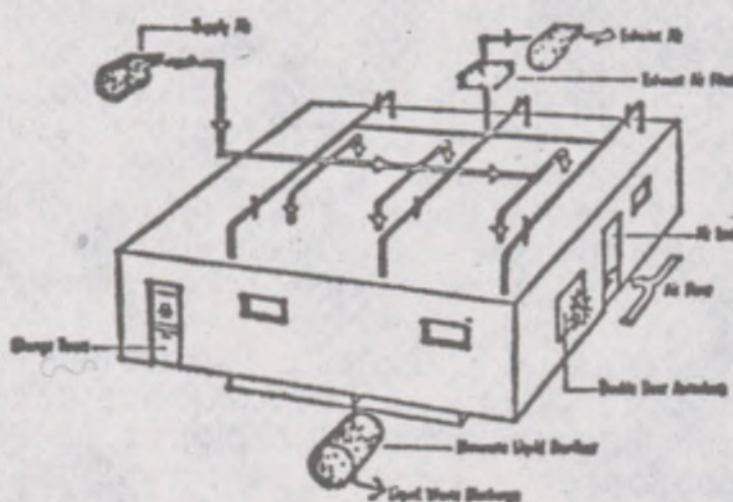


FIGURE V-5

A treatment system to decontaminate exhaust air before it is dispersed to the atmosphere. A central vacuum utility system is not encouraged; if one is installed, each branch line leading to a laboratory shall be protected by a high-efficiency particulate air filter.

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VI. DESCRIPTION OF ALTERNATIVES

The following general classes of action have been considered as alternatives to, or in addition to, the proposed action. The impact of each is described briefly, and reference is made to other portions of this document which have a more complete discussion of the particular impact in question.

A. NO ACTION

This alternative would perpetuate the situation existing prior to June 23, 1976. At that time the only restrictions on recombinant DNA research stemmed from voluntary compliance of the research community with the guidelines developed at the International Conference on Recombinant DNA Molecules, held at Asilomar, California, in February of 1975, which were published in scientific journals. The Asilomar guidelines differ in substance from the NIH Guidelines, and are considerably less stringent and less detailed in their requirements for containment of potentially hazardous organisms. For example, experiments that may be carried out with minimal containment according to the specific language of the Asilomar guidelines (e.g., the construction of an *E. coli* plasmid containing the noncancer-producing DNA segment of SV40) require P3 or P4 according to the NIH Guide-

The alternative of "no action" would essentially remove from the conduct of research the restrictions inherent in the NIH Guidelines. Experiments concerning basic biological processes, and the development of technology applicable to medical, agricultural, and industrial problems, would proceed at a faster rate. Moreover, the immediate cost of conducting research would be markedly decreased with the "no action" alternative, since the need for costly physical containment would be less.

**B. NIH PROHIBITION OF FUNDING OF ALL
EXPERIMENTS WITH RECOMBINANT DNA**

American scientists have played a leading role in bringing the potential hazards of recombinant DNA research to the attention of scientists, governments, and international organizations. As a result, there is an effort to adopt safety procedures for the conduct of this research in many countries. Although nations differ in their perceptions of the need to adopt safety measures, and of what the exact measures should be, the NIH Guidelines are being used as a model. NIH prohibition of the work would undermine American leadership in the establishment of worldwide standards for safety.

Finally, prohibition would be likely to have important impacts on American science, both in research and in development of technology. The leadership of

the United States in biological research would be threatened. Further, historical precedents indicate that measures which interfere with free inquiry in one area of interest, often inhibit the vitality of other aspects of society.

C. DEVELOPMENT OF DIFFERENT GUIDELINES

Each of the stipulations in the NIH Guidelines was made after assessment of the possible hazards associated with particular experiments. The available data, however, were limited, and different conclusions could have been reached. Some issues addressed in the preparation of the Guidelines which could have led to different specifications are as follows:

1. *Levels of physical containment.* For certain experiments in which the potential risk is controversial, the physical containment level could have been higher or lower. Examples of controversial issues are the recommendations with respect to containment levels for recombinant experiments involving bacterial cells and DNA derived from cold-blooded animals, and for experiments involving the use of DNA from animal viruses.

2. *Establishment of a few national P3 facilities openly available to all investigators, with the requirement that all experiments requiring P3 containment be conducted therein.* In effect, this will be the situation with respect to P4 facilities under the Guidelines. There are several advantages to working in regional centers:

- a. It would be less expensive to construct and staff a few such regional centers than many such facilities.
- b. Training would be centralized.
- c. P3 facilities would be more uniformly accessible to qualified investigators from a variety of institutions.
- d. There would be greater assurance that the facilities meet the specified requirements.
- e. Banks of cells containing recombinant DNA could be maintained, with a view to decreasing the number of times the actual recombination process would be performed (such banks can also be maintained in the absence of centralized P3 facilities).
- f. The sites could be placed away from population centers.

The disadvantages of establishing regional centers include:

- a. Long-range planning would be necessary.
- b. Scheduling would be a problem.
- c. The investigator's independence would be diminished.
- d. Competition for access might favor established investigators or established ideas.
- e. The nature of the process, which might require only brief access of P3 facilities in a given day but over a lengthy period of time.
- f. Access problems might unnecessarily discourage valuable research.

3. *All permissible recombinant DNA experiments be conducted in P4 facilities.* This alternative implies no distinction among experiments. It does not recognize that certain recombinant DNA experiments are widely agreed to pose little, if any, possible hazard. It is equivalent to a total prohibition on much recombinant DNA research because of the limited number of P4 facilities that are available and the high cost of con-

struction. Because of access problems, interesting and important research of low or moderate possible hazard would be discouraged.

4. *Experiments prohibited at this time.* Certain types of experiments are prohibited by the Guidelines. Their selection was a matter of judgment, and depended on the assessment of the seriousness of the possible hazard. Alternative assessments would result in either an expansion or a contraction of the list of prohibited experiments and consequent decrease or increase in the possible risks. Some of the controversial recommendations are—

a. *The prohibition of experiments involving more than 10 liters of culture fluid containing recombinant DNAs known to make harmful products without the express approval of the NIH Recombinant Advisory Committee.* Controversy over this recommendation relates to the fact that some investigators and laboratories contend that larger volumes of culture fluid can be safely contained by special procedures and facilities. The recommendation places responsibility for evaluating the containment on the NIH Recombinant Advisory Committee.

b. *Sanction of the use of the bacterium *Escherichia coli* as a recipient for recombinant DNA molecules.* This organism has been studied extensively and is well suited to recombinant DNA research. It has been argued, however, that *E. coli* should not be used at the present time. This is because many *E. coli* strains are intimately associated with humans and other living things, and because they readily exchange DNA (genes) with certain other bacteria in nature.

Theoretically, the most desirable bacterial recipient of recombinant DNA would be a species uniquely adapted to carefully controlled laboratory environments and unable to survive or transmit DNA to other organisms in any natural environment. This means that the bacteria should be unable to survive in normal ecological niches, either in the laboratory or neighboring areas. It should be unable to colonize or survive in or on other living things, or in soil or water. In addition, these properties should not be significantly altered by the insertion into the bacterium of the recombinant DNA. The bacteria must also be able to be manipulated for successful execution of the proposed experiment.

No bacteria is known to meet all these requirements. The guidelines permit the use of various forms of a particular strain of *E. coli* called K12. (The forms are called EK1, EK2 and EK3 in the Guidelines where they are discussed in detail.) Some of these forms already exist, others need to be constructed. Although related to other *E. coli* strains that do not in any way meet the definition of the ideal organism, these permissible strains of *E. coli* partially fulfill many of the criteria in the definition of the ideal strain. At present, no other bacterial species is known to approximate the definition as closely as *E. coli* K-12 and its derivatives. In the future, other bacteria, closer to the ideal, may become known, or the

properties of already known species may be shown to approach the ideal more closely than *E. coli* strain K12 and its derivatives, as defined in the Guidelines.

c. *Sanction of the use of Simian Virus 40 (SV 40) as a carrier of a foreign DNA fragment.* It has been argued that SV40 should not be permitted, since it is known to cause cancer in laboratory animals. There is little evidence that SV40 results in disease in humans. However, SV40 infects humans, and demonstrable antibodies to SV40 indicate that infection has occurred in some members of the general population. Some of the infection may have resulted from the inadvertent inoculation of millions of individuals during the initial mass program of immunization against polio virus before SV40 was identified as a contaminant in the vaccine. The antibodies may have been formed against SV40-like viruses known to exist naturally in humans (1). It is possible that a recombined DNA carried by SV40 could infect humans and significantly affect their health (2). The Guidelines restrict the use of SV40 DNA to DNA from strains of the virus that are defective in the infection process. In addition, stringent physical containment is required.

d. *Sanction of experiments involving the transfer of uncharacterized mixtures of DNA segments derived from warm-blooded animals into bacteria.* Such experiments are believed to present a greater possible risk than others because they involve a conglomeration of undefined genes that might include DNA capable of causing disease.

e. *Sanction of the use of oncogenic viruses.* It has been argued that the introduction into *E. coli* of the whole DNA or any purified segment of the DNA of any virus oncogenic in any species should not be permitted.

D. *No guidelines but NIH consideration of each proposed project on an individual basis before funding.* With this alternative, individual investigators requesting NIH funds for projects involving recombinant DNA research would bring plans for proposed experiments to an NIH committee that would, without the use of formal guidelines, recommend suitable containment measures. Depending on the criteria used by the committee, this might result in lower or higher containment levels than are currently imposed by the Guidelines. The advantages of such a procedure would include constant re-evaluation of potential hazards and containment measures, and up-to-date information for investigators. The disadvantages include the enormous time and resources required for review, given the size of the biological research enterprise in the United States, the problem of finding knowledgeable individuals to serve on such a committee—essentially a full-time occupation—the opportunity for arbitrary decisions, and the bypassing of local input in assessment of hazards.

It should be pointed out that under the present NIH Guidelines, local institutional biohazards committees must consider proposed research projects on an individual basis and may impose more

stringent safeguards than those required by the Guidelines. The judgments of the investigator and his local committee will be reevaluated by the NIH Study Section reviewing the scientific merit of the proposal.

E. GENERAL FEDERAL REGULATION OF ALL SUCH RESEARCH

The NIH Guidelines control only recombinant DNA research supported by NIH. Nevertheless, NIH has assumed a real responsibility to work toward the promulgation of safety measures for all such research. Nationally, NIH has conducted and is continuing to conduct meetings with representatives of other Federal agencies and of private industry. In the case of the Federal Government, consideration is being given to the imposition of the Guidelines either by individual agency adoption or through an Executive Order. Non-Federal groups have indicated that they will voluntarily comply with reasonable guidelines designed to be applicable to their specific needs.

From the international standpoint, the NIH has been in communication with relevant national bodies, the World Health Organization, the European Molecular Biology Organization, and the International Council of Scientific Unions, among others, to encourage the widest possible application of the Guidelines.

A variety of administrative mechanisms could be employed to regulate recombinant DNA research. Relevant agencies are the Center for Disease Control (CDC), including the National Institute for Occupational Safety and Health (NIOSH), or the Occupational Safety and Health Administration, Department of Labor (OSHA). For example NIH could petition OSHA to enforce and monitor such research through its standard procedures. If OSHA concurred, the adopted guidelines could be extended to all facilities under OSHA's responsibility.

Legislation could be passed to impose procedures and specify containment for recombinant DNA experiments. Specific guidelines, as well as appropriate enforcement mechanisms and penalties, could be established as statute. The advantages of this approach would include uniformity in coverage and process. The disadvantages include the need for establishment of a new administrative mechanism and consequent costs, the long time generally required for enactment of legislation, and the relative inflexibility of law. Flexibility is desirable because presently recommended containment procedures will surely require timely revision as knowledge and experience are accumulated.

A body like the National Commission on the Protection of Human Subjects of Biomedical and Behavioral Research could be legislatively established. It should be noted that a bill (S. 2515) currently under consideration in the Congress would assign responsibility for consideration of recombinant DNA experiments to a permanent President's Commission for the Protection of Human Subjects of Biomedical and Behavioral Re-

search. A real concern would be the inability of a group with such a broad mandate to deal effectively with the highly specialized subject of recombinant DNA research.

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VII. ENVIRONMENTAL IMPACT OF THE GUIDELINES

A. IMPACT OF ISSUANCE OF NIH GUIDELINES

The primary impact of issuance of the Guidelines is to provide a mechanism for the protection of the laboratory worker, the general public, and the environment from the possible hazards that might result from recombinant DNA molecule research. These hazards are purely speculative at present; the speculations may prove to be wrong. Nevertheless the Guidelines take cognizance of the possibility of dangers to the laboratory worker, other persons, and the environment posed by the emergency research technology involving recombinant DNA molecules, and call for a number of measures aimed at reducing or eliminating human and environmental exposure to materials containing recombinant DNA molecules, in case they should prove hazardous. The Guidelines govern only work supported by the NIH, including NIH supported research at various institutions (grants and contracts) and research carried out within NIH intramural laboratories.

With regard to the anticipated but speculative benefits of recombinant DNA research, adherence to the Guidelines may postpone their realization. Certain experiments are prohibited; many permissible experiments will be delayed pending availability of suitable containment facilities and certification of appropriate hosts and vectors.

1. *Impact on the safety of laboratory personnel and on the spread of possibly hazardous agents by infected laboratory personnel.* The NIH Guidelines are directly concerned with reducing and eliminating exposures of laboratory personnel and all other persons to host cells and microorganisms containing recombinant DNA molecules. Because laboratory personnel would be the chief source of infection of other people, protection of personnel is of primary importance. Lack of knowledge about the real risks of such molecules makes it impossible to determine either the nature of the hazards or the extent to which laboratory personnel are endangered by exposures to the materials. Nevertheless present understanding of biology permits a ranking of the possible risks that may be associated with a given experiment.

Four levels of possible risk have been established: minimal, low, moderate, and high. Protection of personnel from minimal risk materials is provided by ordinary microbiological techniques. Since

these procedures are generally performed on the open bench, exposures may occur. The avoidance of harmful effects depends more on the exceedingly low potential of these materials to cause a harmful infection than of the elimination of potential exposures. Potential harmful effects would require exposure to large numbers of organisms, e.g., due to accidental ingestion by poor pipetting techniques or self-inoculation by needle and syringe). Such exposures should be prevented by adherence to practices recommended for this risk level.

The safety of personnel handling materials of minimal risk in the prescribed manner is supported by the absence of any documented laboratory-acquired bacterial or viral infections involving known human etiologic agents that are customarily handled in the same fashion—i.e., CDC class 1 agents (see *Glossary*).

The protection of personnel from potential dangers associated with low- and moderate-risk materials is provided by a greater reliance on physical barriers separating the laboratory personnel from the experimental process as well as on safe microbiological practices. Accidental exposure by ingestion would be prevented by the adherence to the required use of mechanical pipetting for low- and moderate-risk materials. Potential exposure to low-risk materials through aerosols is reduced by the requirement that all processes that produce significant aerosols are to be confined to biological safety cabinets. Potential exposure to moderate-risk materials through aerosols is further reduced by the requirement to contain all processes that produce any aerosol. The use of Class I and Class II biological safety cabinets that comply with the standards specified in the Guidelines can reduce the potential exposure by a factor of 10,000 (1). Potential exposures of laboratory personnel not involved in these experiments are further controlled by the specified laboratory access procedures. These measures do not provide absolute protection from exposures, and the required primary barriers can be compromised by lack of attention to technique, poor placement of equipment, and human error. Experience demonstrates that the use of these measures reduces but does not prevent the potential for laboratory-acquired infections with relatively infectious agents such as class 2 and class 3 agents.

The nature of the harmful effects from exposures to low- and moderate-risk recombinant DNA materials cannot be determined. However, the ability for these materials to cause disease or injury, should they be hazardous can be estimated by comparison of their infectivity with that of known class 2 and class 3 agents. The requirement that recipient bacterial cells be class 1 agents (no or minimal risk) and that animal virus vectors be similarly low risk agents (in the absence of recombined DNA) reduces the likelihood that they will have the infectious properties of class 2 or 3 agents upon insertion of foreign DNA.

Recombinant DNA experiments assessed to have high-risk potential require special precautions designed to prevent exposures, as specified in the Guidelines. All such experimental procedures are required to be surrounded by absolute primary barriers that are gas-tight. These are barriers that physically isolate the experimental process from the laboratory worker. Research is conducted within these barriers through attached gloves. Materials are not removed from the barriers until they have been sterilized or put into hermetically sealed containers, which are then surface sterilized.

Experience with class 3 and 4 human etiologic agents demonstrates that the absolute primary barriers can be operated without exposure of the operators under standardized procedures, employing stable, well trained and well-disciplined personnel (2). This conclusion is based on those data in reference 2 that refer to the experience of recent years; the earlier experience is less relevant because of important recent developments in the design and availability of containment equipment. The procedures for combining segments of DNA and inserting them into recipient cells can be standardized, and the Guidelines require that research personnel be well trained and proficient in the necessary operational practices. Inspection and certification of all high-risk research facilities by NIH personnel provide additional assurances that these requirements will be met.

Thus, potentially harmful effects from research with high risk recombinant DNA molecules should be extremely unlikely given strict adherence to the NIH Guidelines.

Insofar as research sponsored by NIH is concerned, potentially harmful effects from experiments judged to present the possibility of very severe hazard should be prevented completely since those experiments are prohibited.

2. *Impact on the environmental spread of possibly hazardous agents.* The NIH guidelines are directly concerned with preventing the release of cells and microorganisms containing recombinant DNA molecules, or the release of recombinant DNA molecules themselves, into the environment, thus preventing potential exposures of humans, other animals and plant communities.

The Guidelines require decontamination of all liquid and solid wastes generated by low-, moderate-, or high-risk experiments. As the potential risk of these materials increases (low $\rightarrow$ high), further measures are required to increase the certainty of containment. The Guidelines recommend the decontamination of no- or minimal-risk materials before their disposal to the environment. This is standard microbiological practice.

The Guidelines prohibit the release of contaminated air under ordinary conditions. Procedures involving low- and moderate-risk materials that may produce aerosols are confined to primary barriers. Contaminants in the exhaust air from these barriers are removed by filtration.

The potential for accidental release of recombinant DNA materials into the atmosphere, however, increases with decreasing containment requirements (moderate $\rightarrow$ minimal). Harmful secondary effects from such accidental release of minimal-, low-, or moderate-risk materials are exceedingly remote. An analysis of 36 reported laboratory-acquired micro-epidemics in the period 1925-1975 involving over 1,000 infections with class 2, class 3, and class 4 human etiologic agents demonstrated no infections among persons who were never in the laboratory building or who were not associated in some way with the laboratory (2). Almost all of these outbreaks occurred in the absence of genuine efforts to control contaminated air, liquid wastes, refuse, and laundry.

Any potential release of high-risk materials to the environment should be prevented by adherence to the NIH Guidelines. All high-risk materials are required to be isolated in physically contained, absolute primary barriers. All effluents from these barriers are sterilized. The barriers themselves are located in maximum-security facilities, which are provided with additional barriers to prevent any accidental release. Air locks, negative air pressure, clothes-change rooms, filtration and incineration of all air exhausted from the facility, and the secondary sterilization of all liquid and solid wastes, provide additional protection to the environment.

The NIH Guidelines also define requirements for protecting the environment from potential dangers that may be associated with the shipment of recombinant DNA materials. Federal packaging standards appropriate for the shipment of class 4 human etiologic agents are required for the shipment of all recombinant materials.

3. *Cost impact.* The direct cost impact of the NIH guidelines is the cost of complying with their provisions. The costs will vary according to the level of potential risk of the research. There are no special facility requirements for work with minimal- and low-risk recombinant DNA materials (P1 and P2). There are equipment requirements for work involving low-risk recombinant DNA materials that will involve little cost impact. Low-risk research requires a biological safety cabinet for procedures that may produce significant aerosols and an autoclave for sterilizing waste materials. These items of equipment, however, are generally available within the existing facilities where such research is being conducted. The cost impact of the NIH guidelines on minimal- and low-risk research is therefore not significant.

Special equipment and facility requirements are specified for moderate-risk recombinant DNA research (P3). All work at this level of potential risk is to be conducted within biological safety cabinets (Class I or II). This requirement will necessitate the acquisition of many additional cabinets, the number being dependent on the scope of the research effort. It is estimated that one cabinet will be required for every three persons

involved in the research. The cost of each cabinet is approximately \$5,000.

Directional air flow, single-pass ventilation, and provisions for ensuring restricted access are facility requirements specified for moderate risk (P3) recombinant DNA research. While many new facilities (those constructed in the last decade) have been constructed with this capability, few older facilities can provide this capability without extensive renovation. Creating adequate access control by construction of architectural barriers (e.g., air locks, double-door alcove, etc.) is not expensive. However, the cost of renovation of air-handling systems to provide for single-pass, directional air flow may prevent some institutions from conducting moderate-risk research. It has been estimated that installation of air-handling systems that comply with the NIH Guidelines would cost approximately \$200 per square foot of space serviced by the system.

The NIH Guidelines require that high-risk (P4) research involving recombinant DNA materials be conducted only in class III biological safety cabinets (glove boxes) that are installed in maximum security facilities. Fewer than 30 facilities within the United States have the potential for meeting the requirements specified in the Guidelines for such facilities. A smaller number may actually be available for this research. It is estimated that approximately \$750,000 would be required to construct and equip a maximum-security facility having two 10-foot by 20-foot laboratory modules with class III cabinetry. This great cost is due to sophisticated mechanical support systems (e.g., negative pressure, exhaust air filtration, air waste treatment plant) and architectural barriers (e.g., clothes-change rooms, air locks, waste-staging areas, and monolithic walls, floors, and ceilings). The cost of class III cabinetry installed is approximately \$3000 per linear foot. In addition, the cabinetry line and the facility each require a double-door autoclave, costing a minimum of \$15,000 and \$65,000 respectively.

4. *Secondary impacts.* There are three secondary impacts which further provide for environmental protection—i.e., reduce the potential risk to the environment from recombinant DNA research:

a. *Limited maximum-security containment capability.* The small number of facilities available to support high-risk research greatly restricts the number of such experiments that can be conducted. The reduction in the number of experiments minimizes the probability of accidental exposure of laboratory workers and subsequent secondary environmental impacts.

b. *Safety awareness.* The safe performance of biomedical research is dependent on an awareness of the risks and the safeguards required to control the risks. Issuance of the NIH Guidelines should strengthen safety performance in general by providing safety information and increasing the awareness of the laboratory worker to the potential hazards associated with biomedical research.

c. *Early recognition of potential hazards.* The Guidelines require that the principal investigator notify NIH of any serious or extended illness or accident that may result in serious exposure to man or to the environment. This monitoring procedure will provide an early warning of possible unforeseen hazard. For example, if a laboratory infection from exposure to a recombinant DNA molecule is confirmed, indicating a real hazard, an increase in safeguards or cessation of experiments can be required to minimize the hazard to other investigators conducting similar studies. This upgrading will also reduce any potential for environmental effects.

B. IMPACT OF EXPERIMENTS CONDUCTED UNDER THE GUIDELINES

1. *Possible undesirable impact—*a. *Dispersion of potentially hazardous agents.* The hypothetical mechanisms by which insertion of foreign genes into cells or viruses might result in the formation of hazardous agents are described in Section IV-C. There is, as stated before, no known instance in which a hazardous agent has been created by recombinant DNA technology. Current knowledge permits no more than speculation that such agents may be produced and an equally speculative assessment of the nature and extent of hazards that may follow upon a particular recombinant DNA experiment. This is the underlying reason that the thrust of the Guidelines is to minimize contact of organisms containing recombinant DNA with other organisms or the environment. Therefore the following analysis of possible undesirable impacts due to dispersion of potentially hazardous agents emphasizes the likelihood of significant dispersion rather than the nature of the hazard itself. The analysis given does not apply in detail to all the possible situations, but can serve as a model for analyzing different situations.

In order that any potential hazard be realized, it is necessary that each of a number of sequential events occur. Each event in the sequence is possible only if the earlier events have occurred. The organism must—

- (a) Contain foreign genes,
- (b) Escape from the experimental situation,
- (c) Survive after escape,
- (d) Become established in an environment permitting its growth and multiplication,
- (e) Contact other living organisms in a significant manner, including contact by a sufficient number of organisms to ensure survival and growth and to cause infection. (Note that the environment in (d) may be a living organism itself).

In those cases where the detrimental effect results from the formation of a harmful protein, the organism containing the recombinant DNA must—

- (f) Contain a gene for a potentially harmful protein,
- (g) Be able to express the foreign gene—that is, synthesize the foreign protein,
- (h) Synthesize the protein in sufficient quantity to be deleterious to the infected organism.

In those cases where the foreign DNA itself may be the cause of undesirable effects, another set of events must be considered. In the case where the foreign DNA increases the pathogenicity of the initial host cell or virus, the inserted DNA must—

- (i) Impart a selective advantage for growth to the carrier of the recombinant DNA as compared with the original cell or virus,
- (j) Alter the metabolism of the carrier so that it becomes disease producing.

In the case where the foreign DNA causes undesirable effects by virtue of its transfer out of the original recipient and reinsertion into cells of another species, the DNA must—

- (k) Leave the original recipient without being destroyed,
- (l) Survive transfer to another cell,
- (m) Become associated with the other cell in a stable manner, either as an independent element or by natural recombination.

For example, in a hypothetical experiment classified as low-risk and carried out according to the requirements of the Guidelines, events (a) through (h) might be required to yield a hazardous situation. Available data might permit assignment of probabilities of : 1 for (a); of 10^{-2} (1 in 100) for (b); of 10^{-4} (1 in 10,000) for (c); and of 10^{-6} (1 in a million) for (d). Lack of any pertinent knowledge concerning events (e) through (h) would make assignment of probabilities impossible. Even assuming a probability of one for each event (e) through (h), the overall probability of a deleterious effect on a member of a species at risk in this hypothetical situation would then be the product of all probabilities (a) through (h), namely 10^{-12} (one in a trillion). This probability then needs to be compared with the number of organisms grown for the experiment. Typically, bacteria are grown in liquid mixtures to a concentration of between 10^8 and 10^{10} organisms per ml. The probability will also need to be corrected for the length of time over which the experiment is to be conducted. In reality, it may frequently be difficult to assess the relevant probabilities.

It is currently impossible to assign specific probabilities for many experiments, although crude estimates can often be made from current knowledge of laboratory-acquired infections, from prototype experiments set up to measure bacterial or viral escape (4), and from knowledge concerning the stability of organisms and DNA. NIH is currently supporting research designed to improve the ability to evaluate certain of these probabilities.

b. *Other considerations.* The foregoing descriptions of the kinds of possibly hazardous situations that might arise from organisms obtained through recombinant DNA experiments must be considered in the light of certain more general issues.

(1) *Monitoring for release of organisms containing recombined DNA.* Control of the spread of any agent outside of an experimental situation to laboratory workers or the outside environment is greatly assisted by adequate means for

monitoring the agent in question. A pertinent example is the monitoring for spillage and spread of radioisotopes. The presence of radioisotopes is readily measured, and the exposure of laboratory personnel or the environment to radiation can be quantified. The situation is fundamentally different in the case of organisms or viruses containing recombined DNA. No simple general procedure exists for identifying an organism released from the laboratory against the large background level of related and unrelated organisms occurring naturally.

It is possible, however, to devise special pertinent procedures for detection of some of the agents used in recombinant DNA experiments. For example, development of bacterial strains, phages, or plasmids carrying readily detectable genetic traits would enable the monitoring of laboratory personnel, people working in the area, and their families for the presence of those agents. This would be analogous to the examination of drinking water, lakes, etc., for fecal contamination with enteric organisms. Detection in such instances could be at levels as low as 10^{-7} (1 part in 10,000,000). The adequacy of such screening is not presently known.

Given the nature of the series of events that might characterize a hazardous situation, the time factors involved in those events become relevant. Certain possible types of organisms containing recombinant DNA might, if they escaped and if they were hazardous, be immediately perceived as such—e.g., production of toxic foreign proteins. We might therefore be aware of the potential problem soon after dispersal of the organism, and reasonable means for minimizing further dispersal could be undertaken. In other instances—e.g., a cancer-producing DNA fragment—evidence of harmful effects might not be apparent for many years. The connection between the causative organisms and the observed harmful effects could be difficult to establish. Further, dispersal of the hazardous agent might then be so widespread as to make control difficult or impossible.

(2) *Natural occurrence of DNA recombination between unrelated organisms.* Concern over the potential for hazard in organisms containing recombined DNA develops from the central idea that such recombinants will be unique types of organisms, not normally arising in nature, and that their properties will therefore be unknown and unpredictable. Natural environments provide many opportunities for recombination of DNA between unrelated species, as for example, in the intestines of animals. Whether, or at what frequency, such recombinations may occur is not known at present, but it is probably low given the very low extent of shared base sequences that can be detected in DNAs derived from distantly related organisms. It would appear that naturally occurring interspecies recombinants, if they occur in nature, may have been selected against in evolution. However tests for shared base sequences are of limited sensitivity.

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(3) *Relative irreversibility of spread of organisms.* Should organisms containing recombinant DNA be dispersed into the environment, they might, depending on their fitness relative to naturally occurring organisms, find a suitable ecological niche for their own reproduction, and a potentially dangerous organism could then multiply and possibly spread. Subsequent cessation of experiments would not stop the diffusion of the hazardous agent. While means to eradicate the organism might be found, as in the case of smallpox, it is also possible that such means will not be available, or that they will be available too late to prevent or stop untoward events.

As described earlier, the likelihood is that newly constructed organisms will be less fit than those occurring naturally and therefore will disappear over time.

2. *Beneficial impacts of recombinant DNA research.* Section IV-C-2 describes the various anticipated benefits of recombinant DNA research. As with the possible hazards, many of the proposed benefits are speculative. Assessment of the likelihood that they will be realized will depend on information acquired from future experimentation. For example, assessment of the category of anticipated benefits that depends on the synthesis of eukaryote proteins in prokaryote cells (see IV-C-1-b) awaits additional data on the expression of the foreign genes. Should these benefits be realized, it may be expected that the cost of manufacturing certain clinically important proteins can be markedly decreased. Other clinically important proteins that are either in short supply (e.g. human growth hormone) or unobtainable by existing techniques may be made readily available. Innovative approaches to immunization against infectious diseases can also be expected.

Some of the indicted benefits appear certain. These are the benefits to be derived from an increased understanding of both basic biological processes and the mechanisms underlying a variety of disease states.

Application of the restrictions imposed by the Guidelines will retard progress toward the realization of the possible benefits. In addition to the prohibitions on certain experiments, there are many permissible experiments which will need to be postponed until the requirements in the Guidelines can be met. The acquisition and installation of P3 facilities requires adequate funds, extensive planning and installation. P4 facilities are limited in number. Experiments that require hosts and vectors with demonstrably limited ability to survive in natural environments must await development of appropriate hosts and vectors, their testing, and finally their certification by the NIH Recombinant Advisory Committee. Time will also be required for the various review processes that are required.

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APPENDIX A

GLOSSARY

1. Aerosol: A colloid of liquid or solid particles suspended in a gas, usually air.
2. Antibody: A protein which is formed in the body as a result of the inoculation of an antigen.
3. Antigen: A substance which when injected into an animal causes the formation of antibodies.
4. Autoclave: An apparatus for effecting sterilization by steam under pressure. It is fitted with a gauge that automatically regulates the pressure, and therefore the degree of heat to which the contents are subjected.
5. Bacteriophage: A virus that infects only bacteria.
6. Bld: Bureaus, Institutes, and Divisions of NIH.
7. Biohazard: A contraction of the words biological hazard; infectious agents presenting a risk or potential risk to the well-being of man, or other animals, either directly through infection or indirectly through disruption of the environment.
8. Biohazardous Agent: Any microbial unit capable or potentially capable of presenting a biohazard.
9. Biohazard Area: Any area (a complete operating complex, a single facility, a single room within a facility, etc.) in which work has been, or is being performed with biohazardous agents or materials.
10. Biohazard Control: Any set of equipment and procedures utilized to prevent or minimize the exposure of man and his environment to biohazardous agents or materials.
11. Biohazardous Material: Any substance which contains or potentially contains biohazardous agents.
12. Biowaste: Liquid wastes from biological research procedures.
13. CDC: Center for Disease Control, United States Public Health Service, Atlanta, Georgia.
14. CDC Classification of etiologic agents on the basis of hazard: A system for evaluating the hazards associated with various etiologic agents, and definition of minimal safety conditions for their management in microbiological investigations. The basis for Agent Classification is as follows:
Class 1: Agents of no or minimal hazard under ordinary conditions of handling.
Class 2: Agents of ordinary potential hazard. This class includes agents which may produce disease of varying degrees of severity from accidental inoculation or injection or other means of cutaneous penetration but which are contained by ordinary laboratory techniques.
Class 3: Agents involving special hazard or agents derived from outside the United States which require a federal permit for importation unless they are specified for higher classification. This class includes

pathogens which require special conditions for containment.

Class 4: Agents that require the most stringent conditions for their containment because they are extremely hazardous to laboratory personnel or may cause serious epidemic disease. This class includes Class 3 agents from outside the United States when they are employed in entomological experiments or when other entomological experiments are conducted in the same laboratory area.

Class 5: Foreign animal pathogens that are excluded from the United States by law or whose entry is restricted by USDA administrative policy.

NOTE: Federally licensed vaccines containing live bacteria or viruses are not subject to these classifications. These classifications are applicable, however, to cultures of the strains used for vaccine production, or further passages of the vaccine strains.

15. Class I biological safety cabinet: A ventilated cabinet for personnel protection only, having an open front with inward flow of air away from the operator. The cabinet exhaust air is filtered through a high efficiency particulate air (HEPA) filter before being discharged to the outside atmosphere. This cabinet can be used for work with low- to moderate-hazard risk agents where no product protection is required.

16. Class II biological safety cabinet: An open-front cabinet for personnel and product protection with mass recirculated airflow with HEPA filtered exhaust and HEPA filtered recirculated air. This cabinet can be used for work with low- to moderate-hazard risk agents. It is not suitable for use with explosive and flammable substances, toxic agents, or radioactive materials.

17. Class III biological safety cabinet: A gas-tight cabinet providing total isolation for personnel and product protection with a HEPA-filtered air supply and a HEPA-filtered exhaust. The cabinet is fitted with gloves and is maintained under negative air pressure. This cabinet provides the highest containment reliability and should be utilized for all activities involving high-hazard risk agents.

18. Clone: A population of cells derived, by asexual reproduction, from a single cell. Every cell in the population is presumed to be genetically identical. In recombinant DNA research, every cell in a clone contains the same recombinant DNA species.

19. Coding sequence: The orderly array of codons which are subunits of a gene.

20. Chromosome: One or more small rod-shaped body(s) in the nucleus of a cell that contains genetic information for that cell. A collection of genes.

21. Deoxyribonucleic acid, or DNA: A complex substance of which genes are composed.

22. Effluent: A liquid or gas flowing from a process.

23. Endogenous: Developing or originating within the organism, or arising from causes within the organism.

24. *Escherichia coli*: A bacterium commonly found in the intestinal tract of animals.

25. Etiologic agent: A viable microorganism or its toxin which causes, or may cause, human disease.

26. Eukaryotic cell: A cell that contains a nucleus with a nuclear membrane surrounding multiple chromosomes; also contains extranuclear organelles.

27. Gene: The smallest portion of a chromosome that contains the hereditary information for the production of a protein.

28. Genetic engineering: Directed intervention with the content and/or organization of an organism's genetic complement.

29. Genome: The complete set of hereditary information in a cell as the chromosomes in

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a eukaryote or the single chromosome in a prokaryote.

30. HEPA filter: (High Efficiency Particulate Air Filter) A disposable, extended medium, dry type filter with a particle removal efficiency of no less than 99.97% for 0.3µm particles.

31. Infectious: Capable of invading a susceptible host, replicating, and causing an altered host reaction commonly referred to as a disease.

32. Laminar air flow: Air flow in which the entire body of air within a designated space moves with uniform velocity in one direction along parallel flow lines.

33. Laboratory acquired infection: Any infection resulting from exposure to biohazardous materials in a laboratory environment. Exposure may be the result of a specific accident or inadequate biohazard control procedure or equipment.

34. Messenger ribonucleic acid (mRNA): A complex molecule that transmits the information from the gene to a template on which a protein is formed.

35. Mitochondrion: A DNA-containing structure present in all aerobic eukaryotic cells. The mitochondria produce energy for the cell and divide by fission after cell division has occurred.

36. Nucleotide: A basic unit of the polymeric structure of DNA. Each unit contains a sugar (deoxyribose), phosphoric acid, and one of the following organic substances: adenine, guanine, thymine or cytosine.

37. Oncogenesis: The process of tumor formation.

38. Organelle: An independent structural body existing within cells, generally related to a particular cellular function, and containing a special group of genes within an extra-chromosomal DNA molecule (e.g., mitochondria and chloroplasts).

39. Pathogenic: Producing or capable of producing disease.

40. Phenotype: The visible traits of an organism as determined by the genome or genotype.

41. Plasmid: A genetic element outside of the chromosome that is capable of replicating independently of the chromosome.

42. Polymer: A large molecule composed of simpler repeating units. DNA is a polymer composed of nucleotides, while starch and cellulose are polymers composed of sugars.

43. Prokaryotic organism or Prokaryote: Cells of bacteria or blue-green algae which are characterized as being rather small, having a single chromosome that is not enclosed by a nuclear membrane, and lacking organelles.

44. Restriction endonuclease: An enzyme capable of breaking DNA at specific sites. The action of the enzyme is unique in that "sticky" ends are formed which can join with other fragments of DNA to form a recombinant DNA molecule. In nature, these bacterial enzymes restrict invasion of foreign DNA.

45. Reverse transcriptase: An enzyme found in certain viruses which reverses the normal synthesis of RNA from DNA. DNA is formed for the replication of viral RNA.

46. R plasmid: A plasmid that carries genetic information for resistance to antibiotics and/or other antibacterial drugs.

47. Shotgun experiment: An experiment in which all the DNA fragments cleaved by a restriction endonuclease are inserted into a vector DNA, which is then put into a cell. This is in contrast to other recombinant DNA experiments where only selected fragments of DNA are inserted into a vector DNA.

48. Sterilize: Any act which results in the absence of all life on or in an object.

49. Vector: A carrier of a recombinant DNA molecule; usually a plasmid or bacteriophage.

50. Viable: Literally, "capable of life." Generally refers to the ability of microbial cells to grow and multiply as evidenced by, for example, formation of colonies on an agar culture medium. Frequently organisms may be viable under one set of culture conditions and not under another set, making it extremely important to define precisely the conditions used for determining viability.

APPENDIX B

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Appendix C

DOCUMENTS DESCRIBING THE IMPLEMENTATION OF THE GUIDELINES

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, NATIONAL INSTITUTES OF HEALTH

June 18, 1976.

To: Director, NIH, Through: Director, NIGMS, NIH.

From: Executive Secretary, Recombinant DNA Molecule Program Advisory Committee.

Subject: Operation of the Office of Recombinant DNA Activities (ORDA).

The proposed structure and responsibilities of an Office of Recombinant DNA Activities (ORDA) were described in Dr. Kirschstein's memorandum to you of April 28, 1976. The purpose of this document is to present our views as to how such an office can function effectively at the NIH. Consequently, the following relationships and activities are discussed:

I. Office of the Director, NIH (OD, NIH). The Office of Recombinant DNA Activities (ORDA) will be responsible for keeping the Office of the Director, NIH, (OD, NIH) and

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particularly the Deputy Director for Science informed concerning the activities of ORDA, the status of BID extramural programs and intramural research involving recombinant DNA molecules, and on scientific and public developments which may affect NIH policy decisions and procedures regarding recombinant DNA technology. ORDA will interact with the Deputy Director for Science and the Associate Director for Collaborative Research, NIH in their capacities as chairman and vice-chairman, respectively, of the Recombinant DNA Molecule Program Advisory Committee (Recombinant Advisory Committee).

OD, NIH, in turn, should involve ORDA in all major planning activities leading to formation of NIH policies and procedures. As is current practice, the Executive Secretariat, NIH will provide ORDA with information copies of all correspondence relating to recombinant DNA matters. OD, NIH should provide ORDA with copies of outgoing correspondence, responses to Congressional inquiries, etc., to ensure that the NIH maintains uniform positions on the various matters relating to this technology.

An Executive Recombinant DNA Committee (Executive Committee) should be established in the Office of the Director, NIH. Members of the Committee would be: Deputy Director for Science (Chairman); Associate Director for Extramural Research and Training; Associate Director for Collaborative Research; Associate Director for Program Planning and Evaluation; Director, Office of Research Safety, NCI; and Associate Director for Environmental Health and Safety, DRS. The Special Assistant for Intramural Affairs will serve as Executive Secretary of the Executive Committee. There will be representation on this committee of one or more of the BIDS most involved in the support of research utilizing this technology. Problems (such as suitability of institutional biohazards committees, adequacy of review of applications, appropriateness of proposed new initiatives by BIDS, etc.) which cannot be resolved at the level of ORDA will be referred to the Executive Committee. Problems which can not be resolved at the level of the Executive Committee will be referred to the Recombinant Advisory Committee or subcommittees thereof by telephone, mail or presentation at the next meeting. The Deputy Director for Science will have the ultimate responsibility for decisions and can make urgent decisions without consultation with the committees. (OD, NIH may wish to propose an alternative approach other than the establishment of an Executive Committee).

The Deputy Director for Science, NIH, will have the responsibility for assigning to the individual BIDS various projects developed by the Executive Committee or Recombinant Advisory Committee or solicited by ORDA.

The Office of the Director, NIH will be responsible for promulgation and enforcement of regulations, and for accountability to congressional committees, DHEW, and the public. ORDA will keep the Deputy Director for Science, NIH informed of any potential problems which may lead to regulatory activities and/or need for accountability and may make appropriate recommendations in these circumstances.

II. *Dissemination of information.* The Office of the Director, NIH will be responsible for the promulgation of "Guidelines for Research Involving Recombinant DNA Molecules" (Guidelines), and should undertake the initial mass distribution of Guidelines to institutions and research laboratories through its mailing keys and use of the appropriate instrument, such as the "NIH Guide for Grants and Contracts" (NIH Guide), NIH Manual Issuance (NIH Manual), etc. Thereafter, ORDA will be responsible for distributing Guidelines and responding to requests by

institutions and investigators regarding NIH policies and procedures. Dissemination of major changes in the Guidelines should also be handled as above.

The NIAID will have responsibility for publication of the "Nucleic Acid Recombinant Scientific Memoranda" (NARSM). Major announcements in NARSM, such as distribution of Guidelines, statements of NIH policies and procedures, announcements of certified host-vector systems, training courses, workshops, conferences, etc. will be coordinated with ORDA.

III. *Division of research grants.* ORDA will work with the Associate Director for Scientific Review, DRG on procedures for the review of grant applications involving recombinant DNA technology. On request, ORDA will brief executive secretaries and study sections on NIH policies and procedures.

Involvement of DRG in the processing of grant applications is discussed in Appendix A.

IV. *Institutes and divisions.* Institutes and Divisions will be required to report to ORDA on all activities involving recombinant DNA technology, including: intramural research projects, extramural grants and contracts, workshops, training courses, conferences, etc. BIDS will provide ORDA with copies of all incoming and outgoing correspondence dealing with recombinant DNA activities. Awarding components must consult with ORDA prior to issuing Requests for Proposals (RFPs) and Requests for Applications (RFAs) likely to result in projects utilizing recombinant DNA technology. Procedures for obtaining information on extramural research, and for the processing of applications are proposed in Appendix A. Procedures for monitoring intramural research are proposed in Appendix B.

ORDA will be a source of information for the Institutes and Divisions, and their initial review groups, regarding current NIH policies and procedures. ORDA may establish an inter-BID Recombinant DNA Coordinating Committee to facilitate interchange of information. Because of the procedures proposed, NIH awarding components may wish to consider naming specific staff for liaison with ORDA.

V. *Special NIH relationships.* ORDA will maintain close working relationships with the Director, Office of Research Safety, NCI, the Associate Director for Environmental Health and Safety, DRS and the NIH Biohazards Committee, and will coordinate their activities on matters relating to recombinant DNA technology. The Office of Research Safety, NCI will continue to have primary responsibility for matters relating to physical containment of recombinant DNA materials, and will continue to maintain a register of high containment facilities in this country and abroad. However, plans for site inspections of P4 physical containment facilities currently or envisaged to be engaged in recombinant DNA research, and of other facilities as deemed necessary, will be coordinated through ORDA, and copies of site visit reports will be filed with ORDA.

VI. *Federal relationships.* ORDA will develop interrelationships with other federal agencies concerned with recombinant DNA technology, including but not limited to the following: National Academy of Sciences, National Science Foundation, Energy Research and Development Administration, Department of Agriculture, Environmental Protection Agency, National Aeronautics and Space Administration, and the Occupational Safety and Health Administration.

Parenthetically, it should be mentioned that representatives of the National Academy of Sciences and National Science Foundation are already attending meetings of the Recombinant Advisory Committee on a regular basis, and the National Aeronautics and Space Administration and the Energy Re-

search and Development Administration have sent a representative to several of the meetings.

VII. *Non-Federal and international relationships.* ORDA will attempt to develop interrelationships with private foundations, professional societies, scientific journals and industry, and to coordinate NIH policies with international bodies concerned with recombinant DNA technology. The Executive Secretary of the Recombinant Advisory Committee already has a working relationship with the European Molecular Biology Organization.

VIII. *Institutional Biohazards Committees.* ORDA will receive directly from each institution involved in recombinant DNA activities the roster of its institutional biohazards committee. The minimum information should include the names, addresses, occupations and qualifications of the chairman and members of the committee. Institutions will be notified by the appropriate instrument (NIH Guide, NIH Manual, etc.) of the necessity for filing this information with ORDA.

As stipulated in the Guidelines, ORDA will assist in the formation of area biohazards committees composed of members of a given institution and/or other organizations beyond its own staff. An area committee will be necessary when expertise from outside a given institution is necessary for the biohazards committee to fulfill its functions.

ORDA will review the composition of institutional biohazards committees for compliance with the recommendations stated in the Guidelines, and will maintain updated lists of such complying committees. Serious questions about the suitability of a committee will be brought to the attention of the Executive Committee.

IX. *Information on accidents, containment and innovations.* As stipulated by the Guidelines, investigators are required to report to ORDA and to their institutional biohazards committees any serious or extended illness of a worker, or any accidents of the type described in the Guidelines. The Guidelines also require that investigators report to ORDA and their biohazards committee any problems pertaining to operation and implementation of biological and physical containment safety practices and procedures, or equipment or facility failure.

ORDA will receive from investigators information on purported EK2 and EK3 systems, and information bearing on the Guidelines, such as technical information relating to hazards and new safety procedures or innovations.

ORDA will receive and file these reports and, as appropriate bring them to the attention of the Deputy Director for Science, NIH, the Office of Research Safety, NCI, and the Recombinant Advisory Committee or subcommittees thereof. ORDA may, after review, recommend appropriate action to the Deputy Director for Science, NIH.

X. *Recombinant DNA molecule program advisory committee.* ORDA will have the management responsibilities for the Recombinant Advisory Committee, will serve as its staff, and will provide the Executive Secretary. Staff functions will include the gathering, analysis and dissemination of information, the presentation of issues, etc.

XI. *Transition and implementation.* Proposals for initial gathering of information on NIH activities in this area and implementation of the Guidelines are discussed in this Appendix C.

The relationships, responsibilities and procedures proposed in this memorandum and its appendices are wide-ranging and complex. They are, however, an attempt to describe how NIH might administer the Guidelines governing this controversial technology responsibly and effectively. I look forward to

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hearing your comments and those of your staff on these proposals.

WILLIAM J. GARTLAND, Jr., Ph. D.

APPENDIX A TO APPENDIX C

PROCESSING, REVIEW, AND MANAGEMENT OF EXTRAMURAL PROJECTS INVOLVING RECOMBINANT DNA TECHNOLOGY

I. *General.* The purpose of this appendix is to discuss procedures for the processing, review and management of NIH supported projects which involve the use of recombinant DNA technology. The term "application", as used here, refers to all contract proposals and grant applications for research projects, program projects, centers, training, fellowships, research career development, etc., as defined in NIH Manual Issuance 4101: "Activity Codes, Organizational Codes and Definitions used in Extramural Programs." The procedures would apply to applications reviewed by DRG study sections and Institute and Division initial review groups.

II. *Capture of information.* One of the primary functions of the Office of Recombinant DNA Activities (ORDA) is to maintain a central register of NIH supported projects which involve recombinant DNA technology so that the NIH will know where these projects are located and will have the capability of rapidly communicating with project directors should the need arise.

In order to maintain an updated central register of projects it will be necessary for the NIH to modify application forms to indicate on the face sheet whether or not recombinant DNA technology is involved in the project. This could be modeled after the statement currently in use regarding research involving human subjects. The information would be captured, as is the case for human experimentation, and permit sorting by different parameters such as awarding component, geographic location of projects, etc.

III. *Receipt of applications.* Through the use of appropriate instrument (NIH Guide, NIH Manual, etc.), the NIH will inform applicants of the necessity for assessing the physical and biological containment required for the proposed experiments as stipulated in the NIH guidelines. This assessment must be incorporated into the application.

All applications requesting support for projects involving recombinant DNA technology will be required to have on file two documents: A Memorandum of Understanding and Agreement (MUA) and a Certification Statement (Certification) from the institutional biohazards committee. The NIH must and will require that a properly executed MUA and Certification accompany all applications proposing to use recombinant DNA technology. This will eliminate the need for tracking these documents after the application is accepted for review. The originals of these documents will be placed in the official files of the NIH awarding components with copies on file in ORDA.

IV. *Review of applications.* The executive secretaries of initial review groups are responsible for identifying all applications involving recombinant DNA technology, and for placing on the first page of every summary statement the following special note:

RECOMBINANT DNA MOLECULES—POTENTIAL BIOHAZARD

The executive secretaries are responsible for ensuring that the initial review groups make an independent assessment of the biological and physical containment levels required for the proposed experiments, and for stating in the text of the summary statement the initial review group's determination as to whether the containment levels proposed by the investigator meet the levels

stipulated in the NIH guidelines. If the proposed containment levels are inadequate, the initial review group should discuss, in as much detail as possible, the inadequacies of the proposed containment and under what circumstances, if at all, the application should be eligible for funding. Initial review groups should be encouraged to disapprove applications if the proposed containment levels are so inadequate as to be irresponsible. It will be the responsibility of the awarding unit to inform applicants directly as to the fact that this was the reason for disapproval.

Executive secretaries and members of relevant initial review groups will receive a copy of the Guidelines to permit them to make these judgments. Problems relating to assessment of biological and physical containment levels proposed by investigators versus those required by the Guidelines will be referred to ORDA.

As in the case of human experimentation, national advisory councils and boards and final review bodies are expected to carefully scrutinize proposals, involving recombinant DNA technology, and make appropriate recommendations.

V. *Award of new and competing renewal projects.* Prior to the award of any project involving recombinant DNA technology, the NIH awarding component will forward to ORDA one copy of each of the following documents: The application, summary statement, MUA, Certification, any comments of the final review body, and a request for clearance to award. In those cases in which the initial or final review group, or staff of an awarding BID finds that a project requires a higher level of containment than that originally proposed by the applicant or the institution, a properly executed revised MUA and Certification Statement will be required prior to a request for approval to award. ORDA will review the documents and indicate concurrence or non-concurrence with the request for clearance to award. In the latter case, ORDA will prepare a memorandum outlining the reasons for disapproval but emphasizing that the action is independent of scientific merit or other reasons. Such a memorandum should be forwarded to the applicant through the awarding unit. In those cases in which ORDA is not able to reach a decision, or in which the awarding component or applicant disputes the decision, the decision will be submitted to the Executive Committee, and, if necessary, to the Recombinant Advisory Committee, for review. The final decision will rest with the Deputy Director for Science, NIH.

BIDs will forward to ORDA a copy of all award statements involving these applications.

ORDA will retain in its files the documents cited above. In the event that the volume of filed documents becomes excessive, ORDA will retain a copy of the face sheet of a funded application rather than the entire application. In those cases in which the proposed project involving recombinant DNA technology is but one component of a multiproject application, ORDA will retain in its files the face sheet of the application and the section(s) describing the project(s) involving recombinant DNA technology.

It must be emphasized that the primary responsibility for ensuring that applications have been properly reviewed, and that required documents are properly executed lies with NIH staff involved with the initial review groups and program areas. The procedures proposed above are intended to serve as a final review prior to award. ORDA will be available to NIH staff for advice and consultation, but it can not be expected to make decisions for review units and awarding components.

VI. *Award of non-competing renewals and incrementally-funded contracts.* Each non-competing renewal of a grant and subsequent budget period of an incrementally-funded contract utilizing recombinant DNA technology must be accompanied by an updated Certification Statement from the institutional biohazards committee. Prior to any award of this type the program official in the awarding component has the responsibility for reviewing the application for conformity with the Guidelines, for determining whether the proposed protocols do or do not require a higher level of containment than was required in the application as reviewed by the initial review group, and for ensuring that the required documents are properly executed. The program official will then forward to ORDA one copy of the application and the certification statement, along with a request for clearance to award. The latter will include a statement to the effect that the program official has reviewed the application for conformity with the Guidelines, and that the proposed containment levels are adequate. Thereafter, the procedures described in V will be followed, and BIDs will forward to ORDA a copy of all award statements involving these projects.

If the investigator proposes to significantly alter an approved protocol at the time of the non-competing renewal or subsequent budget period of an incrementally-funded contract, then the procedures described in VII must be followed. It is the responsibility of the program official to ensure that all the information and properly executed documents required in VII are present in the application prior to forwarding the request to ORDA.

VII. *Changes in awarded projects.* Since in many cases the NIH supports projects for project periods longer than one year, a number of situations will arise in funded projects. One situation arises when an investigator makes a decision to utilize recombinant DNA technology after the project has been reviewed and awarded. Another situation arises when an investigator decides to close DNA segments other than those originally reviewed, and for which higher levels of containment may be required. In these cases, and in all cases in which an investigator wishes to significantly alter an approved protocol, the investigator must first apply to the NIH awarding component for permission before proceeding. This requirement should be stated in the appropriate NIH instrument (NIH Manual, NIH Guide, etc.) The investigator will be required to submit to the awarding component a proposed protocol, an assessment of the levels of physical and biological containment required by the Guidelines, an MUA, and a Certification Statement from the institutional biohazards committee. The program official in the awarding component has the responsibility for reviewing the request in light of the Guidelines, for ensuring that the required documents are properly executed, and for forwarding to ORDA a copy of all the documents along with a recommendation. The latter should include the program official's independent assessment of the levels of physical and biological containment required by the NIH Guidelines, and a recommendation as to how to proceed. ORDA will review the request, and, when appropriate, refer the request to the initial review group, the Recombinant Advisory Committee, or ad hoc consultants.

VIII. *Requests for lowering of containment levels.* Under "characterized clones of DNA recombinants derived from shotgun experiments," the Guidelines state:

... before containment conditions lower than the ones used to clone the DNA can be adopted, the investigator must obtain approval from the granting agency. Such ap-

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proval would be contingent upon data concerning: (a) The absence of potentially harmful genes (e.g., sequences contained in indigenous tumor viruses or which code for toxic substances), (b) the relation between the recovered and desired segment (e.g., hybridization and restriction endonuclease fragmentation analysis where applicable), and (c) maintenance of the biological properties of the vector.

This stipulation for NIH approval may be one of the most difficult sections of the Guidelines to implement. This is because of the technical nature of the data to be evaluated, and because of the volume of requests which can be anticipated. Therefore, the following proposed procedures are especially viewed as a feasibility trial.

An investigator who wishes to use lower levels of containment for characterized clones derived from shotgun experiments must state, in writing, the justification for the request to the program official of the NIH awarding component. Such justification will provide data on (a), (b) and (c) as stated above. The program official will retain the original request in the awarding component's file, and forward a copy to ORDA which will submit the request to the Recombinant Advisory Committee or to a subcommittee thereof for evaluation, or, if a precedent has been established, will make a decision independently. The decision will be forwarded to the program official who may appeal. The final decision rests with the Deputy Director for Science, NIH.

IX. *Large-scale experiments.* The Guidelines state that:

* * * at this time large-scale experiments (e.g., more than 10 liters of culture) with recombinant DNAs known to make harmful products are not to be carried out * * *. However, specific experiments in this category may be exempted from this rule if special biological containment precautions and equipment designed for large-scale operations are used, and provided that these experiments are expressly approved by the Recombinant DNA Molecule Program Advisory Committee.

An investigator who wishes to conduct such experiments must submit a request, along with a properly executed MUA and Certification Statement from the institutional biohazards committee, to the program official of the NIH awarding component. The program official will retain the original request in the awarding component's file, and forward copies to ORDA. ORDA will bring the request to the attention of the Recombinant Advisory Committee or subcommittees thereof, by mail, telephone, or presentation at the next meeting or, if a precedent has been established, will make a decision independently.

APPENDIX B TO APPENDIX C

NIH INTRAMURAL RESEARCH

Because NIH intramural research projects are reviewed in a very different fashion than extramural projects, different procedures are applicable than those proposed in Appendix A.

At present, the Chief of the Laboratory in which an investigator plans to utilize recombinant DNA technology requests approval through the Scientific Director of the relevant BID to the Deputy Director for Science, NIH with copies to the Associate Director for Environmental Health and Safety, DRS. The request for approval is in the form of a draft Memorandum of Understanding and Agreement (MUA) which describes the type of experiment, nature of host-vector system, assessment of potential risk, proposed safety measures, proposed training of personnel, etc. The Deputy Direc-

tor for Science then requests the NIH Biohazards Committee to review the research plan and procedures proposed in the draft MUA. The recommendations of the NIH Biohazards Committee are forwarded to the Deputy Director for Science, NIH. Recommendations of the NIH Biohazards Committee must be included in a final MUA, and the Associate Director for Environmental Health and Safety, DRS must certify that the safety measures included in the final MUA are available. The research cannot proceed until the final MUA is fully approved. The original copy of the MUA is sent to the Associate Director for Environmental Health and Safety, DRS with copies to the requesting investigator, the Laboratory Chief, the Scientific Director and the Executive Secretary of the NIH Biohazards Committee.

It is proposed here that a copy of the final MUA be forwarded to ORDA for review. If ORDA does not concur with the recommendations of the NIH Biohazards Committee, it may request the Deputy Director for Science, NIH to bring the matter to the attention of the Executive Committee or the Recombinant Advisory Committee for resolution.

ORDA will assist the NIH Biohazards Committee with problems relating to assessment of biological and physical containment levels proposed by investigators versus those required by the Guidelines, with requests for the use of lower containment levels for characterized clones derived from shotgun experiments, and with requests for permission to do large-scale experiments with recombinants known to make harmful products. ORDA will also assist the NIH Biohazards Committee in periodic review and revisions of MUAs. If ORDA does not concur with the decisions of the NIH Biohazards Committee, it may request the Deputy Director for Science, NIH to bring the matter to the attention of the Executive Committee or the Recombinant Advisory Committee.

APPENDIX C TO APPENDIX C

TRANSITION AND IMPLEMENTATION

The procedures proposed in Appendices A and B should be implemented as soon as possible. However, clearly there will be an interim period after the Guidelines are issued and before all the procedures are functioning. It is the purpose of this Appendix to propose how the Office of Recombinant DNA Activities (ORDA) might initiate coordination and gathering of information during this period.

I. *Intramural research.* ORDA will brief the Scientific Directors of the BIDs who will be expected to assure ORDA and the Deputy Director for Science, NIH of present and future compliance by intramural research scientists with the Guidelines.

ORDA will request the Deputy Director for Science, NIH to provide a copy of the final MUA on all intramural projects, utilizing recombinant DNA technology, which are already in progress. After review of the MUAs, ORDA will report any concerns to the Deputy Director for Science, NIH.

II. *Extramural programs.* ORDA will brief the Executive Committee for Extramural Affairs on NIH policies and procedures.

BIDs will be required to report to ORDA all presents or planned workshops, training courses, conferences, etc., relating to recombinant DNA technology. BIDs must also report all present or planned RPFs and RFAs likely to result in projects utilizing recombinant DNA technology. After review of this information, ORDA will report any concerns to the Deputy Director for Science, NIH and/or the Executive Committee.

With regard to active grants and contracts, BIDs will be required to submit to ORDA a copy of the application, summary state-

ment and award statement for each currently funded project involving recombinant DNA technology. NIH awarding components will be responsible for ensuring that this reporting is as complete as possible.

BIDs will send a letter to investigators identified in the paragraph above to determine whether active research projects are in compliance with the Guidelines. Responses to this query will be retained in BID official files, and a copy will be forwarded to ORDA for review. If ORDA is satisfied that a project is in compliance with the Guidelines, no further action is required. If the investigator reports that the project is not in full compliance with the guidelines, those aspects of the project which are not in compliance will have to be terminated. However, investigators will have the opportunity to petition the Recombinant Advisory Committee to permit continued use of characterized clones already in existence and constructed under Asilomar guidelines. Presumably, the use of these clones will be permitted to continue until the Recombinant Advisory Committee or a subcommittee thereof, has rendered its opinion.

The above procedures assume that all investigators are already at least in compliance with Asilomar guidelines. If projects are identified which appear not to be in compliance with Asilomar guidelines, they will be brought to the immediate attention of the Deputy Director for Science, NIH and the Recombinant Advisory Committee.

APPENDIX D

RECOMBINANT DNA RESEARCH

Guidelines

as published in the
FEDERAL REGISTER, Part II,
July 7, 1976

On Wednesday, June 23, 1976, the Director, National Institutes of Health, with the concurrence of the Secretary of Health, Education, and Welfare, and the Assistant Secretary for Health, issued guidelines that will govern the conduct of NIH-supported research on recombinant DNA molecules. The NIH is also undertaking an environmental impact assessment of these guidelines for recombinant DNA research in accordance with the National Environmental Policy Act of 1969.

The NIH Guidelines establish carefully controlled conditions for the conduct of experiments involving the production of such molecules and their insertion into organisms such as bacteria. These Guidelines replace the recommendations contained in the 1975 "Summary Statement of the Asilomar Conference on Recombinant DNA Molecules." The latter would have permitted research under less strict conditions than the NIH Guidelines.

The chronology leading to the present Guidelines is described in detail in the NIH Director's decision document that follows. In summary, scientists engaged in this research called, in 1974, for a moratorium on certain kinds of experiments until an international meeting could be convened to consider the potential hazards of recombinant DNA molecules. They also called upon the NIH to establish a committee to provide advice on recombinant DNA technology.

The international meeting was held at the Asilomar Conference Center, Pacific Grove, California, in February 1975. The consensus of this meeting was that certain experiments should not be done at the present time, but that most of the work on construction of recombinant DNA molecules should proceed with appropriate physical and biological barriers. The Asilomar Conference report also

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made interim assignments of the potential risks associated with different types of experiments. The NIH then assumed responsibility for translating the broadly based Asilomar recommendations into detailed guidelines for research.

The decision by the NIH Director on these Guidelines was reached after extensive scientific and public airing of the issues during the sixteen months which have elapsed since the Asilomar Conference. The issues were discussed at public meetings of the Recombinant DNA Molecule Program Advisory Committee (Recombinant Advisory Committee) and the Advisory Committee to the NIH Director. The Recombinant Advisory Committee extensively debated three different versions of the Guidelines during this period.

The Advisory Committee to the NIH Director, augmented with consultants representing law, ethics, consumer affairs and the environment, was asked to advise as to whether the proposed Guidelines balanced responsibility to protect the public with the potential benefits through the pursuit of new knowledge. The many different points of view expressed at this meeting were taken into consideration in the decision.

The NIH recognizes a special obligation to disseminate information on these guidelines as widely as possible. Accordingly, the Guidelines will be sent to all of the approximately 25,000 NIH grantees and contractors. Major professional societies which represent scientists working in this area will also be asked to endorse the Guidelines. The Guidelines will be sent to medical and scientific journals and editors of these journals will be asked to request that investigators include a description of the physical and biological containment procedures used in any recombinant research they report on. International health and scientific organizations will also receive copies of the guidelines for their review.

Filing of an environmental impact statement will provide opportunity for the scientific community, Federal, State and local agencies and the general public to address the potential benefits and hazards of this research area. In order for there to be further opportunity for public comment and consideration, these guidelines are being offered for general comment in the FEDERAL REGISTER. It must be clearly understood by the reader that the material that follows is not proposed rulemaking in the technical sense, but is a document on which early public comment and participation is invited.

Please address any comments on these draft policies and procedures to the Director, National Institutes of Health, 9000 Rockville Pike, Bethesda, Maryland 20014. All comments should be received by November 1, 1976.

Additional copies of this notice are available from the Acting Director, Office of Recombinant DNA Activities, National Institute of General Medical Sciences, National Institutes of Health, 9000 Rockville Pike, Bethesda, Maryland 20014.

DONALD S. FREDRICKSON, M.D.,
Director,
National Institutes of Health.

JUNE 25, 1976.

DECISION OF THE DIRECTOR, NATIONAL INSTITUTES OF HEALTH TO RELEASE GUIDELINES FOR RESEARCH ON RECOMBINANT DNA MOLECULES

JUNE 23, 1976.

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INTRODUCTION

Today, with the concurrence of the Secretary of Health, Education, and Welfare and the Assistant Secretary for Health, I am releasing guidelines that will govern the conduct of NIH-supported research on recombinant DNA molecules (molecules resulting from the recombination in cell-free systems of segments of deoxyribonucleic acid, the material that determines the hereditary characteristics of all known cells). These guidelines establish carefully controlled conditions for the conduct of experiments involving the insertion of such recombinant genes into organisms, such as bacteria. The chronology leading to the present guidelines and the decision to release them are outlined in this introduction.

In addition to developing these guidelines, NIH has undertaken an environmental impact assessment of these guidelines for recombinant DNA research in accordance with the National Environmental Policy Act of 1969 (NEPA). The guidelines are being released prior to completion of this assessment. They will replace the current Asilomar guidelines, discussed below, which in many instances allow research to proceed under less strict conditions. Because the NIH guidelines will afford a greater degree of scrutiny and protection, they are being released today, and will be effective while the environmental impact assessment is under way.

Recombinant DNA research brings to the fore certain problems in assessing the potential impact of basic science on society as a whole, including the manner of providing public participation in those assessments. The field of research involved is a rapidly moving one, at the leading edge of biological science. The experiments are extremely technical and complex. Molecular biologists active in this research have means of keeping informed, but even they may fail to keep abreast of the newest developments. It is not surprising that scientists in other fields and the general public have difficulty in understanding advances in recombinant DNA research. Yet public awareness and understanding of this line of investigation is vital.

It was the scientists engaged in recombinant DNA research who called for a moratorium on certain kinds of experiments in order to assess the risks and devise appropriate guidelines. The capability to perform DNA recombinations, and the potential hazards, had become apparent at the Gordon Research Conference on Nucleic Acids in July 1973. Those in attendance voted to send an open letter to Dr. Philip Handler, President of the National Academy of Sciences, and to Dr. John R. Hogness, President of the Institute of Medicine, NAS. The letter, appearing in "Science 181," 1114, (1973), suggested "that the Academies [sic] establish a study committee to consider this problem and to recommend specific actions or guidelines, should that seem appropriate."

In response, NAS formed a committee, and its members published another letter in "Science 185," 303, (1974). Entitled "Potential Biohazards of Recombinant DNA Molecules," the letter proposed:

First, and most important, that until the potential hazards of such recombinant DNA molecules have been better evaluated or until adequate methods are developed for preventing their spread, scientists throughout the world join with the members of this committee in voluntarily deferring . . . [certain] experiments . . .

Second, plans to link fragments of animal DNAs to bacterial plasmid DNA or bacteriophage DNA should be carefully weighed . . .

Third, the Director of the National Institutes of Health is requested to give immediate consideration to establishing an advisory committee charged with (i) overseeing an experimental program to evaluate the potential biological and ecological hazards of the above types of recombinant DNA molecules; (ii) developing procedures which will minimize the spread of such molecules within human and other populations; and (iii) devising guidelines to be followed by investigators working with potentially hazardous recombinant DNA molecules.

Fourth, an international meeting of involved scientists from all over the world should be convened early in the coming year to review scientific progress in this area and to further discuss appropriate ways to deal with the potential biohazards of recombinant DNA molecules.

On October 7, 1974, the NIH Recombinant DNA Molecule Program Advisory Committee (hereafter "Recombinant Advisory Committee") was established to advise the Secretary, HEW, the Assistant Secretary for Health, and the Director, NIH, "concerning a program for developing procedures which will minimize the spread of such molecules within human and other populations, and for devising guidelines to be followed by investigators working with potentially hazardous recombinants."

The international meeting proposed in the "Science" article (185, 303, 1974) was held in February 1975 at the Asilomar Conference Center, Pacific Grove, California. It was sponsored by the National Academy of Sciences and supported by the National Institutes of Health and the National Science Foundation. One hundred and fifty people attended, including 52 foreign scientists from 15 countries, 16 representatives of the press, and 4 attorneys.

The conference reviewed progress in research on recombinant DNA molecules and discussed ways to deal with the potential biohazards of the work. Participants felt that experiments on construction of recombinant DNA molecules should proceed, provided that appropriate biological and physical containment is utilized. The conference made recommendations for matching levels of containment with levels of possible hazard for various types of experiments. Certain experiments were judged to pose such serious potential dangers that the conference recommended against their being conducted at the present time.

A report on the conference was submitted to the Assembly of Life Sciences, National Research Council, NAS, and approved by its Executive Committee on May 20, 1975. A summary statement of the report was published in "Science 188," 991 (1975), "Nature 225," 442, (1975), and the "Proceedings of the National Academy of Sciences 72," 1981, (1975). The report noted that "in many countries steps are already being taken by national bodies to formulate codes of practice for the conduct of experiments with known or potential biohazard. Until these are

established, we urge individual scientists to use the proposals in this document as a guide."

The NIH Recombinant Advisory Committee held its first meeting in San Francisco immediately after the Asilomar conference. It proposed that NIH use the recommendations of the Asilomar conference as guidelines for research until the committee had an opportunity to elaborate more specific guidelines, and that NIH establish a newsletter for informal distribution of information. NIH accepted these recommendations.

At the second meeting, held on May 12-13, 1975, in Bethesda, Maryland, the committee received a report on biohazard-containment facilities in the United States and reviewed a proposed NIH contract program for the construction and testing of microorganisms that would have very limited ability to survive in natural environments and would thereby limit the potential hazards. A subcommittee chaired by Dr. David Hogness was appointed to draft guidelines for research involving recombinant DNA molecules, to be discussed at the next meeting.

The NIH committee, beginning with the draft guidelines prepared by the Hogness subcommittee, prepared proposed guidelines for research with recombinant DNA molecules at its third meeting, held on July 18-19, 1975, in Woods Hole, Massachusetts.

Following this meeting, many letters were received which were critical of the guidelines. The majority of critics felt that they were too lax, others that they were too strict. All letters were reviewed by the committee, and a new subcommittee, chaired by Dr. Elizabeth Kutter, was appointed to revise the guidelines.

A fourth committee meeting was held on December 4-5, 1975, in La Jolla, California. For this meeting a "variorum edition" had been prepared, comparing line-for-line the Hogness, Woods Hole, and Kutter guidelines. The committee reviewed these, voting item-by-item for their preference among the three variations and, in many cases, adding new material. The result was the "Proposed Guidelines for Research Involving Recombinant DNA Molecules," which were referred to the Director, NIH, for a final decision in December 1975.

As Director of the National Institutes of Health, I called a special meeting of the Advisory Committee to the Director to review these proposed guidelines. The meeting was held at NIH, Bethesda, on February 9-10, 1976. The Advisory Committee is charged to advise the Director, NIH, on matters relating to the broad setting—scientific, technological, and socioeconomic—in which the continuing development of the biomedical sciences, education for the health professions, and biomedical communications must take place, and to advise on their implications for NIH policy, program development, resource allocation, and administration. The members of the committee are knowledgeable in the fields of basic and clinical biomedical sciences, the social sciences, physical sciences, research, education, and communications. In addition to current members of the committee, I invited a number of former committee members as well as other scientific and public representatives to participate in the special February session.

The purpose of the meeting was to seek the committee's advice on the guidelines proposed by the Recombinant Advisory Committee. The Advisory Committee to the Director was asked to determine whether, in their judgment, the guidelines balanced scientific responsibility to the public with scientific freedom to pursue new knowledge.

Public responsibility weighs heavily in this genetic research area. The scientific community must have the public's confidence that the goals of this profoundly important research accord respect to important ethical, legal, and social values of our society. A key element in achieving and maintaining this public trust is for the scientific community to ensure an openness and candor in its proceedings. The meetings of the Director's Advisory Committee, the Asilomar group, and the Recombinant Advisory Committee have reflected the intent of science to be an open community in considering the conduct of recombinant DNA experiments. At the Director's Advisory Committee meeting, there was ample opportunity for comment and an airing of the issues, not only by the committee members but by public witnesses as well. All major points of view were broadly represented.

I have been reviewing the guidelines in light of the comments and suggestions made by participants at that meeting, as well as the written comments received afterward. As part of that review I asked the Recombinant Advisory Committee to consider at their meeting of April 1-2, 1976, a number of selected issues raised by the commentators. I have taken those issues and the response of the Recombinant Advisory Committee into account in arriving at my decision on the guidelines. An analysis of the issues and the basis for my decision follow:

I. GENERAL POLICY CONSIDERATIONS

A word of explanation might be interjected at this point as to the nature of the studies in question. Within the past decade, enzymes capable of breaking DNA strands at specific sites and of coupling the broken fragments in new combinations were discovered, thus making possible the insertion of foreign genes into viruses or certain cell particles (plasmids). These, in turn, can be used as vectors to introduce the foreign genes into bacteria or into cells of plants or animals in test tubes. Thus transplanted, the genes may impart their hereditary properties to new hosts. These cells can be isolated and cloned—that is, bred into a genetically homogeneous culture. In general, there are two potential uses for the clones so produced: as a tool for studying the transferred genes, and as a new useful agent, say for the production of a scarce hormone.

Recombinant DNA research offers great promise, particularly for improving the understanding and possibly the treatment of various diseases. There is also a potential risk—that microorganisms with transplanted genes may prove hazardous to man or other forms of life. Thus special provisions are necessary for their containment.

All commentators acknowledged the exemplary responsibility of the scientific community in dealing publicly with the potential risks in DNA recombinant research and in calling for a self-imposed moratorium on certain experiments in order to assess potential hazards and devise appropriate guidelines. Most commentators agreed that the process leading to the formulation of the proposed guidelines was a most responsible and responsive one. Suggestions by the commentators on broad policy considerations are presented below. They relate to the science policy aspects of the guidelines, the implementation of the guidelines for NIH grantees and contractors, and the scope and impact of the guidelines nationally and internationally.

A. SCIENCE POLICY CONSIDERATIONS

Commentators were divided on how best to steer a course between stifling research through excessive regulation and allowing

it to continue with sufficient controls. Several emphasized that the public must have assurance that the controls afford adequate protection against potential hazards. In the views of these commentators, the burden is on the scientific community to show that the danger is minimal and that the benefits are substantial and far outweigh the risks.

Opinion differed on whether the proposed guidelines were an appropriate response to the potential benefits and hazards. Several found the guidelines to so exaggerate safety procedures that inquiry would be unnecessarily retarded, while others found the guidelines weighted toward promoting research. The issue was how to strike a reasonable balance—in fact, a proper policy "bias"—between concerns to "go slow" and those to progress rapidly.

There was strong disagreement about the nature and level of the possible hazards of recombinant DNA research. Several commentators believed that the hazards posed were unique. In their view, the occurrence of an accident or the escape of a vector could initiate an irreversible process, with a potential for creating problems many times greater than those arising from the multitude of genetic recombinations that occur spontaneously in nature. These commentators stress the moral obligation on the part of the scientific community to do no harm.

Other commentators, however, found the guidelines to be adequate to the hazards posed. In their view, the guidelines struck an appropriate balance so that research could proceed cautiously. Still other commentators found the guidelines too onerous and restrictive in light of the potential benefits of this research for medicine, agriculture, and industry. Some felt that the guidelines are perhaps more stringent than necessary given the available evidence on the likelihood of hazards, but supported them as a compromise that would best serve the scientific community and the public at large. Many commentators urged that the guidelines be adopted as soon as possible to afford more specific direction to this research area.

I understand and appreciate the concerns of those who urge that this research proceed because of the benefits and of those who urge caution because of potential hazards. The guidelines issued today allow the research to go forward in a manner responsive and appropriate to hazards that may be realized in the future.

The object of these guidelines is to ensure that experimental DNA recombination will have no ill effects on those engaged in the work, on the general public, or on the environment. The essence of their construction is subdivision of potential experiments by class, decision as to which experiments should be permitted at present, and assignment to these of certain procedures for containment of recombinant organisms.

Containment is defined as physical and biological. Physical containment involves the isolation of the research by procedures which have evolved over many years of experience in laboratories studying infectious microorganisms. P1 containment—the first physical containment level—is that used in most routine bacteriology laboratories. P2 and P3 afford increasing isolation of the research from the environment. P4 represents the most extreme measures used for containing virulent pathogens, and permits no escape of contaminated air, waste, or untreated materials. "Biological" containment is the use of vectors or hosts that are crippled by mutation so that the recombinant DNA is incapable of surviving under natural conditions.

The experiments now permitted under the guidelines involve no known additional haz-

ard to the workers or the environment beyond the relatively low risk known to be associated with the source materials. The additional hazards are speculative and therefore not quantifiable. In a real sense they are considerably less certain than are the benefits now clearly derivable from the projected research.

For example, the ability to produce, through "molecular cloning," relatively large amounts of pure DNA from the chromosomes of any living organism will have a profound effect in many areas of biology. No other procedure, not even chemical synthesis, can provide pure material corresponding to particular genes. DNA "probes," prepared from the clones will yield precise evidence on the presence or absence, the organization, and the expression of genes in health and disease.

Potential medical advances were outlined by scientists active in this research area who were present at the meeting of the Director's Advisory Committee. Of enormous importance, for example, is the opportunity to explore the malfunctioning of cells in complicated diseases. Our ability to understand a variety of hereditary defects may be significantly enhanced, with amelioration of their expression a real possibility. There is the potential to elucidate mechanisms in certain cancers, particularly those that might be caused by viruses.

Instead of mere propagation of foreign DNA, the expression of the genes of one organism by the cell machinery of another may alter the new host and open opportunities for manipulating the biological properties of cells. In certain prokaryotes (organisms with a poorly developed nucleus, like bacteria), this exchange of genetic information occurs in nature. Such exchange explains, for instance, an important mechanism for the changing and spreading of resistance to antibiotics in bacteria. Beneficial effects of this mechanism might be the production of medically important compounds for the treatment and control of disease. Examples frequently cited are the production of insulin, growth hormone, specific antibodies, and clotting factors absent in victims of hemophilia.

Aside from the potential medical benefits, a whole host of other applications in science and technology have been envisioned. Examples are the large-scale production of enzymes for industrial use and the development of bacteria that could ingest and destroy oil spills in the sea. Potential benefits in agriculture include the enhancement of nitrogen fixation in certain plants, permitting increased food production.

While the projected research offers the possibility of many benefits, it must proceed only with assurance that potential hazards can be controlled or prevented. Some commentators are concerned that nature may maintain a barrier to the exchange of DNA between prokaryotes and eukaryotes (higher organisms, with a well-formed nucleus)—a barrier that can now be crossed by experimentalists. They further argue that expression of the foreign DNA may alter the host in unpredictable and undesirable ways. Conceivable harm could result if the altered host has a competitive advantage that would foster its survival in some niche within the ecosystem. Other commentators believe that the endless experiments in recombination of DNA which nature has conducted since the beginning of life on the earth, and which have accounted in part for the evolution of species, have most likely involved exchange of DNA between widely disparate species. They argue that prokaryotes such as bacteria in the intestines of man do exchange DNA with this eukaryotic host and that the failure of the altered prokaryotes to be detected at tests to a sharply limited capacity of such recombinants to survive. Thus nature, this

argument runs, has already tested the probabilities of harmful recombination and any survivors of such are already in the ecosystem. The fact is that we do not know which of the above-stated propositions is correct.

The international scientific community, as exemplified by the Asilomar conference and the deliberations attendant upon preparation of the present guidelines, has indicated a desire to proceed with research in a conservative manner. And most of the considerable public commentary on the subject, while urging caution, has also favored proceeding. Three European groups have independently arrived at the opinion that recombinant DNA research should proceed with caution. These are the Working Party on Experimental Manipulation of the Genetic Composition of Micro-Organisms, whose "Ashby Report" was presented to Parliament in the United Kingdom by the Secretary of State for Education and Science in January 1975; the Advisory Committee on Medical Research of the World Health Organization, which issued a press release in July 1975; and the European Molecular Biology Organization Standing Committee on Recombinant DNA, meeting in February 1976.

There is no means for a flat proscription of such research throughout the world community of science. There is also no need to attempt it. It is likely that the evaluation engendered in the preparation and application of these guidelines will lead to beneficial review of some of the containment practices in other work that is not technically defined as recombinant DNA research.

Recombinant DNA research with which these guidelines are concerned involves microorganisms such as bacteria or viruses or cells of higher organisms growing in tissue culture. It is extremely important for the public to be aware that his research is not directed to altering of genes in humans although some of the techniques developed in this research may have relevance if this is attempted in the future.

NIH recognizes its responsibility to conduct and support research designed to determine the extent to which certain potentially harmful effects from recombinant DNA molecules may occur. Among these are experiments, to be conducted under maximum containment, that explore the capability of foreign genes to alter the character of host or vector, rendering it harmful, as through the production of toxic products.

Given the general desire that no rare and unexpected event arising from this research shall cause irreversible damage, it is obvious that merely to establish conservative rules of conduct for one group of scientists is not enough. The precautions must be uniformly and unanimously observed. Second, there must be full and timely exchange of experiences so that guidelines can be altered on the basis of new knowledge. The guidelines must also be implemented in a manner that protects all concerned—the scientific workers most likely to encounter unexpected hazards and all forms of life within our biosphere. The responsibility of the scientists involved is an inescapable and extreme as is their opportunity to beneficially enrich our understanding.

B. IMPLEMENTATION CONSIDERATIONS WITHIN THE NIH

All the commentators had suggestions concerning the structure and function of decision making as it relates to the principal investigator, the local biohazards committee, the peer review group, and the NIH Recombinant Advisory Committee. These comments and my response on the section of the guidelines relating to roles and responsibilities of investigators, their institutions, and the National Institutes of Health are presented below.

Of considerable concern to all commentators was the process by which NIH would proceed to implement the guidelines. The scientific community generally urged that there be no Federal regulations, while some of the public commentators recommended the regulatory process.

Many who opposed changing the proposed guidelines into Federal regulations expressed concern for flexibility and administrative efficiency, which could best be achieved, in their view, through voluntary compliance. Other commentators, however, believed it imperative to proceed toward regulation. In their view, the guidelines could be implemented for purposes of NIH funding and would govern the conduct of experiments until regulations were in effect. Another commentator who thought regulation would be harmful rather than helpful suggested that if there were to be regulations, they should be along lines similar to those that govern the sale, distribution, use, and disposal of radioisotopes.

The question of how best to proceed now that the guidelines have been released deserves careful attention. I share the concern of those who feel that the guidelines must remain flexible. It is especially important that there be opportunity to change them quickly, based on new information relating to scientific evidence, potential risks, or safety aspects of the research program.

The suggestions for regulation need further attention at this time. The process for regulation not only involves the Director of NIH, but also the Assistant Secretary for Health and the Secretary of Health, Education, and Welfare. These guidelines are being promulgated now in order to afford additional protection to all concerned. Consideration of their conversion to regulations can proceed with continuing review of their content and present and future implications. Meanwhile, the NIH shall continue to provide the opportunity for public comment and participation at least equivalent to that provided if steps towards regulations were to proceed immediately. The guidelines will be published in the FEDERAL REGISTER forthwith to allow for further public comment.

C. IMPLEMENTATION CONSIDERATIONS BEYOND THE PURVIEW OF NIH

Special concern has been expressed by many commentators regarding the application of the guidelines to research outside NIH by investigators other than its grantees or contractors. It has been urged that the guidelines be made applicable to recombinant DNA research conducted or supported by other agencies in HEW and by NSF, ERDA, DoD, and other governmental departments. Most commentators believe that these or similar guidelines should also govern research in the private sector, including industry, voluntary organizations, and foundations. Many feel that experiments conducted in colleges, universities, and even in high schools require some form of monitoring. And finally, all agree that in view of the potential hazards of recombinant DNA research to the biosphere, some form of international understanding on guidelines for the research is essential.

The committee, in the proposed guidelines, has suggested as one means of control that a description of the physical and biological containment procedures practiced in a research project be included in the publication of research results. In the scientific community this can be a powerful force for conformity, and we will undertake to present the recommendation to all appropriate journals. We are also prepared to take steps to disseminate the guidelines widely, and to arrange for a continual flow of information outward concerning the activities of the Re-

combinant Advisory Committee and the Advisory Committee to the Director, NIH, in the evolution of the guidelines and their implementation.

In response to these suggestions, I have already held a meeting with relevant HEW agencies and with representatives from other departments of the Federal Government. The purpose of the meeting was to exchange information on recombinant DNA research and to discuss the NIH guidelines. It served as an important beginning to address a common concern of these public institutions. A number of the representatives indicated that various departments might very well adopt the guideline for research conducted both in-house and supported outside. Following up, I have begun preliminary discussions with the Assistant Secretary for Health and the Secretary of HEW, to determine possible methods to ensure adoption of the guidelines by all Federal agencies. Encouraged by these efforts, we held a meeting on June 2 with representatives of industry to provide them with full information about the guidelines and to help determine the present and future interests of industrial laboratories in this type of research. The meeting provided one of the first opportunities for industry representatives to convene for a discussion of this research area, and an industry committee under the auspices of the Pharmaceutical Manufacturers Association will be formed to review the guidelines for potential application to the drug industry. Further meetings will be scheduled with other groups that have an active interest in recombinant DNA research.

It is my hope that the guidelines will be voluntarily adopted and honored by all who support or conduct such research throughout the United States, and that at least very similar guidelines will obtain throughout the rest of the world. NIH places the highest priority on efforts to inform and to work with international organizations, such as the World Health Organization and the International Council of Scientific Unions, with a view to achieving a consensus on safety standards in this most important research area.

There has been considerable international cooperation and activity in the past, and I expect it to continue in the future. The aforementioned Ashby Report, presented to Parliament in January 1975, describes the advances in knowledge and possible benefits to society of the experiments involving recombinant DNA molecules, and attempts to assess the hazards in these techniques. The Asilomar meeting also had a number of international representatives, as mentioned previously. The European Molecular Biology Organization (EMBO) has been involved in considering guidelines for recombinant DNA research. They have closely followed the activities of NIH, and will thus be encouraged, I believe, to monitor their research with augmented cooperation and coordination. For example, EMBO recently announced plans for a voluntary registry of recombinant DNA research in Europe. Following this EMBO initiative, NIH shall similarly maintain a voluntary registry of investigators and institutions engaged in such research in the United States. Plans for establishing this registry are under way.

D. ENVIRONMENTAL POLICY CONSIDERATIONS

A number of commentators urged NIH to consider preparing an environmental impact statement on recombinant DNA research activity. They evoked the possibility that organisms containing recombinant DNA molecules might escape and affect the environment in potentially harmful ways.

I am in full agreement that the potentially harmful effects of this research on the environment should be assessed. As discussed

throughout this paper, the guidelines are premised on physical and biological containment to prevent the release or propagation of DNA recombinants outside the laboratory. Deliberate release of organisms into the environment is prohibited. In my view, the stipulated physical and biological containment ensures that this research will proceed with a high degree of safety and precaution. But I recognize the legitimate concern of those urging that an environmental impact assessment be done. In view of this concern and ensuing public debate, I have reviewed the appropriateness of such an assessment and have directed that one be undertaken.

The purpose of this assessment will be to review the environmental effects, if any, of research that may be conducted under the guidelines. The assessment will provide further opportunity for all concerned to address the potential benefits and hazards of this most important research activity. I expect a draft of the environmental impact statement should be completed by September 1 for comment by the scientific community, Federal and State agencies, and the general public.

It should be noted that the development of the guidelines was in large part tantamount to conducting an environmental impact assessment. For example, the objectives of recombinant DNA research, and alternate approaches to reach those objectives, have been considered. The potential hazards and risks have been analyzed. Alternative approaches have been thoroughly considered, to maximize safety and minimize potential risk. And an elaborate review structure has been created to achieve these safety objectives. From a public policy viewpoint, however, the environmental impact assessment will be yet another review that will provide further opportunity for the public to participate and comment on the conduct of this research.

II. METHODS OF CONTAINMENT

Comments on the containment provisions of the proposed guidelines were directed to the definitions of both physical and biological containment and to the safety and effectiveness of the prescribed levels. Several commentators found the concept of physical containment imprecise and too subject to the possibility for human error. Others questioned the concept of biological containment in terms of its safety and purported effectiveness in averting potential hazards. The commentators were divided on which method of containment would provide the most effective and safe system to avoid hazards. Several suggested that each of the physical containment levels be more fully explained.

W. Emmett Barkley, Ph.D., Director of the Office of Research Safety, National Cancer Institute, was asked to review the section on physical containment in light of these comments. Dr. Barkley convened a special committee of safety and health experts, who met to consider not only this section of the guidelines but also the section on the roles and responsibilities of researchers and their institutions. The committee thoroughly reviewed the section on physical containment and recommended a number of changes. The Recombinant Advisory Committee, meeting on April 1-2, 1976, reviewed the recommendations of the Barkley group. These are incorporated, with editorial revisions, in the final version of the guidelines.

The present section on physical containment is directly responsive to those commentators who asked for greater detail and explanation. Although different in detail, the four levels of containment approximate those given by the Center for Disease Control for human etiologic agents and by the National Cancer Institute for oncogenic viruses. For each of the proposed levels, optional items have been excluded, and only those items

deemed absolutely necessary for safety are presented. Necessary facilities, practices, and equipment are specified. To give further guidance to investigators and their institutions, a supplement to the guidelines explains more fully safety practices appropriate to recombinant DNA research. And a new section has been added to ensure that shipment of recombinant DNA materials conforms, where appropriate, to the standards, prescribed by the U.S. Public Health Service, the Department of Transportation, and the Civil Aeronautics Board.

The section on physical containment is carefully designed to offer a constructive approach to meeting potential hazards for recombinant experiments at all levels of presumed risk. Certain commentators had suggested that the first level of physical containment (P1) be merged with the second level (P2). This suggestion, however, would tend to apply overly stringent standards for some experiments and might result in a lowering of standards necessary at the second level. I believe the level of control must be consistent with a reasonable estimate of the hazard; and the section on physical containment does provide this consistency. Accordingly, the first and second levels of physical containment remain as separate sections in the guidelines.

Because of the nature and operation of facilities required for experiments to be done at the fourth level of containment (P4), a provision has been included that the NIH shall review such facilities prior to funding them for recombinant DNA studies. The situation merits the special attention of experts who have maximum familiarity with the structure, operation, and potential problems of P4 installations. Several commentators advocated that NIH arrange for sharing of P4 facilities, both in the NIH intramural program and in institutions supported through NIH awards. In response to these suggestions, we are currently reviewing our facilities, including those at the Frederick Cancer Research Center (Fort Detrick), to determine how such a program can best be devised. It is most important that P4 facilities be made available to investigators. It should be noted that incidents of infection by even the most highly infectious and dangerous organisms are extremely infrequent at P4 facilities, and therefore the potential for hazard in certain complex experiments in recombinant DNA research is considerably reduced.

III. PROHIBITED EXPERIMENTS

1. Practically all commentators supported the present prohibition of certain experiments. There were suggestions for a clearer definition of the prohibition of certain experiments where increased antibiotic resistance may result. And it was urged by some that the prohibition be broadened to include experiments that result in resistance to any antibiotic, irrespective of its use in medicine or agriculture. Consideration of such a suggestion must take into account that antibiotic resistance occurs naturally among bacteria, and that resistance is a valuable marker in the study of microbial genetics in general and recombinants in particular.

In view of these concerns, however, the Recombinant Advisory Committee was asked to reconsider carefully the prohibition and related sections concerning antibiotic resistance. The committee noted that the prohibition relating to drug resistance was intended to ban those experiments that could compromise drug use in controlling disease agents in veterinary as well as human medicine and this is now clearly stated.

In the draft guidelines there were two statements concerning resistance to drugs which related to experiments with *E. coli*. The statements appeared to allow experi-

ments that would extend the range of resistance of this bacterium to therapeutically useful drugs and disinfectants, and thus seemed to be in conflict with the general prohibition on such research. There are numerous reports in the scientific literature indicating that *E. coli* can acquire resistance to all antibiotics known to act against it. Since *E. coli* acquires resistance naturally, the prohibition directed against increasing resistance does not apply. The ambiguous statements have been deleted from the present guidelines. On the other hand, new language has been inserted in the section dealing with other prokaryote species to set containment levels for permitted experiments.¹

2. The Recombinant Advisory Committee was also asked to clarify whether the prohibition of use of DNA derived from pathogenic organisms (those classified as 3, 4, and 5 by the Center for Disease Control, USPHS) also included the DNA from any host infected with these organisms. The committee explained that this prohibition did extend to experiments with cells known to be so infected. To avoid misunderstanding, the prohibition as now worded includes such cells. In addition, the prohibitions have been extended to include moderate-risk oncogenic viruses, as defined by the National Cancer Institute, and cells known to be infected with them.

3. Two other issues relating to the section on prohibited experiments were raised by Roy Curtiss III, Ph.D., Professor, Department of Microbiology, University of Alabama School of Medicine, Birmingham, who is a member of the Recombinant Advisory Committee. Dr. Curtiss noted that for the class of experiments prohibited on the basis of production of highly toxic substances, only substances from microorganisms were cited as examples. He suggested that other examples be included, such as venoms from insects and snakes. The committee approved the suggestion and I concur.

In the proposed guidelines, release of organisms containing recombinant DNA molecules into the environment was prohibited unless a series of controlled tests had been done to leave no reasonable doubt of safety. Dr. Curtiss felt that the guidelines should provide greater specificity for testing and should include some form of review prior to release of the organism. I have decided that the guidelines should, for the present, prohibit any deliberate release of organisms containing recombinant DNA into the environment. With the present limited state of knowledge, it seems highly unlikely that there will be in the near future, any recombinant organism that is universally accepted as being beneficial to introduce into the environment. When the scientific evidence becomes available that the potential benefits of recombinant organisms, particularly for agriculture, are about to be realized, then the guidelines can be altered to meet the need for release. It is most important that the potential environmental impact of the release be considered.

IV. PERMISSIBLE EXPERIMENTS: *E. COLI* K-12 HOST-VECTOR SYSTEMS

The continued use of *E. coli* as a host has drawn considerable comment, including some suggestions that its use be prohibited presently or within a specified time limit. It should be stressed that the use of *E. coli* as detailed in the guidelines is limited to *E.*

coli K-12, a strain that has been carried in the laboratory for decades, and does not involve the use of any strain of *E. coli* that is freshly isolated from a natural source. *E. coli* K-12 does not usually colonize the normal bowel, even when given in large doses, and exhibits little if any multiplication while passing through the alimentary canal. For years it has been the subject of more intense investigation than any other single organism, and knowledge of its genetic makeup and recombinant behavior exceeds greatly that pertaining to any other organism. I believe that because of this experience, *E. coli* K-12 will provide a host-vector system that is safer than other candidate microorganisms.

NIH recognizes the importance of supporting the development of alternative host-vector systems (such as *B. subtilis*, which has no ecological niche in man) and will encourage such development. It should be noted, however, that for each new host-vector system, the same questions of risk from altered properties attendant upon the presence of recombinant genes will apply as apply to *E. coli*. NIH does not believe it wise to set a time limit on replacement of *E. coli* systems by other organisms.

There were specific suggestions concerning the three levels of biological containment prescribed for use of *E. coli* K-12 vectors. Some commentators requested a more detailed explanation of the adequacy of protection for laboratory personnel with the first level of containment (EK1).² Sections of the guidelines dealing with physical containment and roles and responsibilities now specify the need for safety practices and accident plans.

For the second level of containment (EK2), it is required that a cloned DNA fragment be contained in a host-vector system that has no greater than a 10⁻⁸ probability of survival in a nonpermissive or natural environment. It was suggested that the selection of this level of biological containment and the appropriate tests for verification be more fully explained in the guidelines. The committee, in responding to a request for further examination of this point, reviewed at considerable length the testing for an EK2 system and recommended certain modifications. We have accepted the committee's new language that better explains testing of survival of a genetic marker carried on the vector, preferably on an inserted DNA fragment.

Possible tests to determine the level of biological containment afforded by these altered host-vector systems are outlined in this section. Because this is such a new area of scientific research and development, however, it is inappropriate to standardize such testing at the present time. Standards will gradually be set as more experience with EK2 host-vector systems is acquired. The committee, for example, during its April 1976 meetings gave its first approval to an EK2 host-vector system. What is necessary is that new

²The EK1 system presently consists of a battery of different vectors and of *E. coli* K-12 mutants, all of which afford a considerable degree of biological containment. The diversity of vectors and of host mutants in this battery has permitted a wide range of important scientific questions to be attacked. For example, the availability of different vectors with cleavage sites for different restriction endonucleases have increased the kind of DNA segments that can be cloned. By contrast, the first EK2 host-vector systems are only now being considered by the Recombinant Advisory Committee. While NIH is supporting the development of more EK2 host-vector systems, it is not expected that a battery equivalent to that available for the EK1 system will be certified by the Recombinant Advisory Committee in the near future.

and more effective tests be devised by investigators, and this effort is very likely to occur under the present guidelines. For example, one task recognized by the committee is to clarify how survival of the organism and the cloned DNA should be defined in terms of temperature, medium, and other variables.

It is also very important to note here that the stringent requirements set by the committee for EK2 biological containment jeopardize considerably the capacity of such crippled organisms to survive and replicate even under permissive laboratory conditions. More experience will be required to determine whether EK2 containment will permit some lines of important research to be followed.

Several commentators suggested that methods and procedures to confirm an EK system at the third level of containment (EK3) be more fully explained. The Recombinant Advisory Committee was asked to consider this suggestion. After considerable discussion the committee declined to define the procedures more fully at this time, because development of an EK3 system is still far enough in the future not to warrant specific testing procedures. Further, it is not clear what tests are best suited. The language, therefore, remains general. The committee, however, is aware of the concerns for a more completely defined system of testing, and has considered the possibility of organizing a symposium for purposes of designating tests. In my view, more fully developed protocols for testing EK3 systems are warranted, and it is necessary that guidelines here be more fully developed before the committee proceeds to certify such a system. In this regard the NIH is prepared through the National Institute of Allergy and Infectious Diseases to support contracts to accomplish this task. We will seek the advice and assistance of the committee to define the scope of necessary work.

These guidelines also include a statement that for the time being no EK2 or EK3 host-vector system will be considered bona fide until the Recombinant Advisory Committee has certified it. I share the concern of the commentators that new host-vector systems require the highest quality of scientific review and scrutiny. At this early stage of development, it is most important that the committee provide that scrutiny. Further, I believe that until more experience has been gained, the committee should encourage and the NIH support research that will independently confirm and augment the data on which certification of EK2 host-vector systems are based.

V. CLASSIFICATION OF EXPERIMENTS USING THE *E. COLI* K-12 CONTAINMENT SYSTEMS

The guidelines assign different levels of containment for experiments in which DNA from different sources is to be introduced into an *E. coli* K-12 host-vector system. The variation is based on both facts and assumptions. There are some prokaryotes (bacteria) which constantly exchange DNA with *E. coli*. Here it is assumed that experimental conditions beyond those obtained in careful, routine microbiology laboratories are superfluous, because any exchange experiments have undoubtedly been performed already in nature.

In every instance of artificial recombination, consideration must be given to the possibility that foreign DNA may be translated into protein (expressed), and also to the possibility that normally repressed genes of the host may be expressed and thus change, undesirably, the characteristics of the cell. It is assumed that the more similar the DNAs of donor and host, the greater the probability of expression of foreign DNA, or of possible derepression of host genes. In those cases where the donor exchanges DNA with *E. coli* in nature, it is unlikely that recom-

¹Specifically, experiments that would extend resistance to therapeutically useful drugs must use P3 physical containment plus a host-vector comparable to EK1, or P2 containment plus a host-vector comparable to EK2.

bination experiments will create new genetic combinations. When prokaryote donors not known to exchange DNA with *E. coli* in nature are used, however, there is a greater potential for new genetic combinations to be formed and be expressed. Therefore, it is required that experiments involving prokaryotic DNA from a donor that is not known to exchange DNA with *E. coli* in nature be carried out at a higher level of containment. Recombination using prokaryotic DNA from an organism known to be highly pathogenic is prohibited.

There are only limited data available concerning the expression of DNA from higher forms of life (eukaryotes) in *E. coli* (or any other prokaryote). Therefore, the containment prescriptions for experiments inserting eukaryotic DNA into prokaryotes are based on risks having quite uncertain probabilities.

On the assumption that a prokaryote host might translate eukaryotic DNA, it is further presumed that the product of that foreign gene would be most harmful to man if it were an enzyme, hormone, or other protein that was similar (homologous) to proteins already produced by or active in man. An example is a bacterium that could produce insulin. Such a "rogue" bacterium could be of benefit if contained, a nuisance or possibly dangerous if capable of surviving in nature. This is one reason that the higher the phylogenetic order of the eukaryote, the higher the recommended containment, at least until the efficiency of expression of DNA from higher eukaryotes in prokaryotes can be determined.

There is a second, more concrete reason for scaling containment upward as the eukaryote host becomes similar to man. This is the concern that viruses capable of propagating in human tissue, and possibly causing diseases, can contaminate DNA, replicate in prokaryote hosts and infect the experimentalist. Such risks are greatest when total DNA from donor tissue is used in "shotgun" recombinant experiments; it diminishes to much lower levels when pure cloned DNA is used.

The commentators were clearly divided on the classification of containment criteria for different kinds of recombinant DNAs. Many commentators considered the guidelines too stringent and rigid. Others viewed the guidelines in certain instances as too permissive. And still others endorsed the guidelines as sensible and reasonable, affording the public an enormous degree of protection from the speculative risks. Several suggestions were made for the specific classes of experiments, and they follow:

1. Comment on the use of DNA from animals and plants in recombinant experiments varied widely. Some commentators suggested banning the use of DNA from primates, other mammals, and birds. Others suggested that higher levels of the containment be used for all such experiments. Still others believed that the guidelines were too strict for experiments of this class. I have carefully reviewed the issues raised by the commentators and the response of the committee to certain queries concerning use of animal and plant DNA in these experiments.

In my view, the classification for the use of DNA from primates, other mammals, and birds is appropriate to the potential hazards that might be posed. The physical and biological containment levels are very strict. For example, biological containment levels are at EK2 or EK3, and will effectively preclude experimentation until useful EK2 and EK3 systems are available. EK2 systems are still in the initial stages of development, and the first system was only certified at the most recent meeting of the Recombinant Advisory Committee. An EK3 host-vector system has yet to be tested, and its certification is far enough in the future to place a moratorium

on those experiments requiring biological containment at an EK3 level. The physical containment levels of P3 or P4 themselves afford a very high degree of protection. I am satisfied that the guidelines demonstrate the caution and prudence that must govern the conduct of experiments in this category.

The guidelines allow reduced containment levels for primate DNA when it is derived from embryonic tissue or germ-line cells. This is based on evidence that embryonic material is less likely to contain viruses than is tissue from the adult. Obviously, the embryonic tissue must be free of adult tissue, and the present guidelines so indicate.

I have also carefully considered the special concerns arising from the use of DNA from cold-blooded vertebrates and other cold-blooded animals, because several commentators questioned the basis of lower physical and biological containment levels for DNA from these species. The Recombinant Advisory Committee has debated this extensively, and they were asked to do so once again in April.* The committee has now recommended high containment levels (P3+EK2) when the DNA is from a cold-blooded vertebrate known to produce a potent toxin. That recommendation is included in the present guidelines. Where no toxin is involved the committee supported lower containment levels. The guidelines specify P2+EK2 levels for such work. There was considerable discussion concerning the advisability of recommending lower containment (P2+EK1) when the DNA is isolated from embryonic tissue or germ-line cells from cold-blooded vertebrates. Those supporting lower containment levels argued that the justification for P2+EK2 was the possibility that cold-blooded vertebrates may carry viruses and that the distinction between adult and germ cell tissue is real. Others argued that, contrary to the situation with primate DNA, viruses are not a central problem with cold-blooded vertebrates and therefore no distinction should be made on the basis of tissue origin. Finally, the committee recommended, on a divided vote (8 to 4), to adopt P2+EK1 when the cold-blooded vertebrate DNA is isolated from embryonic tissue or germ-line cells. Upon reviewing these considerations, I have decided to retain the containment levels for embryonic or germ-line DNA from cold-blooded vertebrates as recommended by the committee.

In April the committee also reviewed, at our request, the classification of experiments where DNA is derived from other cold-blooded animals or lower eukaryotes. Several commentators, for example, had been

*A committee member, David S. Hogness, Ph. D., Professor, Department of Biochemistry, Stanford University, California, submitted a statement in support of lower containment levels based on current scientific evidence. That evidence is based on certain differences between cold- and warm-blooded vertebrates. One of the criteria used for the evaluation of the relative risk that might be encountered with different levels of shotgun experiment is the degree of sequence homology between the DNA of the given species and that of humans. This criterion is used to estimate the likelihood that segments of DNA from the given species might be integrated into the human genome by recombination; the greater the homology, the greater the likelihood of integration. Studies of sequence homologies indicate that there is a considerable degree of homology between human DNA and DNA from other primates, much less homology between primates and other mammals, and even lower but detectable homology between birds and primates. By contrast, no significant homologies between cold-blooded vertebrates and primates have been detected.

concerned about the fact that insects are known to carry agents pathogenic to man. In the committee review, it was noted that viruses carried by insects and known to transmit disease to man are RNA rather than DNA viruses and do not reproduce via DNA copied from RNA. In order, however, to make the intent clearer, the guidelines have been rewritten for experiments of this class. New language is inserted to ensure that strict containment levels are employed when the DNA comes from known pathogens or species known to carry them. Further, to reduce the potential hazards, we have also included in the guidelines the requirement that any insect must be grown under laboratory conditions for at least 10 generations prior to its use as a DNA source.

2. As alluded to above, certain commentators expressed concern that when *E. coli* becomes the host of recombinant DNA from prokaryotes with which DNA is not usually exchanged, there is hazard of altered host characteristics resulting from translation of the DNA into functioning proteins. The committee was asked to review the guidelines and take into account this potential hazard. They agreed that the containment levels should be increased for this category of experiment, from P2+EK1 to either P2+EK2 or P3+EK1. That recommendation is included in the present guidelines.

Comments were made concerning that class of experiments in which the recombinant DNA, regardless of source, has been cloned. A clone is a population of cells derived from a single cell and therefore all the cells are presumed to be genetically identical. As outlined in the proposed guidelines, clones could be used at lower containment levels if they had been rigorously characterized and shown to be free of harmful genes. Several commentators inquired how the characterization was to be performed and the freedom from harmful genes demonstrated. Although the committee acknowledges that these terms are unavoidably vague, they do cite appropriate scientific methods to make relevant determinations. Again, this is a rapidly changing area and more clarity and precision can be expected with experience. Reduced containment requirements for this class of experiment are warranted because of the purified nature of clones. Further, the granting agency must approve the clone before containment conditions can be reduced, thus providing an additional element of review.

4. Another comment was related to the use of DNA from organelles (intracellular elements that contain special groups of genes for particular cell functions). Concern was expressed about the potential contamination of purified organelle DNA with DNA from viruses because of the similarity of their structures. The committee agrees, and the guidelines now specify a requirement, that the organelles be isolated prior to extracting DNA, as a further means of reducing the hazard of viral contamination.

5. Some commentators were troubled about the lowering of containment for that class of experiments involving recombinations with cell DNA segments purified by chemical or physical methods. They asked that procedures for determining the state of purification be more fully detailed and that the Recombinant Advisory Committee certify the purity. There are, however, appropriate techniques, such as gel electrophoresis, with which a purity of 99 percent by mass can be achieved and ascertained. There is no way for the committee to certify these results beyond repeating the experiments themselves. These techniques are well documented and described in the literature. I do not believe it is necessary or feasible for the committee to review each procedure for purification of DNA.

6. Comments were made concerning the use of DNA derived from animal viruses. It

was urged that containment levels for this class of experiment be increased. On the basis of my review, I find the containment conditions appropriate to the potential hazard posed. As defined in the guidelines, experiments are to be done at very strict levels of containment and these can be lowered only when the cloned DNA recombinants have been shown to be free of possibly harmful genes by suitable biochemical and biological tests. This also pertains to DNA that is copied from RNA viruses. In no instance are the guidelines more lenient, and in most instances they are more stringent than conditions obtaining in many laboratories where such viruses are studied in non-DNA-recombinant experiments.

VI. CLASSIFICATION OF EXPERIMENTS USING CONTAINMENT SYSTEMS OTHER THAN *E. COLI* K-12

1. No issue with regard to these guidelines raised more comment than the use of animal viruses as vectors. Of special concern to many commentators was the use of the simian (monkey) virus 40 (hereafter "SV40"). Some suggested a complete ban on the use of this virus; others urged its retention as a vector. SV40 is not known to produce any disease in man, although it can be grown in human cells and on very rare occasions has been isolated from humans. Many humans have received SV40 virus inadvertently in vaccines prepared from virus grown in monkey kidney-cell cultures. An intensive search has been made and is continuing for evidence that SV40 might cause cancer or be otherwise pathogenic for man. At present, it is my view that the extensive knowledge we have of SV40 virus provides us with sufficient sophistication to ensure its safe handling under the conditions developed for its use in the guidelines.

I believe work with SV40 should continue under the most careful conditions, but I do recognize and appreciate the concerns expressed over its possible harmful effects in humans. In light of these concerns, I asked the Recombinant Advisory Committee to review this section of the guidelines. The committee reconsidered the containment conditions for this class of experiments and judged them appropriate to meet the potential hazards.⁴

This class of experiments will proceed under the most careful and stringent conditions. Work with SV40 virus will be done at the maximum level of physical containment (P4). The extraordinary precautions required in a P4 facility lessen the likelihood of a potential hazard from this work. Only defective SV40 virus will be used as vector; that is, the SV40 virus particles that carry the foreign DNA cannot multiply by themselves. When a number of strict conditions are met, this work will be permitted to go on at the third level of containment (P3), which in itself requires care and precision. It should be noted that SV40 virus and its DNA can be efficiently disinfected by Clorox and autoclaving. These are customary procedures for disinfecting glassware and other items used in SV40 animal-cell work.

Some commentators suggested that the containment criteria for experiments using polyoma virus as the vector be strengthened. There is no evidence that polyoma infects humans or replicates to any significant extent in human cells. It holds promise as a vector, as is more fully documented in an appendix to these guidelines.

⁴ One member dissented from this position. During the discussion, additional language was recommended (and adopted) to ensure that the defective SV40-virus/helper-virus system, with its inserted non-SV40 DNA segment, does not replicate in human cells with significantly more efficiency than does SV40.

2. Several commentators found the guidelines inadequate regarding experiments with plant host-vector systems. Because NIH shared these concerns, a group of extensive experience with plants was appointed to review this section. The group met concurrently with the Recombinant Advisory Committee in April 1976 and made several modifications. The suggested revisions were acceptable to the full committee, and we have included them in the guidelines.

The modifications are responsive to the stated concerns of the commentators. A description of greenhouse facilities is given, and physical containment conditions have been modified to take into account operations with whole plants. On the whole the respective portions of the guidelines relating to plants are more fully explained and the intent is clarified.

I have also accepted the recommendation of the subcommittee to lower the biological containment level from EK2 to EK1 for experiments in which the DNA from plants is used in conjunction with the *E. coli* K-12 host-vector system, thereby setting containment in this instance at the same level required for experiments with lower-eukaryote DNA.

VII. ROLES AND RESPONSIBILITIES

1. Most commentators had suggestions for the section on the roles and responsibilities of investigators, their local institutions, and NIH. Commentators generally urged openness, candor, and public participation in the process, emphasizing shared responsibility and accountability from the local to the national level. We reviewed that section of the guidelines in light of these comments and have asked the Recombinant Advisory Committee to review certain issues.

It is clear that much of the success of the guidelines will lie in the wisdom with which they are implemented. Because of the importance of this section, especially in terms of safety programs and plans, we have carefully weighed the comments and suggestions made in this regard. NIH has a special responsibility to take a leading role in ensuring that safety programs are part of all recombinant DNA research. Dr. Barkley and a specially convened committee were asked to provide greater detail for safety, accident, and training plans for this section of the guidelines. Based on their recommendations, the section has been extensively rewritten to clarify the respective responsibilities of the principal investigator, the institution (including the institutional biohazards committee), the NIH initial review group (study section), the NIH Recombinant DNA Molecule Program Advisory Committee, and NIH staff.

This section has a definitive administrative framework for assuring that safety is an essential and integrated component of research involving recombinant DNA molecules. The guidelines require investigators to institute, monitor, and evaluate containment and safety practices and procedures. Before research is done, the investigator must have safety and accident plans in place and training exercises for the staff well under way.

Some commentators suggested that the investigator be required to obtain informed consent of laboratory personnel prior to their participation. Rather than rely explicitly on an informed consent document, the guidelines now make the investigator responsible for advising his program and support staff as to the nature and assessment of the real and potential biohazards. He must explain and provide for any advised or requested precautionary medical policies, vaccinations, or serum collections. Further, an appendix to the guidelines includes detailed explanations for dealing with accidents, as well as instruc-

tions for the training of staff in safety and accident procedures.

In response to suggestions for epidemiological monitoring, the guidelines now require the principal investigator to report certain categories of accidents, in writing, to appropriate officials. NIH is investigating procedures for long-term surveillance of workers engaged in recombinant DNA research.

2. A number of comments on the role and responsibilities of the institutional biohazards committee were received. Comments were directed to the structure of the committee, the scope of its responsibility, and the methods for operation. Comments on structure included suggestions that the committee have a broadly based representation, especially in terms of health and safety expertise. Some others suggested NIH require certain classes of representation. In response to these suggestions, the guidelines now recommend membership from a diversity of disciplines relevant to recombinant DNA molecule technology, biological safety, and engineering.

For broader representation beyond the immediate scientific expertise, the guidelines now recommend that local committees should possess, or have available, the competence necessary to determine the acceptability of their findings in terms of applicable laws, regulations, standards of practice, community attitudes, and health and environmental considerations. The names of and relevant background information on the committee members will be reported to NIH.

In response to suggestions that decisions of the committee be made publicly available, the guidelines now recommend that minutes of the meetings should be kept and made available for public inspection.

Commentators generally approved of the responsibility given to the institutional biohazards committee to serve as a source of advice and reference to the investigator on scientific and safety questions. It was further suggested that the committee's responsibility be broadened in the development, monitoring, and evaluation of safety standards and procedures. In response to these suggestions, the guidelines now indicate that the institutional biohazards committee has the responsibility to certify, and recertify annually, to NIH that the facilities, procedures, practices, training, and expertise of involved personnel have been reviewed and approved. The Recombinant Advisory Committee suggested that examination might be unnecessary for P1 facilities, but we believe that all facilities should be reviewed to emphasize the importance of safety programs.

Some commentators suggested that the guidelines should stipulate that the local committees be required to determine the containment conditions to be imposed for a given project (which the draft guidelines specifically noted was not their responsibility). The Recombinant Advisory Committee took exception to this suggestion. They urged NIH not to include these conditions as local requirements, arguing among other things that review by the NIH study sections would provide the necessary scrutiny at the national level and assure uniformity of standards in application of the guidelines. I do not believe that NIH should require the local institution to have its biohazards committee assess what containment conditions are required for a given project. On the other hand, the guidelines should not prohibit the local institution from having its biohazards committee perform this function. Accordingly, I have deleted the prohibition that appeared in the proposed guidelines.

Another suggestion was that the local committee ensure that research is carried out in accordance with standards and procedures under the Occupational Safety and Health

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Act (OSHA). This is an area of importance to the local institutions under Federal and State law, but need not be included as a requirement in the guidelines. NIH will maintain liaison with the Occupational Safety and Health Administration (Department of Labor) to ensure maximum Federal cooperation in this venture.

I would also encourage all institutions, as suggested by several commentators, to review their insurance compensation programs to determine whether their laboratory personnel, in the research area, are covered for injuries.

3. The commentators approved of having the NIH study sections responsible for making an independent evaluation of the classification of the proposed research under the guidelines, along with the customary judgment of the scientific merit of each grant application. This additional element of review will ensure careful attention to potential hazards in the research activity. The study sections will also scrutinize the proposed safeguards. Biological safety expertise shall be available to the study section for consultation and guidance in this regard.

4. Several commentators made suggestions concerning the structure, function, and scope of responsibility of the NIH Recombinant DNA Molecule Program Advisory Committee.

Comments on possible structural mechanisms for decision making included suggestions that there be a scientific and technical committee and a general advisory public policy committee. It was also suggested that the scientific committee include scientists who are not actively engaged in recombinant research, and that the public policy committee have a broad scientific and public representation.

I have carefully reviewed these comments and suggestions. In response, the following structure has been devised. The Recombinant Advisory Committee shall serve as the scientific and technical committee. Its membership shall continue to include scientists who represent disciplines actively engaged in recombinant DNA research. In my view, it is most important that this committee have the necessary expertise to assure that the guidelines are of the highest scientific quality. The committee has provided this expertise in the past, and it must continue to do so. The committee shall also include members from other scientific disciplines.

It should be noted that the present committee recommended on its own initiative that a nonscientist be appointed. Emmette S. Redford, Ph. D., LL. D., Ashbel Smith Professor of Government and Public Affairs at the Lyndon B. Johnson School of Public Affairs, University of Texas at Austin, serves in that capacity. An ethicist has also been nominated for appointment.

The Advisory Committee to the Director, NIH, shall serve to provide the broader public policy perspectives. This committee, at its meeting on February 9-10, 1976, reviewed the proposed guidelines with the participation of public witnesses, and shall continue to provide such review for future activities of the Recombinant Advisory Committee.

In response to suggestions, the responsibilities of the Recombinant Advisory Committee have been expanded. In addition to reviewing the guidelines for possible modification as scientific evidence warrants, the committee will certify EK2 and EK3 systems. In response to requests by the investigator, local committee, or study section, the committee will also provide evaluation and review in order to advise on levels of required containment, on lowering of requirements when colonized recombinants are to be used, and on questions concerning potential biohazard and adequacy of containment provisions.

Commentators also asked that the committee review ongoing research initiated prior to the implementation of the guidelines. Now that the guidelines are being released, NIH-funded investigators in this field will be asked to give assurance, within a given period, that they will comply. Any investigators who constructed clones under the Asilomar guidelines will be asked to petition NIH for special consideration of their case, if the new guidelines require higher containment than did the Asilomar guidelines. Here the advice of the Recombinant Advisory Committee will be sought.

There were also suggestions that the committee certify chemical purification of recombinant DNA, but as I indicated earlier, these procedures are too well known to require NIH monitoring.

5. In light of comments received, NIH will provide review, through appropriate NIH offices, of data from institutional biohazards committees (including accident reports) and will ensure dissemination of these findings as appropriate. Dr. William Gartland will head the newly created NIH Office of Recombinant DNA Activities for these purposes. In addition, NIH will provide for rapid dissemination of information through its Nucleic Acid Recombinant Scientific Memoranda (NARSM), distributed by the National Institute for Allergy and Infectious Diseases. NIH will also provide an appropriate mechanism for approving and certifying clones before containment conditions can be lowered.

With these extended modifications, the section of the guidelines dealing with roles and responsibilities now sets forth a more fully developed review structure involving the principal investigator, local biohazards committees, and the Recombinant Advisory Committee, as well as peer review committees. Guidelines now provide extensive opportunity for advice, from the local to the national level. Several levels of review and scrutiny are provided, ensuring the highest standards for scientific merit and conditions for safety.

The Recombinant Advisory Committee in conjunction with the Director's Advisory Committee shall continue to serve as an ongoing forum for examining progress in the technology and safety of recombinant DNA research. Their responsibility, and that of the NIH Director, is to ensure that the guidelines, through modification when called for, reflect the soundest scientific and safety evidence as it accrues in this area. Their task, in a sense, is just beginning.

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National Institutes of Health.

NATIONAL INSTITUTES OF HEALTH GUIDELINES FOR RESEARCH INVOLVING RECOMBINANT DNA MOLECULES

JUNE 1976.

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I. INTRODUCTION

The purpose of these guidelines is to recommend safeguards for research on recombinant DNA molecules to the National Institutes of Health and to other institutions that support such research. In this context we define recombinant DNAs as molecules that consist of different segments of DNA which have been joined together in cell-free systems, and which have the capacity to infect and replicate in some host cell, either autonomously or as an integrated part of the host's genome.

This is the first attempt to provide a detailed set of guidelines for use by study sections as well as practicing scientists for evaluating research on recombinant DNA molecules. We cannot hope to anticipate all possible lines of imaginative research that are possible with this powerful new methodology. Nevertheless, a considerable volume of written and verbal contributions from scientists in a variety of disciplines has been received. In many instances the views presented to us were contradictory. At present, the hazards may be guessed at, speculated about, or voted upon, but they cannot be

known absolutely in the absence of firm experimental data—and, unfortunately, the needed data were, more often than not, unavailable. Our problem then has been to construct guidelines that allow the promise of the methodology to be realized while advocating the considerable caution that is demanded by what we and others view as potential hazards.

In designing these guidelines we have adopted the following principles, which are consistent with the general conclusions that were formulated at the International Conference Center, Pacific Grove, California, in February 1975 (3): (i) There are certain experiments for which the assessed potential hazard is so serious that they are not to be attempted to the present time. (ii) The remainder can be undertaken at the present time provided that the experiment is justifiable on the basis that new knowledge or benefits to humankind will accrue that cannot readily be obtained by use of conventional methodology and that appropriate safeguards are incorporated into the design and execution of the experiment. In addition to an insistence on the practice of good microbiological techniques, these safeguards consist of providing both physical and biological barriers to the dissemination of the potentially hazardous agents. (iii) The level of containment provided by these barriers is to match the estimated potential hazard for each of the different classes of recombinants. For projects in a given class, this level is to be highest at initiation and modified subsequently only if there is a substantiated change in the assessed risk or in the applied methodology. (iv) The guidelines will be subjected to periodic review (at least annually) and modified to reflect improvements in our knowledge of the potential biohazards and of the available safeguards.

In constructing these guidelines it has been necessary to define boundary conditions for the different levels of physical and biological containment and for the classes of experiments to which they apply. We recognize that these definitions do not take into account existing and anticipated special procedures and information that will allow particular experiments to be carried out under different conditions than indicated here without sacrifice of safety. Indeed, we urge that individual investigators devise simple and more effective containment procedures and that study sections give consideration to such procedures which may allow change in the containment levels recommended here.

It is recommended that all publications dealing with recombinant DNA work include a description of the physical and biological containment procedures practiced, to aid and forewarn others who might consider repeating the work.

II. CONTAINMENT

Effective biological safety programs have been operative in a variety of laboratories for many years. Considerable information therefore already exists for the design of physical containment facilities and the selection of laboratory procedures applicable to organisms carrying recombinant DNAs (4-17). The existing programs rely upon mechanisms that, for convenience, can be divided into two categories: (i) A set of standard practices that are generally used in microbiological laboratories, and (ii) special procedures, equipment, and laboratory installations that provide physical barriers which are applied in varying degrees according to the estimated biohazard.

Experiments on recombinant DNAs by their very nature lend themselves to a third containment mechanism—namely, the application of highly specific biological barriers. In fact, natural barriers do exist which either limit the infectivity of a vector or vehicle

(plasmid, bacteriophage or virus) to specific hosts, or its dissemination and survival in the environment. The vectors that provide the means for replication of the recombinant DNAs and/or the host cells in which they replicate can be genetically designed to decrease by many orders of magnitude the probability of dissemination of recombinant DNAs outside the laboratory.

As these three means of containment are complementary, different levels of containment appropriate for experiments with different recombinants can be established by applying different combinations of the physical and biological barriers to a constant use of the standard practices. We consider these categories of containment separately here in order that such combinations can be conveniently expressed in the guidelines for research on the different kinds of recombinant DNAs (Section III).

A. Standard practices and training. The first principle of containment is a strict adherence to good microbiological practices (4-13). Consequently, all personnel directly or indirectly involved in experiments on recombinant DNAs must receive adequate instruction. This should include at least training in aseptic techniques and instruction in the biology of the organisms used in the experiments so that the potential biohazards can be understood and appreciated.

Any research group working with agents with a known or potential biohazard should have an emergency plan which describes the procedures to be followed if an accident contaminates personnel or environment. The principal investigator must ensure that everyone in the laboratory is familiar with both the potential hazards of the work and the emergency plan. If a research group is working with a known pathogen for which an effective vaccine is available, all workers should be immunized. Serological monitoring, where appropriate, should be provided.

B. Physical containment levels. A variety of combinations (levels) of special practices, equipment, and laboratory installations that provide additional physical barriers can be formed. For example, 31 combinations are listed in "Laboratory Safety at the Center for Disease Control" (4); four levels are associated with the "Classification of Etiologic Agents on the Basis of Hazard" (5), four levels were recommended in the "Summary Statement of the Asilomar Conference on Recombinant DNA Molecules" (3); and the National Cancer Institute uses three levels for research on oncogenic viruses (6). We emphasize that these are an aid to, and not a substitute for, good technique. Personnel must be competent in the effective use of all equipment needed for the required containment level as described below. We define only four levels of physical containment here, both because the accuracy with which one can presently assess the biohazards that may result from recombinant DNAs does not warrant a more detailed classification, and because additional flexibility can be obtained by combination of the physical with the biological barriers. Though different in detail, these four levels (P1<P2<P3<P4) approximate those given for human etiologic agents by the Center for Disease Control (i.e., classes 1 through 4; ref. 5), in the Asilomar summary statement (i.e., minimal, low moderate, and high; ref. 3), and by the National Cancer Institute for oncogenic viruses (i.e., low, moderate, and high; ref. 6), as is indicated by the P-number or adjective in the following headings. It should be emphasized that the descriptions and assignments of physical containment detailed below are based on existing approaches to containment of hazardous organisms.

We anticipate, and indeed already know of, procedures (14) which enhance physical

containment capability in novel ways. For example, miniaturization of screening, handling, and analytical procedures provides substantial containment of a given host-vector system. Thus, such procedures should reduce the need for the standard types of physical containment, and such innovations will be considered by the Recombinant DNA Molecule Program Advisory Committee.

The special practices, equipment and facility installations indicated for each level of physical containment are required for the safety of laboratory workers, other persons, and for the protection of the environment. Optional items have been excluded; only those items deemed absolutely necessary for safety are presented. Thus, the listed requirements present basic safety criteria for each level of physical containment. Other microbiological practices and laboratory techniques which promote safety are to be encouraged. Additional information giving further guidance on physical containment is provided in a supplement to the guidelines (Appendix D).

P1 Level (Minimal). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P1 level is a laboratory that possesses no special engineering design features. It is a laboratory commonly used for microorganisms of no or minimal biohazard under ordinary conditions of handling. Work in this laboratory is generally conducted on open bench tops. Special containment equipment is neither required nor generally available in this laboratory. The laboratory is not separated from the general traffic patterns of the building. Public access is permitted.

The control of biohazards at the P1 level is provided by standard microbiological practices of which the following are examples: (i) Laboratory doors should be kept closed while experiments are in progress. (ii) Work surfaces should be decontaminated daily and following spills of recombinant DNA materials. (iii) Liquid wastes containing recombinant DNA materials should be decontaminated before disposal. (iv) Solid wastes contaminated with recombinant DNA materials should be decontaminated or packaged in a durable leak-proof container before removal from the laboratory. (v) Although pipetting by mouth is permitted, it is preferable that mechanical pipetting devices be used. When pipetting by mouth, cotton-plugged pipettes shall be employed. (vi) Eating, drinking, smoking, and storage of food in the working area should be discouraged. (vii) Facilities to wash hands should be available. (viii) An insect and rodent control program should be provided. (ix) The use of laboratory gowns, coats, or uniforms is discretionary with the laboratory supervisor.

P2 Level (Low). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P2 level is similar in construction and design to the P1 laboratory. The P2 laboratory must have access to an autoclave within the building; it may have a Biological Safety Cabinet.¹ Work which does not produce a considerable aerosol is conducted on the open bench. Although this laboratory is not separated from the general traffic patterns of the building, access to the laboratory is limited when experiments requiring P2 level physical containment are being conducted. Experiments of lesser biohazard potential can be carried out concurrently in carefully demarcated areas of the same laboratory.

The P2 laboratory is commonly used for experiments involving microorganisms of low biohazard such as those which have been classified by the Center for Disease Control as Class 2 agents (5).

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The following practices shall apply to all experiments requiring P2 level physical containment: (i) Laboratory doors shall be kept closed while experiments are in progress. (ii) Only persons who have been advised of the potential biohazard shall enter the laboratory. (iii) Children under 12 years of age shall not enter the laboratory. (iv) Work surfaces shall be decontaminated daily and immediately following spills of recombinant DNA materials. (v) Liquid wastes of recombinant DNA materials shall be decontaminated before disposal. (vi) Solid wastes contaminated with recombinant DNA materials shall be decontaminated or packaged in a durable leak-proof container before removal from the laboratory. Packaged materials shall be disposed of by incineration or sterilized before disposal by other methods. Contaminated materials that are to be processed and reused (i.e., glassware) shall be decontaminated before removal from the laboratory. (vii) Pipetting by mouth is prohibited; mechanical pipetting devices shall be used. (viii) Eating, drinking, smoking, and storage of food are not permitted in the working area. (ix) Facilities to wash hands shall be available within the laboratory. Persons handling recombinant DNA materials should be encouraged to wash their hands frequently and when they leave the laboratory. (x) An insect and rodent control program shall be provided. (xi) The use of laboratory gowns, coats, or uniforms is required. Such clothing shall not be worn to the lunch room or outside the building. (xii) Animals not related to the experiment shall not be permitted in the laboratory. (xiii) Biological Safety Cabinets¹ and/or other physical containment equipment shall be used to minimize the hazard of aerosolization of recombinant DNA materials from operations or devices that produce a considerable aerosol (e.g., blender, lyophilizer, sonicator, shaking machine, etc.). (xiv) Use of the hypodermic needle and syringe shall be avoided when alternate methods are available.

P3 Level (Moderate). A laboratory suitable for experiments involving recombinant DNA molecules requiring physical containment at the P3 level has special engineering design features and physical containment equipment. The laboratory is separated from areas which are open to the general public. Separation is generally achieved by controlled access corridors, air locks, locker rooms or other double-doored facilities which are not available for use by the general public. Access to the laboratory is controlled. Biological Safety Cabinets¹ are available within the controlled laboratory area. An autoclave shall be available within the building and preferably within the controlled laboratory area. The surfaces of walls, floors, bench tops, and ceilings are easily cleanable to facilitate housekeeping and space decontamination.

Directional air flow is provided within the controlled laboratory area. The ventilation system is balanced to provide for an inflow of supply air from the access corridor into the laboratory. The general exhaust air from the laboratory is discharged outdoors and so dispersed to the atmosphere as to prevent reentry into the building. No recirculation of the exhaust air shall be permitted without appropriate treatment.

No work in open vessels involving hosts or vectors containing recombinant DNA molecules requiring P3 physical containment is conducted on the open bench. All such procedures are confined to Biological Safety Cabinets.¹

The following practices shall apply to all experiments requiring P3 level physical containment: (i) The universal biohazard sign is required on all laboratory access doors. Only persons whose entry into the laboratory

is required on the basis of program or support needs shall be authorized to enter. Such persons shall be advised of the potential biohazards before entry and they shall comply with posted entry and exit procedures. Children under 12 years of age shall not enter the laboratory. (ii) Laboratory doors shall be kept closed while experiments are in progress. (iii) Biological Safety Cabinets¹ and other physical containment equipment shall be used for all procedures that produce aerosols of recombinant DNA materials (e.g., pipetting, plating, flaming, transfer operations, grinding, blending, drying, sonicating, shaking, etc.). (iv) The work surfaces of Biological Safety Cabinets¹ and other equipment shall be decontaminated following the completion of the experimental activity contained within them. (v) Liquid wastes containing recombinant DNA materials shall be decontaminated before disposal. Solid wastes contaminated with recombinant DNA materials shall be decontaminated or packaged in a durable leak-proof container before removal from the laboratory. Packaged material shall be sterilized before disposal. Contaminated materials that are to be processed and reused (i.e., glassware) shall be sterilized in the controlled laboratory area or placed in a durable leak-proof container before removal from the controlled laboratory area. This container shall be sterilized before the materials are processed. (vii) Pipetting by mouth is prohibited; mechanical pipetting devices shall be used. (viii) Eating, drinking, smoking, and storage of food are not permitted in the laboratory. (ix) Facilities to wash hands shall be available within the laboratory. Persons shall wash hands after experiments involving recombinant DNA materials and before leaving the laboratory. (x) An insect and rodent control program shall be provided. (xi) Laboratory clothing that protects street clothing (i.e., long sleeve solid-front or wrap-around gowns, no-button or slipover jackets, etc.) shall be worn in the laboratory. **FRONT-BUTTON LABORATORY COATS ARE UNSUITABLE.** Gloves shall be worn when handling recombinant DNA materials. Provision for laboratory shoes is recommended. Laboratory clothing shall not be worn outside the laboratory and shall be decontaminated before it is sent to the laundry. (xii) Raincoats, overcoats, topcoats, coats, hats, caps, and such street outerwear shall not be kept in the laboratory. (xiii) Animals and plants not related to the experiment shall not be permitted in the laboratory. (xiv) Vacuum lines shall be protected by filters and liquid traps. (xv) Use of the hypodermic needle and syringe shall be avoided when alternate methods are available. (xvi) If experiments of lesser biohazard potential are to be conducted in the same laboratory concurrently with experiments requiring P3 level physical containment they shall be conducted only in accordance with all P3 level requirements. (xvii) Experiments requiring P3 level physical containment can be conducted in laboratories where the directional air flow and general exhaust air conditions described above cannot be achieved, provided that this work is conducted in accordance with all other requirements listed and is contained in a Biological Safety Cabinet¹ with attached glove ports and gloves. All materials before removal from the Biological Safety Cabinet¹ shall be sterilized or transferred to a non-breakable, sealed container, which is then removed from the cabinet through a chemical decontamination tank, autoclave, ultraviolet air lock, or after the entire cabinet has been decontaminated.

P4 Level High. Experiments involving recombinant DNA molecules requiring physical containment at the P4 level shall be confined to work areas in a facility of the type designed to contain microorganisms that are

extremely hazardous to man or may cause serious epidemic disease. The facility is either a separate building or it is a controlled area, within a building, which is completely isolated from all other areas of the building. Access to the facility is under strict control. A specific facility operations manual is available. Class III Biological Safety Cabinets¹ are available within work areas of the facility.

A P4 facility has engineering features which are designed to prevent the escape of microorganisms to the environment (14, 15, 16, 17). These features include: (i) Monolithic walls, floors, and ceilings in which all penetrations such as for air ducts, electrical conduits, and utility pipes are sealed to assure the physical isolation of the work area and to facilitate housekeeping and space decontamination; (ii) air locks through which supplies and materials can be brought safely into the facility; (iii) contiguous clothing change and shower rooms through which personnel enter into and exit from the facility; (iv) double-door autoclaves to sterilize and safely remove wastes and other materials from the facility; (v) a blowdown treatment system to sterilize liquid effluents if facility drains are installed; (vi) a separate ventilation system which maintains negative air pressures and directional air flow within the facility; and (vii) a treatment system to decontaminate exhaust air before it is dispersed to the atmosphere. A central vacuum utility system is not encouraged; if one is installed, each branch line leading to a laboratory shall be protected by a high efficiency particulate air filter.

The following practices shall apply to all experiments requiring P4 level physical containment: (i) The universal biohazard sign is required on all facility access doors and all interior doors to individual laboratory rooms where experiments are conducted. Only persons whose entry into the facility or individual laboratory rooms is required on the basis of program or support needs shall be authorized to enter. Such persons shall be advised of the potential biohazards and instructed as to the appropriate safeguards to ensure their safety before entry. Such persons shall comply with the instructions and all other posted entry and exit procedures. Under no condition shall children under 15 years of age be allowed entry. (ii) Personnel shall enter into and exit from the facility only through the clothing change and shower rooms. Personnel shall shower at each exit from the facility. The air locks shall not be used for personnel entry or exit except for emergencies. (iii) Street clothing shall be removed in the outer facility side of the clothing change area and kept there. Complete laboratory clothing including undergarments, pants and shirts or jumpsuits, shoes, head cover, and gloves shall be provided and used by all persons who enter into the facility shall be placed in an entry air be stored in lockers provided for this purpose or discarded into collection hampers before personnel enter into the shower area. (iv) Supplies and materials to be taken into the facility shall be placed in an entry air lock. After the outer door (opening to the corridor outside of facility) has been secured, personnel occupying the facility shall retrieve the supplies and materials by opening the interior air lock door. This door shall be secured after supplies and materials are brought into the facility. (v) Doors to laboratory rooms within the facility shall be kept closed while experiments are in progress. (vi) Experimental procedures requiring P4 level physical containment shall be confined to Class III Biological Safety Cabinets.¹ All materials, before removal from these cabinets, shall be sterilized or transferred to a non-breakable sealed container, which is then removed from the system through a chemical decontaminated tank, autoclave, or after the

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entire system has been decontaminated. (vii) No materials shall be removed from the facility unless they have been sterilized or decontaminated in a manner to prevent the release of agents requiring P4 physical containment. All wastes and other materials and equipment not damaged by high temperature or steam shall be sterilized in the double-door autoclave. Biological materials to be removed from the facility shall be transferred to a non-breakable sealed container which is then removed from the facility through a chemical decontamination tank or a chamber designed for gas sterilization. Other materials which may be damaged by temperature or steam shall be sterilized by gaseous or vapor methods in an air lock or chamber designed for this purpose. (viii) Eating, drinking, smoking, and storage of food are not permitted in the facility. Foot-operated water fountains located in the facility corridors are permitted. Separate potable water piping shall be provided for these water fountains. (ix) Facilities to wash hands shall be available within the facility. Persons shall wash hands after experiments. (x) An insect and rodent control program shall be provided. (xi) Animals and plants not related to the experiment shall not be permitted in the facility. (xii) If a central vacuum system is provided, each vacuum outlet shall be protected by a filter and liquid trap in addition to the branch line HEPA filter mentioned above. (xiii) Use of the hypodermic needle and syringe shall be avoided when alternate methods are available. (xiv) If experiments of lesser biohazard potential are to be conducted in the facility concurrently with experiments requiring P4 level containment, they shall be confined in Class I or Class II Biological Safety Cabinets¹ or isolated by other physical containment equipment. Work surfaces of Biological Safety Cabinets¹ and other equipment shall be decontaminated following the completion of the experimental activity contained within them. Mechanical pipetting devices shall be used. All other practices listed above with the exception of (vi) shall apply.

C. *Shipment.* To protect product, personnel, and the environment, all recombinant DNA material will be shipped in containers that meet the requirements issued by the U.S. Public Health Service (Section 72.25 of Part 72, Title 42, Code of Federal Regulations), Department of Transportation (Section 173.387 (b) of Part 173, Title 49, Code of Federal Regulations) and the Civil Aeronautics Board (C.A.B. No. 82, Official Air Transport Restricted Articles Tariff No. 6-D) for shipment of etiologic agents. Labeling requirements specified in these Federal regulations and tariffs will apply to all viable recombinant DNA materials in which any portion of the material is derived from an etiologic agent listed in paragraph (c) of 42 CFR 72.25. Additional information on packing and shipping is given in a supplement to the guidelines (Appendix D, part X).

D. *Biological containment levels.* Biological barriers are specific to each host-vector system. Hence the criteria for this mechanism of containment cannot be generalized to the same extent as for physical containment. This is particularly true at the present time when our experience with existing host-vector systems and our predictive knowledge about projected systems are sparse. The classification of experiments with recombinant DNAs that is necessary for the construction of the experimental guidelines (Section III) can be accomplished with least confusion if we use the host-vector system as the primary element and the source of the inserted DNA as the secondary element in the classification. It is therefore convenient to specify the nature of the biological containment under host-vector headings such as those given below for *Escherichia coli* K-12.

III. EXPERIMENTAL GUIDELINES

A general rule that, though obvious, deserves statement is that the level of containment required for any experiment on DNA recombinants shall never be less than that required for the most hazardous component used to construct and clone the recombinant DNA (i.e. vector, host, and inserted DNA). In most cases the level of containment will be greater, particularly when the recombinant DNA is formed from species that ordinarily do not exchange genetic information. Handling the purified DNA will generally require less stringent precautions than will propagating the DNA. However, the DNA itself should be handled at least as carefully as one would handle the most dangerous of the DNAs used to make it.

The above rule by itself effectively precludes certain experiments—namely, those in which one of the components is in Class 5 of the "Classification of Etiologic Agents on the Basis of Hazard" (5), as these are excluded from the United States by law and USDA administrative policy. There are additional experiments which may engender such serious biohazards that they are not to be performed at this time. These are considered prior to presentation of the containment guidelines for permissible experiments.

A. *Experiments that are not to be performed.* We recognize that it can be argued that certain of the recombinants placed in this category could be adequately contained at this time. Nonetheless, our estimates of the possible dangers that may ensue if that containment fails are of such magnitude that we consider it the wisest policy to at least defer experiments on these recombinant DNAs until there is more information to accurately assess that danger and to allow the construction of more effective biological barriers. In this respect, these guidelines are more stringent than those initially recommended (1).

The following experiments are not to be initiated at the present time: (i) Cloning of recombinant DNAs derived from the pathogenic organisms in Classes 3, 4, and 5 of "Classification of Etiologic Agents on the Basis of Hazard" (5), or oncogenic viruses classified by NCI as moderate risk (6), or cells known to be infected with such agents, regardless of the host-vector system used. (ii) Deliberate formation of recombinant DNAs containing genes for the biosynthesis of potent toxins (e.g., botulinum or diphtheria toxins; venoms from insects, snakes, etc.). (iii) Deliberate creation from plant pathogens of recombinant DNAs that are likely to increase virulence and host range. (iv) Deliberate release into the environment of any organism containing a recombinant DNA molecule. (v) Transfer of a drug resistance trait to microorganisms that are not known to acquire it naturally if such acquisition could compromise the use of a drug to control disease agents in human or veterinary medicine or agriculture.

In addition, at this time large-scale experiments (e.g., more than 10 liters of culture) with recombinant DNAs known to make harmful products are not to be carried out. We differentiate between small- and large-scale experiments with such DNAs because the probability of escape from containment barriers normally increases with increasing scale. However, specific experiments in this category that are of direct societal benefit may be excepted from this rule if special biological containment precautions and equipment designed for large-scale operations are used, and provided that these experiments are expressly approved by the Recombinant DNA Molecule Program Advisory Committee of NIH.

B. *Containment guidelines for permissible experiments.* It is anticipated that most re-

combinant DNA experiments initiated before these guidelines are next reviewed (i.e., within the year) will employ *E. coli* K-12 host-vector systems. These are also the systems for which we have the most experience and knowledge regarding the effectiveness of the containment provided by existing hosts and vectors necessary for the construction of more effective biological barriers.

For these reasons, *E. coli* K-12 appears to be the system of choice at this time, although we have carefully considered arguments that many of the potential dangers are compounded by using an organism as intimately connected with a man as is *E. coli*. Thus, while proceeding cautiously with *E. coli*, serious efforts should be made toward developing alternate host-vector systems; this subject is discussed in considerable detail in Appendix A.

We therefore consider DNA recombinants in *E. coli* K-12 before proceeding to other host-vector systems.

1. *Biological containment criteria using E. coli K-12 host-vectors EK1 host-vectors.* These are host-vector systems that can be estimated to already provide a moderate level of containment, and include most of the presently available systems. The host is always *E. coli* K-12, and the vectors include nonconjugative plasmids [e.g., pSC101, ColE1 or derivatives thereof (19-26)] and variants of bacteriophage γ (27-29).

The *E. coli* K-12 nonconjugative plasmid system is taken as an example to illustrate the approximate level of containment referred to here. The available data from experiments involving the feeding of bacteria to humans and calves (30-32) indicate that *E. coli* K-12 did not usually colonize the normal bowel, and exhibited little, if any, multiplication while passing through the alimentary tract even after feeding high doses (i.e., 10^9 to 10^{10} bacteria per human or calf). However, general extrapolation of these results may not be warranted because the implantation of bacteria into the intestinal tract depends on a number of parameters, such as the nature of the intestinal flora present in a given individual and the physiological state of the inoculum. Moreover, since viable *E. coli* K-12 can be found in the feces after humans are fed 10^7 bacteria in broth (30) or 3×10^4 bacteria protected by suspension in milk (31), transductional and conjugational transfer of the plasmid vectors from *E. coli* K-12 to resident bacteria in the fecal matter before and after excretion must also be considered.

The nonconjugative plasmid vectors cannot promote their own transfer, but require the presence of a conjugative plasmid for mobilization and transfer to other bacteria. When present in the same cell with derepressed conjugative plasmids such as F or R100, the nonconjugative ColE1, ColE1-trp and pSC101 plasmids are transferred to suitable recipient strains under ideal laboratory conditions at frequencies of about 0.5, 10^{-4} to 10^{-5} , and 10^{-6} per donor cell, respectively. These frequencies are reduced by another factor of 10^2 to 10^4 if the conjugative plasmid employed is repressed with respect to expression of donor fertility.

The experimental transfer system which most closely resembles nonconjugative plasmid transfer in nature is a triparental mating. In such matings, the bacterial cell possessing the nonconjugative plasmid must first acquire a conjugative plasmid from another cell before it can transfer the nonconjugative plasmid to a secondary recipient. With ColE1, the frequencies of transfer are 10^{-2} and 10^{-4} to 10^{-5} when using conjugative plasmid donors possessing derepressed and repressed plasmids, respectively. Mobilization of ColE1-trp and pSC101 under similar laboratory conditions is so low as to be usually undetectable (33). Since most conjugative plasmids in nature are repressed for expres-

sion of donor fertility, the frequency at which nonconjugative plasmids are mobilized and transferred by this sequence of events *in vivo* is difficult to estimate. However, in calves fed on an antibiotic-supplemented diet, it has been estimated that such triparental nonconjugative R plasmid transfer occurs at frequencies of no more than 10^{-16} to 10^{-12} per 24 hours per calf (32). In terms of considering other means for plasmid transmission in nature, it should be noted that transduction does operate *in vivo* for *Staphylococcus aureus* (34) and probably for *E. coli* as well. However, no data are available to indicate the frequencies of plasmid transfer *in vivo* by either transduction or transformation.

These observations indicate the low probabilities for possible dissemination of such plasmid vectors by accidental ingestion, which would probably involve only a few hundred or thousand bacteria provided that at least the standard practices (Section II-A above) are followed, particularly the avoidance of mouth pipetting. The possibility of colonization and hence of transfer are increased, however, if the normal flora in the bowel is disrupted by, for example, antibiotic therapy (35). For this reason, persons receiving such therapy must not work with DNA recombinants formed with any *E. coli* K-12 host-vector system during the therapy period and for seven days thereafter; similarly, persons who have achlorhydria or who have had surgical removal of part of the stomach or bowel should avoid such work, as should those who require large doses of antacids.

The observations on the fate of *E. coli* K-12 in the human alimentary tract are also relevant to the containment of recombinant DNA formed with bacteriophage λ variants. Bacteriophage can escape from the laboratory either as mature infectious phage particles or in bacterial host cells in which the phage genome is carried as a plasmid or prophage. The fate of *E. coli* K-12 host cells carrying the phage genome as a plasmid or prophage is similar to that for plasmid-containing host cells as discussed above. The survival of the λ phage genome when released as infectious particles depends on their stability in nature, their infectivity and on the probability of subsequent encounters with naturally occurring λ -sensitive *E. coli* strains. Although the probability of survival of λ and its infection of resident intestinal *E. coli* in animals and humans has not been measured, it is estimated to be small given the high sensitivity of λ to the low pH of the stomach, the insusceptibility to λ infection of smooth *E. coli* cells (the type that normally resides in the gut), the infrequency of naturally occurring λ -sensitive *E. coli* (36) and the failure to detect infective λ particles in human feces after ingestion of up to 10^{11} λ particles (37).

Moreover, λ particles are very sensitive to desiccation.

Establishment of λ as a stable lysogen is a frequent event (10^0 to 10^{-1}) for the att⁺ int⁺ cI⁺ phage so that this mode of escape would be the preponderant laboratory hazard; however, most EK1 λ vectors currently in use lack the att and int functions (27-29) thus reducing the probability of lysogenization to about 10^{-5} to 10^{-6} (38-40). The frequency for the conversion of λ to a plasmid state for persistence and replication is also only about 10^{-6} (41). Moreover, the routine treatment of phage lysates with chloroform (42) should eliminate all surviving bacteria including lysogens and λ plasmid carriers. Lysogenization could also occur when an infectious λ containing cloned DNA infects a λ -sensitive cell in nature, and recombines with a resident

lambdoid prophage. Although λ -sensitive *E. coli* strains seem to be rare, a significant fraction do carry lambdoid prophages (43-44) and thus this route of escape should be considered.

While not exact, the estimates for containment afforded by using these host-vectors are at least as accurate as those for physical containment, and are sufficient to indicate that currently employed plasmid and λ vector systems provide a moderate level of biological containment. Other nonconjugative plasmids and bacteriophages that, in association with *E. coli* K-12 can be estimated to provide the same approximate level of moderate containment are included in the EK1 class.

EK2 host-vectors. These are host-vector systems that have been genetically constructed and shown to provide a high level of biological containment as demonstrated by data from suitable tests performed in the laboratory. The genetic modifications of the *E. coli* K-12 host and/or the plasmid or phage vector should not permit survival of a genetic marker carried on the vector, preferably a marker within an inserted DNA fragment, in other than specially designed and carefully regulated laboratory environments at a frequency greater than 10^{-8} . This measure of biological containment has been selected because it is a measurable entity. Indeed, by testing the contributions of pre-existing and newly introduced genetic properties of vectors and hosts, individually or in various combinations, it should be possible to estimate with considerable precision, that the specially designed host-vector system can provide a margin of biological containment in excess of that required. For the time being, no host-vector system will be considered to be a bona fide EK2 host-vector system until it is so certified by the NIH Recombinant DNA Molecule Program Advisory Committee.

For EK2 host-vector systems in which the vector is a plasmid, no more than one in 10^6 host cells should be able to perpetuate the vector and/or a cloned DNA fragment under non-permissive conditions designed to represent the natural environment either by survival of the original host or as a consequence of transmission of the vector and/or a cloned DNA fragment by transformation, transduction or conjugation to a host with properties common to those in the natural environment.

In terms of potential EK2 plasmid-host systems, the following types of genetic modifications should reduce survival of cloned DNA. The examples given are for illustrative purposes and should not be construed to encompass all possibilities. The presence of the non-conjugative plasmids ColE1-trp and pS101 in an *E. coli* K-12 strain possessing a mutation eliminating host-controlled restriction and modification (hsdS) results in about 10^2 -fold reduction in mobilization to restriction-proficient recipients. The combination of the dapD8, Δ bioH-asd, Δ gal-chl^r and rfb mutations in *E. coli* K-12 results in no detectable survivors in feces of rats following feeding by stomach tube of 10^{10} cells in milk and similarly leads to complete lysis of cells suspended in broth medium lacking diaminopimelic acid. *E. coli* K-12 strains with Δ thyA and deoC(dra) mutations undergo thymineless death in growth medium lacking thymine and give a 10^5 -fold reduced survival during passage through the rat intestine compared to wild-type thy⁺ *E. coli* K-12. (However, the Δ thyA mutation alone or in combination with a deoB(drm) mutation only reduces *in vivo* survival by a factor of 10^2 .) Other host mutations, as yet untested, that might further reduce survival of the plasmid-host system or reduce plasmid transmission are: the combination polA(TS) recA(TS) Δ thyA which might interfere with ColE1 replication and lead to DNA degrada-

tion at body temperatures; Con mutations that reduce the ability of conjugative plasmids to enter the plasmid-host complex and thus should reduce mobilization of the cloned DNA to other strains; and mutations that confer resistance to known transducing phages. Mutations can also be introduced into the plasmid to cause it to be dependent on a specific host, to make its replication thermosensitive and/or to endow it with a killer capability such that all cells (other than its host) into which it might be transferred will not survive.

In the construction of EK2 plasmid-host systems it is important to use the most stable mutations available, preferably deletions. Obviously, the presence of all mutations contributing to higher degrees of biological containment must be verified periodically by appropriate tests. In testing the level of biological containment afforded by a proposed EK2 plasmid-host system, it is important to design relevant tests to evaluate the survival of the vector and/or a cloned DNA fragment under conditions that are possible in nature and that are also most advantageous for its perpetuation. For example, one might conduct a triparental mating with a primary donor possessing a redepressed F-type or I-type conjugative plasmid, the safer host with Δ bioH-asd, dapD8, Δ gal-chl^r, rfb, Δ thyA, deoC, trp and hsdS mutations and a plasmid vector carrying an easily detectable marker such as for ampicillin resistance or an inserted gene such as trp⁺, and a secondary recipient that is Su⁺ hsdS trp (i.e., permissive for the recombinant plasmid). Such matings would be conducted in a medium lacking diaminopimelic acid and thymine and survival of the Ap^r or trp marker in any of the three strains followed as a function of time. Survival of the vector and/or a cloned marker by transduction could also be evaluated by introducing a known generalized transducing phage into the system. Similar experiments should also be done using a secondary recipient that is restrictive for the plasmid vector as well as with primary donors possessing repressed conjugative plasmids with incompatibility group properties like those commonly found in enteric microorganisms. Since a common route of escape of plasmid-host systems in the laboratory might be by accidental ingestion, it is suggested that the same types of experiments be conducted in suitable animal-model systems. In addition to these tests on survival of the vector and/or a cloned DNA fragment, it would be useful to determine the survival of the host strain under nongrowth conditions such as in water and as a function of drying time after a culture has been spilled on a lab bench.

For EK2 host-vector systems in which the vector is a phage, no more than one in 10^6 phage particles should be able to perpetuate itself and/or a cloned DNA fragment under non-permissive conditions designed to represent the natural environment either (a) as a prophage or plasmid in the laboratory host used for phage propagation or (b) by surviving in natural environments and transferring itself and/or a cloned DNA fragment to a host (or its resident lambdoid prophage) with properties common to those in the natural environment.

In terms of potential EK2 λ -host systems, the following types of genetic modification should reduce survival of cloned DNA. The examples given are for illustrative purposes and should not be construed to encompass all possibilities. The probability of establishing λ lysogeny in the normal laboratory host should be reduced by removal of the phage att site, the int function, the repressor gene(s) and adding virulence-enhancing mutations. The frequency of plasmid formation, although normally already less than 10^{-6} , could be further reduced by defects in

the P₂-Q region, including mutations such as *vir-s*, *cro*(TS), *c17*, *ri^s*, *O*(TS), *P*(TS), and *nin*. Moreover, chloroform treatment used routinely following cell lysis would reduce the number of surviving cells, including possible lysogens or plasmid carriers, by more than 10%. The host may also be modified by deletion of the host *λatt* site and inclusion of one or more of the mutations described above for plasmid-host systems to further reduce the chance of formation and survival of any lysogen or plasmid carrier cell.

The survival of escaping phage and the chance of encountering a sensitive host in nature are very low, as discussed for EK1 systems. The infectivity of the phage particles could be further reduced by introducing mutations (e.g., suppressed ambers) which would make the phage particles extremely unstable except under special laboratory conditions (e.g., high concentrations of salts or putrescine). Another means would be to make the phage itself a two-component system, by eliminating the tail genes and reproducing the phage as heads packed with DNA; when necessary and under specially controlled conditions, these heads could be made infective by adding tail preparations. An additional safety factor in this regimen is the extreme instability of the heads, unless they are stored in 10mM putrescine, a condition easy to obtain in the laboratory but not in nature. The propagation of the escaping phage in nature could further be blocked by adding various conditional mutations which would permit growth only under special laboratory conditions or in a special permissive laboratory host with suppressor or *gro*-type (*mop*, *dnaB*, *rpoB*) mutations. An additional safety feature would be the use of an r⁻ m⁻ (*hsdS*) laboratory host, which produces phage with unmodified DNA which should be restricted in r⁺ m⁺ bacteria that are probably prevalent in nature. The likelihood of recombination between the *λ* vector and lambdoid prophages which are present in some *E. coli* strains might be reduced by elimination of the Red function and the presence of the recombination-reducing Gam function together with mutations contributing to the high lethality of the *λ* phage. However, these second-order precautions might not be relevant if the stability and infectivity of the escaping *λ* particles are reduced by special mutations or by propagating the highly unstable heads.

Despite multiple mutations in the phage vectors and laboratory hosts, the yield of phage particles under suitable laboratory conditions should be high (10¹⁰–10¹¹ particles/ml). This permits phage propagation in relatively small volumes and constitutes an additional safety feature.

The phenotypes and genetic stabilities of the mutations and chromosome alterations included in these *λ*-host systems indicate that containment well in excess of the required 10⁻⁶ or lower survival frequency for the *λ* vector with or without a cloned DNA fragment should be attained. Obviously the presence of all mutations contributing to this high degree of biological containment must be verified periodically by appropriate tests. Laboratory tests should be performed with the bacterial host to measure all possible routes of escape such as the frequency of lysogen formation, the frequency of plasmid formation and the survival of the lysogen or carrier bacterium. Similarly, the potential for perpetuation of a cloned DNA fragment carried by infectious phage particles can be tested by challenging typical wild-type *E. coli* strains or a *λ*-sensitive nonpermissive laboratory K-12 strain, especially one lysogenic for a lambdoid phage.

In view of the fact that accurate assessment of the probabilities for escape of in-

fectious *λ* grown on r⁻ m⁻ Su⁺ hosts is dependent upon the frequencies of r⁻, Su⁺, and *λ*-sensitive strains in nature, investigators need to screen *E. coli* strains for these properties. These data will also be useful in predicting frequencies of successful escape of plasmid cloning vectors harbored in r⁻ m⁻ Su⁺ strains.

When any investigator has obtained data on the level of containment provided by a proposed EK2 system, these should be reported as rapidly as possible to permit general awareness and evaluation of the safety features of the new system. Investigators are also encouraged to make such new safer cloning systems generally available to other scientists. NIH will take appropriate steps to aid in the distribution of these safer vectors and hosts.

EK3 host-vectors. These are EK2 systems for which the specified containment shown by laboratory tests has been independently confirmed by appropriate tests in animals, including humans or primates, and in other relevant environments in order to provide additional data to validate the levels of containment afforded by the EK2 host-vector systems. Evaluation of the effects of individual or combinations of mutations contributing to the biological containment should be performed as a means to confirm the degree of safety provided and to further advance the technology of developing even safer vectors and hosts. For the time being, no host-vector system will be considered to be a bona fide EK3 host-vector system, until it is so certified by the NIH Recombinant DNA Molecule Program Advisory Committee.

2. Classification of experiments using the *E. coli* K-2 containment systems. In the following classification of containment criteria for different kinds of recombinant DNAs, the stated levels of physical and biological containment are minimums. Higher levels of biological containment (EK3>EK2>EK1) are to be used if they are available and are equally appropriate for the purposes of the experiment.

<a> Shotgun experiments. These experiments involve the production of recombinant DNAs between the vector and the total DNA or (preferably) any partially purified fraction thereof from the specified cellular source.

(i) Eukaryotic DNA recombinants—Primates. P3 physical containment+an EK3 host-vector, or P4 physical containment+an EK2 host-vector, except for DNA from uncontaminated embryonic tissue or primary tissue cultures therefrom, and germ-line cells for which P3 physical containment+an EK2 host-vector can be used. The basis for the lower estimated hazard in the case of DNA from the latter tissues (if freed of adult tissue) is their relative freedom from horizontally acquired adventitious viruses.

Other mammals. P3 physical containment+an EK2 host-vector.

Birds. P3 physical containment+an EK2 host-vector.

Cold-blooded vertebrates. P2 physical containment+an EK2 host-vector except for embryonic or germ-line DNA which require P2 physical containment+an EK1 host-vector. If the eukaryote is known to produce a potent toxin, the containment shall be increased to P3+EK2.

Other cold-blooded animals and lower eukaryotes. This large class of eukaryotes is divided into the following two groups:

(1) Species that are known to produce a potent toxin or are known pathogens (i.e., an agent listed in Class 2 of ref. 5 or a plant pathogen) or are known to carry such pathogenic agents must use P3 physical containment+an EK2 host-vector. Any species that has a demonstrated capacity for carrying particular pathogenic agents is included in this

group unless it has been shown that those organisms used as the source of DNA do not contain these agents; in this case they may be placed in the second group.

(2) The remainder of the species in this class can use P2+EK1. However, any insect in this group should have been grown under laboratory conditions for at least 10 generations prior to its use as a source of DNA.

Plants. P2 physical containment+an EK1 host-vector. If the plant carries a known pathogenic agent or makes a product known to be dangerous to any species, the containment must be raised to P3 physical containment+an EK2 host-vector.

(ii) Prokaryotes DNA recombinants—Prokaryotes that exchange genetic information with *E. coli*.

The level of physical containment is directly determined by the rule of the most dangerous component (see introduction to Section III). Thus P1 conditions can be used for DNAs from those bacteria in Class 1 of ref. 5. ("Agents of no or minimal hazard * * *") which naturally exchange genes with *E. coli*; and P2 conditions should be used for such bacteria if they fall in Class 2 of ref. 5 ("Agents of ordinary potential hazard * * *"), or plant pathogens or symbionts. EK1 host-vectors can be used for all experiments requiring only P1 physical containment; in fact, experiments in this category can be performed with *E. coli* K-12 vectors exhibiting a lesser containment (e.g., conjugative plasmids) than EK1 vectors. Experiments with DNA from species requiring P2 physical containment which are of low pathogenicity (for example, enteropathogenic *Escherichia coli*, *Salmonella typhimurium*, and *Klebsiella pneumoniae*) can use EK1 host-vectors, but those of moderate pathogenicity (for example, *Salmonella typhi*, *Shigella dysenteriae* type I, and *Vibrio cholerae*) must use EK2 host-vectors.³ A specific example of an experiment with a plant pathogen requiring P2 physical containment+an EK2 host-vector, would be cloning the tumor gene of *Agrobacterium tumefaciens*.

Prokaryotes that do not exchange genetic information with *E. coli*. The minimum containment conditions for this class consist of P2 physical containment+an EK2 host-vector or P3 physical containment+an EK1 host-vector, and apply when the risk that the recombinant DNAs will increase the pathogenicity or ecological potential of the host is judged to be minimal. Experiments with DNAs from pathogenic species (Class 2 ref. 5 plus plant pathogens) must use P3+EK2.

(iii) Characterized clones of DNA recombinants derived from shotgun experiments. When a cloned DNA recombinant has been rigorously characterized⁴ and there is sufficient evidence that it is free of harmful genes,⁴ then experiments involving this recombinant DNA can be carried out under P1+EK1 conditions if the inserted DNA is from a species that exchanges genes with *E. coli*, and under P2+EK1 conditions if not.

** Purified cellular DNAs other than plasmids, bacteriophages, and other viruses.** The formation of DNA recombinants from cellular DNAs that have been enriched⁵ by physical and chemical techniques (i.e., not by cloning) and which are free of harmful genes can be carried out under lower containment conditions than used for the corresponding shotgun experiment. In general, the containment can be decreased one step in physical containment (P4→P3→P2→P1) while maintaining the biological containment specified for the shotgun experiment, or one step in biological containment (EK3→EK2→EK1) while maintaining the specified physical containment—provided that the

See footnotes on p. 38459.

new condition is not less than that specified above for characterized clones from shotgun experiments (Section <a>—III).

<c> *Plasmids, bacteriophages, and other viruses.* Recombinants formed between EK-type vectors and other plasmid or virus DNAs have in common the potential for acting as double vectors because of the replication functions in these DNAs. The containment conditions given below apply only to propagation of the DNA recombinants in *E. coli* K-12 hosts. They do not apply to other hosts where they may be able to replicate as a result of functions provided by the DNA inserted into the EK vectors. These are considered under other host-vector systems.

(1) *Animal viruses.* P4+EK2 or P3+EK3 shall be used to isolate DNA recombinants that include all or part of the genome of an animal virus. This recommendation applies not only to experiments of the "shotgun" type but also to those involving partially characterized subgenomic segments of viral DNAs (for example, the genome of defective viruses, DNA fragments isolated after treatment of viral genomes with restriction enzymes, etc.). When cloned recombinants have been shown by suitable biochemical and biological tests to be free of harmful regions, they can be handled in P3+EK2 conditions. In the case of DNA viruses, harmless regions include the late region of the genome; in the case of DNA copies of RNA viruses, they might include the genes coding for capsid proteins or envelope proteins.

(ii) *Plant viruses.* P3+EK1 or P2+EK2 conditions shall be used to form DNA recombinants that include all or part of the genome of a plant virus.

(iii) *Eukaryotic organelle DNAs.* The containment conditions given below apply only when the organelle DNA has been purified* from isolated organelles. Mitochondrial DNA from primates: P3+EK1 or P2+EK2. Mitochondrial or chloroplast DNA from other eukaryotes: P2+EK1. Otherwise, the conditions given under shotgun experiments apply.

(iv) *Prokaryotic plasmid and phage DNAs.* Plasmids and phage from hosts that exchange genetic information with *E. coli*. Experiments with DNA recombinants formed from plasmids or phage genomes that have not been characterized with regard to presence of harmful genes or are known to contribute significantly to the pathogenicity of their normal hosts must use the containment conditions specified for shotgun experiments with DNAs from the respective host. If the DNA recombinants are formed from plasmids or phage that are known not to contain harmful genes, or from purified* and characterized plasmid or phage DNA segments known not to contain harmful genes, the experiments can be performed with P1 physical containment+an EK1 host-vector.

Plasmids and phage from hosts that do not exchange genetic information with E. coli. The rules for shotgun experiments with DNA from the host apply to their plasmids or phages. The minimum containment conditions for this category (P2+EK2, or P3+EK1) can be used for plasmid and phage, or for purified* and characterized segments of plasmid and phage DNAs, when the risk that the recombinant DNAs will increase the pathogenicity or ecological potential of the host is judged to be minimal.

NOTE: Where applicable, cDNAs (i.e., complementary DNAs) synthesized in vitro from cellular or viral RNAs are included within each of the above classifications. For example, cDNAs formed from cellular RNAs that are not purified and characterized are included under <a>, shotgun experiments; cDNAs formed from purified and

characterized RNAs are included under ; cDNAs formed from viral RNAs are included under <c>; etc.

3. *Experiments with other prokaryotic host-vectors.* Other prokaryotic host-vector systems are at the speculative, planning, or developmental stage, and consequently do not warrant detailed treatment here at this time. However, the containment criteria for different types of DNA recombinants formed with *E. coli* K-12 host-vectors can, with the aid of some general principles given here, serve as a guide for containment conditions with other host-vectors when appropriate adjustment is made for their different habitats and characteristics. The newly developed host-vector systems should offer some distinct advantage over the *E. coli* K-12 host-vectors—for instance, thermophilic organism or other host-vectors whose major habitats do not include humans and/or economically important animals and plants. In general, the strain of any prokaryotic species used as the host is to conform to the definition of Class 1 etiologic agents given in ref. 5 (i.e., "Agents for no or minimal hazard * * *"), and the plasmid or phage vector should not make the host more hazardous. Appendix A gives a detailed discussion of the *B. subtilis* system, the most promising alternative to date.

At the initial stage, the host-vector must exhibit at least a moderate level of biological containment comparable to EK1 systems, and should be capable of modification to obtain high levels of containment comparable to EK2 and EK3. The type of confirmation test(s) required to move a host-vector from an EK2-type classification to an EK3-type will clearly depend upon the preponderant habitat of the host-vector. For example, if the unmodified host-vector propagates mostly in, on, or around higher plants, but not appreciably in warm-blooded animals, modification should be designed to reduce the probability that the host-vector can escape to and propagate in, on, or around such plants, or transmit recombinant DNA to other bacterial hosts that are able to occupy these ecological niches, and it is these lower probabilities which must be confirmed. The following principles are to be followed in using the containment criteria given for experiments with *E. coli* K-12 host-vectors as a guide for other prokaryotic systems. Experiments with DNA from prokaryotes (and their plasmids or viruses) are classified according to whether the prokaryote in question exchanges genetic information with the host-vector or not, and the containment conditions given for these two classes with *E. coli* K-12 host-vectors applied. Experiments with recombinants between plasmid or phage vectors and DNA that extends the range of resistance of the recipient species to therapeutically useful drugs must use P3 physical containment + a host-vector comparable to EK1 or P2 physical containment + a host-vector comparable to EK2. Transfer of recombinant DNA to plant pathogens can be made safer by using nonreverting, doubly auxotrophic, non-pathogenic variants. Experiments using a plant pathogen that affects an element of the local flora will require more stringent containment than if carried out in areas where the host plant is not common.

Experiments with DNAs from eukaryotes (and their plasmids or viruses) can also follow the criteria for the corresponding experiments with *E. coli* K-12 vectors if the major habitats of the given host-vector overlap those of *E. coli*. If the host-vector has a major habitat that does not overlap those of *E. coli* (e.g., root nodules in plants), then the containment conditions for some eukaryotic recombinant DNAs need to be increased (for instance, higher plants and their viruses in

the preceding example) while others can be reduced.

4. *Experiments with eukaryotic host-vectors—<a> Animal host-vector systems.* Because host cell lines generally have little if any capacity for propagation outside the laboratory, the primary focus for containment is the vector, although cells should also be derived from cultures expected to be of minimal hazard. Given good microbiological practices, the most likely mode of escape of recombinant DNAs from a physically contained laboratory is carriage by humans; thus vectors should be chosen that have little or no ability to replicate in human cells. To be used as a vector in a eukaryotic host, a DNA molecule needs to display all of the following properties:

(1) It shall not consist of the whole genome of any agent that is infectious for humans or that replicates to a significant extent in human cells in tissue culture.

(2) Its functional anatomy should be known—that is, there should be a clear idea of the location within the molecule of:

(a) The sites at which DNA synthesis originates and terminates,

(b) The sites that are cleaved by restriction endonucleases,

(c) The template regions for the major gene products.

(3) It should be well studied genetically. It is desirable that mutants be available in adequate number and variety, and that quantitative studies of recombination have been performed.

(4) The recombinant must be defective, that is, its propagation as a virus is dependent upon the presence of a complementing helper genome. This helper should either (a) be integrated into the genome of a stable line of host cells (a situation that would effectively limit the growth of the vector to that particular cell line) or (b) consist of a defective genome or an appropriate conditional lethal mutant virus (in which case the experiments would be done under non-permissive conditions), making vector and helper dependent upon each other for propagation. However, if none of these is available, the use of a non-defective genome as helper would be acceptable.

Currently only two viral DNAs can be considered as meeting these requirements: These are the genomes of polyoma virus and SV40.

Of these, polyoma virus is highly to be preferred. SV40 is known to propagate in human cells, both *in vivo* and *in vitro*, and to infect laboratory personnel, as evidenced by the frequency of their conversion to producing SV40 antibodies. Also, SV40 and related viruses have been found in association with certain human neurological and malignant diseases. SV40 shares many properties, and gives complementation, with the common human papova viruses. By contrast, there is no evidence that polyoma infects humans, nor does it replicate to any significant extent in human cells *in vitro*. However, this system still needs to be studied more extensively. Appendix B gives further details and documentation.

Taking account of all these factors:

1. *Polyoma virus.* a Recombinant DNA molecules consisting of defective polyoma virus genomes plus DNA sequences of any nonpathogenic organism, including Class 1 viruses (5), can be propagated in or used to transform cultured cells. P3 conditions are required. Appropriate helper virus can be used if needed. Whenever there is a choice, it is urged that mouse cells, derived preferably from embryos, be used as the source of eukaryotic DNA. Polyoma virus is a mouse virus and recombinant DNA molecules containing both viral and cellular sequences are already known to be present in virus stocks grown at a high multiplicity. Thus, recombinants formed *in vitro* between polyoma virus DNA

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and mouse DNA are presumably not novel from an evolutionary point of view.

b. Such experiments are to be done under P4 conditions if the recombinant DNA contains segments of the genomes of Class 2 animal viruses (5). Once it has been shown by suitable biochemical and biological tests that the cloned recombinant contains only harmless regions of the viral genome (see Section IIIB-2-c-1) and that the host range of the polyoma virus vector has not been altered, experiments can be continued under P3 conditions.

2. *SV40 Virus*. a. Defective SV40 genomes, with appropriate helper, can be used as a vector for recombinant DNA molecules containing sequences of any non-pathogenic organism or Class I virus (5), (i.e., a shotgun type experiment). P4 conditions are required. Established lines of cultured cells should be used.

b. Such experiments are to be carried out in P3 (or P4) conditions if the non-SV40 DNA segment is (a) a purified* segment of prokaryotic DNA lacking toxigenic genes, or (b) a segment of eukaryotic DNA whose function has been established, which does not code for a toxic product, and which has been previously cloned in a prokaryotic host-vector system. It shall be confirmed that the defective virus-helper virus system does not replicate significantly more efficiently in human cells in tissue culture than does SV40, following infection at a multiplicity of infection of one or more helper SV40 viruses per cell.

c. A recombinant DNA molecule consisting of defective SV40 DNA lacking substantial segments of the late region, plus DNA from non-pathogenic organisms or Class I viruses (5), can be propagated as an autonomous cellular element in established lines of cells under P3 conditions provided that there is no exogenous or endogenous helper, and that it is demonstrated that no infectious virus particles are being produced. Until this has been demonstrated, the appropriate containment conditions specified in 2. a. and 2. b. shall be used.

d. Recombinant DNA molecules consisting of defective SV40 DNA and sequences from non-pathogenic prokaryotic or eukaryotic organisms or Class I viruses (5) can be used to transform established lines of non-permissive cells under P3 conditions. It must be demonstrated that no infectious virus particles are being produced; rescue of SV40 from such transformed cells by co-cultivation or transfection techniques must be carried out in P4 conditions.

3. Efforts are to be made to ensure that all cell lines are free of virus particles and mycoplasma.

Since SV40 and polyoma are limited in their scope to act as vectors, chiefly because the amount of foreign DNA that the normal virions can carry probably cannot exceed 2×10^6 daltons, the development of systems in which recombinants can be cloned and propagated purely in the form of DNA, rather than in the coats of infectious agents is necessary. Plasmid forms of viral genomes or organelle DNA need to be explored as possible cloning vehicles in eukaryotic cells.

 Plant host-vector systems. For cells in tissue cultures, seedlings, or plant parts (e.g., tubers, stems, fruits, and detached leaves) or whole mature plants of small species (e.g., *Arabidopsis*) the P1-P4 containment conditions that we have specified previously are relevant concepts. However, work with most plants poses additional problems.

See footnotes on p. 38459.

The greenhouse facilities accompanying P2 laboratory physical containment conditions can be provided by: (i) Insect-proof greenhouses, (ii) appropriate sterilization of contaminated plants, pots, soil, and runoff water, and (iii) adoption of the other standard practices for microbiological work. P3 physical containment can be sufficiently approximated by confining the operations with whole plants to growth chambers like those used for work with radioactive isotopes: *Provided*, That (i) such chambers are modified to produce a negative pressure environment with the exhaust air appropriately filtered, (ii) that other operations with infectious materials are carried out under the specified P3 conditions, and (iii) to guard against inadvertent insect transmission of recombinant DNA, growth chambers are to be routinely fumigated and only used in insect proof rooms. The P2 and P3 conditions specified earlier are therefore extended to include these cases for work on higher plants.

The host cells for experiments on recombinant DNAs may be cells in culture, in seedling or plant parts. Whole plants or plant parts that cannot be adequately contained shall not be used as hosts for shotgun experiments at this time, and attempts to infect whole plants with recombinant DNA shall not be initiated until the effects on host cells in culture, seedlings or plant parts have been thoroughly studied.

Organelle or plasmid DNAs and DNAs of viruses of restricted host range may be used as vectors. In general, similar criteria for selecting host-vectors to those given in the preceding section on animal systems are to apply to plant systems.

DNA recombinants formed between the initial moderately contained vectors and DNA from cells of species in which the vector DNA can replicate, require P2 physical containment. However, if the source of the NA is itself pathogenic or known to carry pathogenic agents, or to produce products dangerous to plants, or if the vector is an unmodified virus of unrestricted host range, the experiments shall be carried out under P3 conditions.

Experiments on recombinant DNAs formed between the above vectors and DNAs from other species can also be carried out under P2 if that DNA has been purified* and determined not to contain harmful genes. Otherwise, the experiments shall be carried out under P3 conditions if the source of the inserted DNA is not itself a pathogen, or known to carry such pathogenic agents, or to produce harmful products—and under P4 conditions if these conditions are not met.

The development and use of host-vector systems that exhibit a high level of biological containment permit a decrease of one step in the containment specified above (P4→P3→P2→P1).

<c> *Fungal or similar lower eukaryotic host-vector systems.* The containment criteria for experiments on recombinant DNAs using these host-vectors most closely resemble those for prokaryotes, rather than those for the preceding eukaryotes, in that the host cells usually exhibit a capacity for dissemination outside the laboratory that is similar to that for bacteria. We therefore consider that the containment guidelines given for experiments with *E. coli* K-12 and other prokaryotic host-vectors (Sections IIIB-1 and -2, respectively) provide adequate direction for experiments with these lower eukaryotic host-vectors. This is particularly true at this time since the development of these host-vectors is presently in the speculative stage.

IV. ROLES AND RESPONSIBILITIES

Safety in research involving recombinant DNA molecules depends upon how the research team applies these guidelines. Motivation and critical judgment are necessary, in addition to specific safety knowledge, to ensure protection of personnel, the public, and the environment.

The guidelines given here are to help the principal investigator determine the nature of the safeguards that should be implemented. These guidelines will be incomplete in some respects because all conceivable experiments with recombinant DNAs cannot now be anticipated. Therefore, they cannot substitute for the investigator's own knowledgeable and discriminating evaluation. Whenever this evaluation calls for an increase in containment over that indicated in the guidelines, the investigator has a responsibility to institute such an increase. In contrast, the containment conditions called for in the guidelines should not be decreased without review and approval at the institutional and NIH levels.

The following roles and responsibilities define an administrative framework in which safety is an essential and integrated function of research involving recombinant DNA molecules.

A. *Principal investigator.* The principal investigator has the primary responsibility for: (i) Determining the real and potential biohazards of the proposed research, (ii) determining the appropriate level of biological and physical containment, (iii) selecting the microbiological practices and laboratory techniques for handling recombinant DNA materials, (iv) preparing procedures for dealing with accidental spills and overt personnel contamination, (v) determining the applicability of various precautionary medical practices, serological monitoring, and immunization, when available, (vi) securing approval of the proposed research prior to initiation of work, (vii) submitting information on purported EK2 and EK3 systems to the NIH Recombinant DNA Molecule Program Advisory Committee and making the strains available to others, (viii) reporting to the institutional biohazards committee and the NIH Office of Recombinant DNA Activities new information bearing on the guidelines, such as technical information relating to hazards and new safety procedures or innovations, (ix) applying for approval from the NIH Recombinant DNA Molecule Program Advisory Committee for large scale experiments with recombinant DNAs known to make harmful products (i.e., more than 10 liters of culture), and (x) applying to NIH for approval to lower containment levels when a cloned DNA recombinant derived from a shotgun experiment has been rigorously characterized and there is sufficient evidence that it is free of harmful genes.

Before work is begun, the principal investigator is responsible for: (i) Making available to program and support staff copies of those portions of the approved grant application that describe the biohazards and the precautions to be taken, (ii) advising the program and support staff of the nature and assessment of the real and potential biohazards, (iii) instructing and training this staff in the practices and techniques required to ensure safety, and in the procedures for dealing with accidentally created biohazards, and (iv) informing the staff of the reasons and provisions for any advised or requested precautionary medical practices, vaccinations, or serum collection.

During the conduct of the research, the principal investigator is responsible for: (i)

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Supervising the safety performance of the staff to ensure that the required safety practices and techniques are employed, (ii) investigating and reporting in writing to the NIH Office of Recombinant DNA Activities and the institutional biohazards committee any serious or extended illness of a worker or any accident that results in (a) inoculation of recombinant DNA materials through cutaneous penetration, (b) ingestion of recombinant DNA materials, (c) probable inhalation of recombinant DNA materials following gross aerosolization, or (d) any incident causing serious exposure to personnel or danger of environmental contamination, (iii) investigating and reporting in writing to the NIH Office of Recombinant DNA Activities and the institutional biohazards committee any problems pertaining to operation and implementation of biological and physical containment safety practices and procedures, or equipment or facility failure, (iv) correcting work errors and conditions that may result in the release of recombinant DNA materials, and (v) ensuring the integrity of the physical containment (e.g., biological safety cabinets) and the biological containment (e.g., genotypic and phenotypic characteristics, purity, etc.).

B. *Institution*. Since in almost all cases, NIH grants are made to institutions rather than to individuals, all the responsibilities of the principal investigator listed above are the responsibilities of the institution under the grant, fulfilled on its behalf by the principal investigator. In addition, the institution is responsible for establishing an institutional biohazards committee¹ to: (i) Advise the institution on policies, (ii) create and maintain a central reference file and library of catalogs, books, articles, newsletters, and other communications as a source of advice and reference regarding, for example, the availability and quality of the safety equipment, the availability and level of biological containment for various host-vector systems, suitable training of personnel and data on the potential biohazards associated with certain recombinant DNAs, (iii) develop a safety and operations manual for any P4 facility maintained by the institution and used in support of recombinant DNA research, (iv) certify to the NIH on applications for research support and annually thereafter, that facilities, procedures, and practices and the training and expertise of the personnel involved have been reviewed and approved by the institutional biohazards committee.

The biohazards committee must be sufficiently qualified through the experience and expertise of its membership and the diversity of its membership to ensure respect for its advice and counsel. Its membership should include individuals from the institution or consultants, selected so as to provide a diversity of disciplines relevant to recombinant DNA technology, biological safety, and engineering. In addition to possessing the professional competence necessary to assess and review specific activities and facilities, the committee should possess or have available to it, the competence to determine the acceptability of its findings in terms of applicable laws, regulations, standards of practices, community attitudes, and health and environmental considerations. Minutes of the meetings should be kept and made available for public inspection. The institution is responsible for reporting names of and relevant background information on the members of its biohazards committee to the NIH.

C. *NIH Initial Review Groups (Study Sections)*. The NIH Study Sections, in addition

to reviewing the scientific merit of each grant application involving recombinant DNA molecules, are responsible for: (i) Making an independent evaluation of the real and potential biohazards of the proposed research on the basis of these guidelines, (ii) determining whether the proposed physical containment safeguards certified by the institutional biohazards committee are appropriate for control of these biohazards, (iii) determining whether the proposed biological containment safeguards are appropriate, (iv) referring to the NIH Recombinant DNA Molecule Program Advisory Committee or the NIH Office of Recombinant DNA Activities those problems pertaining to assessment of biohazards or safeguard determination that cannot be resolved by the Study Sections.

The membership of the Study Sections will be selected in the usual manner. Biological safety expertise, however, will be available to the Study Sections for consultation and guidance.

D. *NIH Recombinant DNA Molecule Program Advisory Committee*. The Recombinant DNA Molecule Program Advisory Committee advises the Secretary, Department of Health, Education, and Welfare, the Assistant Secretary for Health, Department of Health, Education, and Welfare, and the Director, National Institutes of Health, on a program for the evaluation of potential biological and ecological hazards of recombinant DNAs (molecules resulting from different segments of DNA that have been joined together in cell-free systems, and which have the capacity to infect and replicate in some host cell, either autonomously or as an integrated part of their host's genome), on the development of procedures which are designed to prevent the spread of such molecules within human and other populations, and on guidelines to be followed by investigators working with potentially hazardous recombinants.

The NIH Recombinant DNA Molecule Program Advisory Committee has responsibility for: (i) Revising and updating guidelines to be followed by investigators working with DNA recombinants, (ii) for the time being, receiving information on purported EK2 and EK3 systems and evaluating and certifying that host-vector systems meet EK2 or EK3 criteria, (iii) resolving questions concerning potential biohazard and adequacy of containment capability if NIH staff or NIH Initial Review Group so request, and (iv) reviewing and approving large scale experiments with recombinant DNAs known to make harmful products (e.g., more than 10 liters of culture).

E. *NIH Staff*. NIH Staff has responsibility for: (i) assuring that no NIH grants or contracts are awarded for DNA recombinant research unless they (a) conform to these guidelines, (b) have been properly reviewed and recommended for approval, and (c) include a properly executed Memorandum of Understanding and Agreement, (ii) reviewing and responding to questions or problems or reports submitted by institutional biohazards committees or principal investigators, and disseminating findings, as appropriate, (iii) receiving and reviewing applications for approval to lower containment levels when a cloned DNA recombinant derived from a shotgun experiment has been rigorously characterized and there is sufficient evidence that it is free of harmful genes, (iv) referring items covered under (ii) and (iii) above to the NIH Recombinant DNA Molecule Program Advisory Committee, as deemed necessary, and (v) performing site inspections of all P4 physical containment facilities, engaged in DNA recombinant research, and of other facilities as deemed necessary.

APPENDIX D

V. FOOTNOTES

¹ Biological Safety Cabinets referred to in this section are classified as *Class I*, *Class II* or *Class III* cabinets. A *Class I* cabinet is a ventilated cabinet for personnel protection having an inward flow of air away from the operator. The exhaust air from this cabinet is filtered through a high efficiency or high efficiency particulate air (HEPA) filter before discharged to the outside atmosphere. This cabinet is used in three operational modes: (1) with an 8 inch high full width open front, (2) with an installed front closure panel (having four eight inch diameter openings) without gloves, and (3) with an installed front closure panel equipped with arm length rubber gloves. The face velocity of the inward flow of air through the full width open front is 75 feet per minute or greater. A *Class II* cabinet is a ventilated cabinet for personnel and product protection having an open front with inward air flow for personnel protection, and HEPA filtered mass recirculated air flow for product protection. The cabinet exhaust air is filtered through a HEPA filter. The face velocity of the inward flow of air through the full width open front is 75 feet per minute or greater. Design and performance specifications for *Class II* cabinets have been adopted by the National Sanitation Foundation, Ann Arbor, Michigan. A *Class III* cabinet is a closed front ventilated cabinet of gas tight construction which provides the highest level of personnel protection of all Biohazard Safety Cabinets. The interior of the cabinet is protected from contaminants exterior to the cabinet. The cabinet is fitted with arm length rubber gloves and is operated under a negative pressure of at least 0.5 inches water gauge. All supply air is filtered through HEPA filters. Exhaust air is filtered through HEPA filters or incinerated before being discharged to the outside environment.

² Defined as observable under optimal laboratory conditions by transformation, transduction, phage infection and/or conjugation with transfer of phage, plasmid and/or chromosomal genetic information.

³ The bacteria which constitute Class 2 of ref. 5 ("Agents of ordinary potential hazard...") represent a broad spectrum of etiologic agents which possess different levels of virulence and degrees of communicability. We think it appropriate for our specific purpose to further subdivide the agents of Class 2 into those which we believe to be of relatively low pathogenicity and those which are moderately pathogenic. The several specific examples given may suffice to illustrate the principle.

⁴ The terms "characterized" and "free of harmful genes" are unavoidably vague. But in this instance, before containment conditions lower than the ones used to clone the DNA can be adopted, the investigator must obtain approval from the National Institutes of Health. Such approval would be contingent upon data concerning: (a) The absence of potentially harmful genes (e.g., sequences contained in indigenous tumor viruses or which code for toxic substances), (b) the relation between the recovered and desired segment (e.g., hybridization and restriction endonuclease fragmentation analysis where applicable), and (c) maintenance of the biological properties of the vector.

⁵ A DNA preparation is defined as enriched if the desired DNA represents at least 99% (w/w) of the total DNA in the preparation. The reason for lowering the containment level when this degree of enrichment has been obtained is based on the fact that the total number of clones that must be examined to obtain the desired clone is

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markedly reduced. Thus, the probability of cloning a harmful gene could, for example, be reduced by more than 10⁶-fold when a non-repetitive gene from mammals was being sought. Furthermore, the level of purity specified here makes it easier to establish that the desired DNA does not contain harmful genes.

*The DNA preparation is defined as purified if the desired DNA represents at least 99 percent (w/w) of the total DNA in the preparation, provided that it was verified by more than one procedure.

*In special circumstances, in consultation with the NIH Office of Recombinant DNA Activities, an area biohazards committee may be formed, composed of members from the institution and/or other organizations beyond its own staff, as an alternative when additional expertise outside the institution is needed for the indicated reviews.

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APPENDIX A TO APPENDIX D

STATEMENT ON THE USE OF *BACILLUS SUBTILIS* IN RECOMBINANT MOLECULE TECHNOLOGY

Unquestionably, *Escherichia coli* is the most well characterized unicellular organism. Years of basic research have enabled investigators to develop a well characterized genetic map, to obtain detailed knowledge of virulent and temperate bacteriophages, and to explore the physiology, genetics, and regulation of plasmids. More recently, the development of DNA-mediated transformation has permitted exogenous fragments or molecules of DNA to be incorporated into the genome or to reside as self-replicating units. The discovery of transformation of *Bacillus subtilis* by Spizizen (1) stimulated the development of an alternative model system. The purpose of this report is to summarize the current status of this genetic system and to describe the actual and potential vectors and vehicles available for recombinant molecule technology.

A. Current knowledge of the chromosomal architecture and mechanisms of genetic exchange in *B. subtilis*. Two mechanisms of genetic exchange have been utilized to establish the linkage map of *B. subtilis*, DNA-mediated transformation (capable of transferring approximately 1 percent of the genome) and transduction with bacteriophage PBS1 (capable of transferring 5-8 percent of the chromosome). Recent detailed genetic studies with PBS1 by Lepesant-Kejzlorova *et al.* (2) have resulted in the development of a circular genetic map for this organism. The current edition of the map (3) contains 196 loci. Biophysical analyses have established that the chromosome is circular (4) and replicates bidirectionally (5).

Transformation with purified fragments of DNA is a highly efficient process in *B. subtilis* with frequencies of 1 to 4 percent usually attained for any auxotrophic or antibiotic resistance markers. Frequencies of approximately 10 percent transformation can be achieved with DNA prepared from gently lysed L-forms or protoplasts (6). These large fragments of DNA are readily incorporated by the recipient cell. Generalized transduc-

tion occurs with bacteriophages SP10 (7), PBS1 (8), and SPP1 (9), while a low frequency of specialized transduction has been reported with bacteriophage ϕ 105 (10).

Although transformation is most efficient in homologous crosses (*B. subtilis* into *B. subtilis*), it has also been possible to exchange DNA among closely related species (11). The most extensively studied members of the *B. subtilis* genospecies include *B. licheniformis*, *B. pumilus*, *B. amyloliquefaciens*, and *B. globigii* (refer to reference 12 for a review and references 13-15 for examples of this heterologous exchange). This exchange occurs even though there is a surprisingly wide discrepancy between DNA-DNA hybridization among these organisms (16). Even though the frequency of transformation is low in the heterologous cross [e.g., *B. amyloliquefaciens* (donor)/*B. subtilis* (recipient)], the newly acquired DNA from *B. amyloliquefaciens* in the *B. subtilis* background can be readily transferred at high efficiencies to other recipient strains of *B. subtilis* (14). Therefore, the extremely high frequency of transformation permits the recognition and selection of rare events.

B. Current and potential vectors for recombinant molecule experiments. Lovett and coworkers have recently described cryptic plasmids in *B. pumilus* (17) and *B. subtilis* (18). Of these organisms, *B. subtilis* ATCC 7003 appears to be the most useful since it carries one to two copies of a plasmid with a molecular weight of 46×10^6 . This strain is also closely related to *B. subtilis* 168. Another strain of *B. subtilis* (ATCC 15841) contains 16 copies of a plasmid with a molecular weight of 4.6×10^6 . Currently it is not known whether genetic markers can be readily introduced into these plasmids. To date it has not been possible to readily stabilize plasmids derived from *B. pumilus* in *B. subtilis* even with heavy selective pressure (P. Lovett, personal communication).

Two temperate bacteriophages are under development as vectors in *B. subtilis*, ϕ 3T and SPO2. Lysogeny of thymine auxotrophs (strains carrying *thyA thyB*) by bacteriophage ϕ 3T results in "conversion" to a *Thy*⁺ phenotype. The attachment site for this bacteriophage and the bacteriophage gene for thymidylate synthetase (*thyP*) map between the bacterial *thyA* and *thyB* loci in the terminal region of the chromosome of *B. subtilis* (19). The viral genome is readily cleaved by the site-specific endonuclease, Bam 1 (20), to produce 5 fragments (one of which carries the *thyP* gene). The *thyP* carrying gene can be integrated into the bacterial genome in the absence of the intact viral genome. Because deletions are available that include the *thyP* region, it is theoretically possible to introduce *thyP* at many sites on the chromosome. The *thyP* gene can be readily purified for insertion into plasmids or utilized as a scaffold to integrate other heterologous DNA into the chromosome of *B. subtilis*. Alternatively, it is possible to purify fragments of the chromosome by gel electrophoresis (21, 22), for insertion into bacteriophage ϕ 3T or SPO2. At present, unfortunately, only the former carries a selective marker, i.e., the gene for thymidylate synthetase, *thyP*.

C. Development of vehicles. *B. subtilis* is a Gram-positive sporulating rod that usually inhabits soil. Although it can exist on cutaneous surfaces of man (23) and experimental animals, it rarely produces disease. To develop a suitable vehicle it is imperative to have a host that is asporogenic. The most appropriate deletion mutation is deletion 29 (cit D). In addition to a deficiency in sporulation this mutant rapidly lyses when it has reached the end of its growth cycle. Presumably this is due to the failure to inactivate one of the autolytic enzymes (24).

Through the introduction of a D-alanine requirement (34 ug/ml) it is possible to block transport of compounds that are transported by active transport (25,26). The further introduction of thymine auxotrophy (defects in the *thyA thyB* loci) will enable the strain to survive only with a plasmid vector carrying the purified *thyP* gene from bacteriophage ϕ 3T or a defective bacteriophage ϕ 3T carrying the *thyP* gene but attached to the chromosome at an alternative site (due to the presence of deletion 29 in the host). We have recently isolated temperature-sensitive *thyP* mutants. If we can isolate a temperature-dependent lysogen that will grow only at 48°C it should be possible to make an unusual vehicle.

D. Site-specific endonucleases. Recently two restriction modification systems have been observed between *B. subtilis* 168 and other bacilli. Trautner *et al.* have isolated an effective system that inhibits infection of the R strain of *B. subtilis* by bacteriophage SPP1 propagated on *B. subtilis* 168 (27). The site-specific nuclease recognizes the sequence GGCC.

CCGG

Young, Radnay, and Wilson observed a restriction modification system between *B. amyloliquefaciens* and *B. subtilis* 168 (28). The endonuclease from *B. amyloliquefaciens* (20) recognizes the sequence GGTAC (29).

CCTAGG

More recently, two additional enzymes have been isolated from *B. globigii* (30). The recognition sequence is not known.

E. Advantages and liabilities of the *B. subtilis* system—a. Advantages. 1. *B. subtilis* is nonpathogenic. Asporogenic deletion mutants are available to preclude the problem of persistence through sporulation.

2. The circular chromosomal map is well defined. At least 196 loci have been positioned.

3. The organism is commercially important in the fermentation industry.

4. Large numbers of organisms can be disposed of readily with minimal environmental impact.

5. Unlike *E. coli*, it lacks endotoxin in the cell wall. Therefore the cells can be used as a single cell protein source.

6. The frequency of transformation is very high, facilitating the detection of rare events.

7. A unique bacteriophage, ϕ 3T, exists that carries a gene that can be readily purified for "scaffolding" experiments.

b. Disadvantages. 1. The knowledge of genetics and physiology of plasmids and viruses is primitive compared with *E. coli*.

2. High-frequency, specialized transduction is not available as a means of gene enrichment.

Based on its promise, it seems appropriate, and not chauvinistic, to urge development of this system.

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- ### APPENDIX B TO APPENDIX D
- #### POLYOMA AND SV40 VIRUS
- Polyoma virus is a virus of mice, and infection of wild mouse populations is a common event, for the virus has often been isolated from a high proportion of healthy adult animals, both wild and laboratory bred, of many colonies (Gross, L., *Proc. Soc. Exp. Biol.* 88, 362-368, 1955; Rowe, W. P., *Bact. Rev.* 25, 18-31, 1961). As far as is known the virus almost never causes a disease in these animals. However, when large quantities of the virus are inoculated into newborn or suckling mice or hamsters, a variety of solid tumors is induced (Gross, L., *Oncogenic Viruses*, Second Edition, Pergamon Press, NY).
- Polyoma virus grows lytically in mouse cells in tissue culture. Thus mouse cells in culture are probably transformed only by virus particles that contain certain kinds of defective genomes. Cells of other rodent species, however, can be transformed by polyoma virus particles that contain complete genomes (Folk, W., *J. Virol.* 11, 424-431, 1973). The virus does not replicate to a significant extent in human cells in tissue culture (Eddy, B.E., *Virol. Monogr.* 7, 1-114, 1969; Pollack, R. E., Salas, J., Wang R. Kusano T., and Green, H., *J. Cell Physiol.* 77, 117-120, 1971). The resistance of the cells seems to be a consequence of the failure of the virus to absorb or uncoat. However even when naked viral DNA is introduced into the cells only an abortive cycle of replication ensues; early viral proteins are made, there is induction of cellular DNA synthesis, but no expression of late viral proteins is detectable (Gruen, R., Grassmann, M. and Grassmann, A. *Virology*, 58, 290-293, 1974).
- There is no evidence that polyoma virus can infect humans (Hartley, J., Huebner, R., Parker, J. and Rowe, W. P., unpublished data). Thus no antibodies to the virus have been detected in people living in buildings that are infested with virus-infected mice, nor in laboratory workers who have been exposed to the virus for a number of years.
- At most, a small segment of polyoma virus DNA shows weak homology with a portion of the late region of SV40 DNA (Ferguson, J. and Davis, R. W., *J. Mol. Biol.* 94, 135-150, 1975). However, there appears to be no genetic interaction between the two viruses and there is no immunological cross-reaction between the gene products of the two viruses.
- SV40 causes persistent but apparently harmless infections of the kidneys of virtually all adult rhesus monkeys (Hsiung, G. D., *Bact. Revs.* 32, 185-205, 1968), it causes tumors when injected into newborn hamsters (Girardi, A. J., Sweet, B. H., Slotnick, V. B. and Hillemann, M. R., *Proc. Soc. Exp. Biol. Med.*, 105, 420-427, 1964) and transforms cells of several mammalian species (including human). SV40 is able to infect humans since antibodies to the virus are found in a small proportion of the human population (Shah, K. V., Goverdhan, M. K. and Ozer, H. L., *Am. J. Epid.* 93, 291-298, 1970) and serum conversions have been noted in many laboratory personnel who have been exposed to the virus (Horvath, L. B., *Acta Microbiol. Acta Sci. Hung.* 12, 201-206, 1965).
- Isolations of SV40 have been reported from humans, twice from patients suffering from the rare demyelinating disease, progressive multifocal leukoencephalopathy (Weiner, L., Herndon, R., Narayan, O., Johnson, R. T., Shah, K., Rubinstein L. G. Preziosi T. J. and Conley, F. K., *New England J. Med.* 286, 385-390, 1972) and apparently from a tumor of a person with metastatic melanoma (Soriano, F., Shelburne, C. E. and Gokcen, M., *Nature*, 249, 421-424, 1974). In other studies a non-structural antigen characteristic of papovaviruses, T antigen, has been detected in the nuclei of cells cultured from 2 meningiomas, while another SV40-specific antigen, U antigen, has been found in the cells of a third tumor of the same type (Weiss, A. F., Portman, R., Fisher, H., Simon, J. and Zang, K. D., *Proc. Nat. Acad. Sci. USA* 72, 609-613, 1975). Furthermore new papovaviruses have been isolated from the brains of patients with PML (JC virus-Padgett, B. L., Walker, D. L., zur Rhein, G. M., Eckroade, R. I. and Dessel, B. H., *Lancet* 1, 1257-1260, 1971), from the urine of a patient carrying a renal allograft (BK virus-Gardner, S. D., Field, A. M., Coleman, D. V. and Hulme, B. *Lancet* 1, 1253-1257, 1971) and from a reticulum cell sarcoma and the urine of patients with the sex-linked recessive disorder, Wiskott-Aldrich syndrome (Takemoto, K. K., Rabson, A. S., Mullarkey, M. F., Blaese, R. M. Garon, C. F. and Nelson, D. J., *Nat. Cancer Inst.*, 53, 1205-1207, 1974). All of these viruses which are distributed widely throughout human populations share antigenic and biological properties with SV 40; the virus particles are identical in size and architecture (Madeley, C. R., In *Virus Morphology*, Churchill-Livingstone, London, 134-135, 1972); the non-structural intracellular T antigen, which appears to be coded by the A gene of SV40 cross reacts extensively with antigens found in cells infected or transformed by BK or JC viruses; both JC and BK viruses induce tumors in newborn hamsters (Walter, D. L., Padgett, B. L., zur Rhein, B. M., Albert, A. E. and Marsh, R. F., *Science* 181, 674-676, 1973; Shah, K. V., Daniel, R. W. and Strandberg, J., *J. Nat. Cancer Inst.* 54, 945-950, 1975); BK virus causes transformation of hamster cells in culture (Major, E. D., and DiMayorca, G., *Proc. Nat. Acad. Sci. US* 70, 3210-3212, 1973; Portolani, M., Barbanti, A., Brodano, G. and LaPlaca, M.J., *Virol.* 15, 420-422, 1975) and is able to complement the growth of certain temperature-sensitive mutants of SV40 (Mason, D. H. and Takemoto, K. K., submitted for publication).
- #### FURTHER WORK
- At present, a potential eukaryotic vector of choice is polyoma virus. And while available information indicates that it fulfills all the necessary criteria, we recommend that the following subjects be further investigated:
1. The molecular mechanism of resistance of human cells to the virus.
 2. The extent of homology between polyoma virus DNA and the DNAs of human papovaviruses.
 3. The ability of human papovaviruses to complement defective polyoma virus genomes.
- Report of a Working Group Consisting of:
 Dr. Bernard Fields, Harvard University School of Medicine.
 Dr. Thomas J. Kelly, Jr., Johns Hopkins University School of Medicine.
 Dr. Andrew Lewis, National Institute of Allergy and Infectious Diseases.
 Dr. Malcolm Martin, National Institute of

Allergy and Infectious Diseases.

Dr. Robert Martin, National Institute of Arthritis, Metabolism, and Digestive Diseases.

Dr. Elmer Pfefferkorn, Dartmouth Medical School.

Dr. Wallace P. Rowe, National Institute of Allergy and Infectious Diseases.

Dr. Aaron Shatkin, Roche Institute of Molecular Biology.

Dr. Maxine Singer, National Cancer Institute.

Rapporteur: Dr. Joe Sambrook, Cold Spring Harbor Laboratory.

APPENDIX C TO APPENDIX D

SUMMARY OF THE WORKSHOP ON THE DESIGN AND TESTING OF SAFER PROKARYOTIC VEHICLES AND BACTERIAL HOSTS FOR RESEARCH ON RECOMBINANT DNA MOLECULES

Torrey Pines Inn, La Jolla, California

The development of techniques for the cloning of DNA from both prokaryotic and eukaryotic organisms in bacteria has had great impact on research in biology and medicine and promises extraordinary social benefits. The biohazards involved in the use of this technology in many instances are very difficult to assess. For this reason codes of practice are being formulated in the United States and other countries for the conduct of those experiments that present a potential biohazard. One of the requirements for conducting certain cloning experiments is the use of safer vector (bacteriophage or plasmid) -host systems, i.e., vector-bacterium systems that have restricted capacity to survive outside of controlled conditions in the laboratory. Approximately sixty scientists from the United States and several foreign countries participated in a workshop on the Design and Testing of Safer Prokaryotic Vehicles and Bacterial Hosts for Research on Recombinant DNA Molecules at La Jolla, California, on December 1 to 3, 1975. The workshop was sponsored by the Research Resources Branch of the National Institute of Allergy and Infectious Diseases. The purposes of the meeting were the exchange of recent data on the development of safer prokaryotic host-vector systems, devising methods of testing the level of containment provided by these systems and exploring the various directions that future research should take in the construction of safer bacterial systems for the cloning of foreign DNA.

The first session of the workshop, chaired by W. Szybalski (University of Wisconsin), was devoted to bacteriophage vectors. Szybalski outlined the main safety features of the two-component, phage-bacterial system, in which the host bacteria offer the safety feature of not carrying the cloned DNA, and the phage vectors cannot be propagated in the absence of an appropriate host. There are two primary escape routes for the clones of foreign DNA carried by the phage vector: (1) Establishment of a stable prophage or plasmid in the laboratory host used for phage propagation, and subsequent escape of this self replicating lysogen or carrier system, and (2) escape of the phage vector which carries the cloned DNA and its subsequent productive encounter with a suitable host in the natural environment. The general consensus was that to ensure safety, both routes should be blocked by appropriate genetic modifications. For phage λ , route (1) can be blocked by phage mutations that interfere with lysogenization (*att*-, *int*-, *cI*-, *cIII*-, *vir*) and plasmid formation (*N*-, *ninR*-, *vS*-, *ri*-, *cI7*-, *Ots*-, *crots*), and by mutations on the *Escherichia coli* host that affect these processes (*attB*-, *dncA*ts) and host survival. Route (2), (which is of low probability since λ phages do not survive well in natural environments (no λ cI phage was recovered after ingestion of 10^8 - 10^{11} particles), are killed by desicca-

tion, and have a low chance to encounter a naturally sensitive host) can be blocked further by the following phage modifications: (a) Mutations which result in extreme instability of the infectious phage particles under all conditions other than those specially designed for phage propagation in the laboratory (e.g., high concentrations of putrescine or some other compound), or (b) employing phage vectors in which the tail genes are deleted and which permit propagation of only the DNA-packed heads; only under laboratory conditions could such heads be made transiently infectious by rejoining them with separately prepared tails. The high instability of the phage would minimize the possibility of transfer of the cloned genes into receptive bacteria found in nature. Moreover, the propagation of the phage can be blocked by many conditional mutations, which would be designed to block any secondary route of escape, mainly depending on transfer of the cloned DNA into another phage or bacterial host. It was recommended further that the vector be designed in such a manner as to permit easy insertion and monitoring of the foreign DNA and rapid assay of the safety features and give a high yield of cloned DNA (not less than 10^{11} molecules per ml). There also was general agreement that host-phage systems other than *E. coli* should be considered, especially those restricted to very rare and unusual environments. Also, plasmids derived from phage vectors and which give very high DNA yields while exhibiting safety features, e.g., λ dv crots, should be considered as vehicles for cloned DNA.

Szybalski and S. Brenner (Cambridge University) stressed that research on recombinant DNA molecules may lend itself to very simple and inexpensive mechanical containment, e.g., a small sealed glove box, since all the vectors that carry such recombinant molecules possibly can be both created and destroyed in such a box, while development of special methods might permit study of many properties of the recombinant DNA, without ever removing it from the box.

These safety features were reflected in the subsequent presentations. F. Blattner and W. Williams (University of Wisconsin) described four specially constructed λ - ϕ 80 phages which incorporate many of these safety features, and which they named Charon phages, for the mythical boatman of the river Styx. Some of these highly contained phages give yields of over 10^{11} particles/ml. R. Davis, J. Cameron and K. Struhl (Stanford University) found that λ phages that carry foreign DNA never grow as well as the parental vector, which would select against their survival in nature. They also reported that some eukaryotic genes could be expressed in *E. coli*, partially compensating for deficiencies in the histidine pathway or in *polA* or *lig* functions. These investigators surveyed over 1000 strains of *E. coli* isolated in the natural environment and did not find a single strain that could support propagation of the λ vir vector.

V. Bode (Kansas State University) discussed the possibility of growing tail-free λ heads. Such heads, which are packed with DNA, are very fragile, unless stored in 0.1 M putrescine buffer. Head yields close to 10^{11} /ml could easily be attained and, when required, heads could be quantitatively rejoined with separately supplied tails under special laboratory conditions. W. Arber, D. Scandella and J. Elliott (University of Basel) described bacterial host mutants that permit efficient infection only by phages with a full complement of DNA. This permits selecting for vectors that carry long fragments of foreign DNA.

K. Matsubara, T. Mukai and Y. Takagi (University of Osaka and Kyushu Univer-

sity), and G. Hobom and P. Philippesen (University of Freiburg and Stanford University) described various defective λ plasmids (λ dv) that could be used as efficient vectors. Matsubara has shown that temperature-sensitive *cro* mutations permit obtaining between 1000 and 3000 cloned molecules per cell and at the same time result in killing of the carrier cells at body temperature. The mutations *Ots* and *Pts* were also evaluated as safety features. Philippesen described many new λ dv plasmids created by cutting λ DNA with *HindIII* and *BamI* restriction endonucleases followed by ligation. The final talk by F. Young, G. Wilson and M. Williams (University of Rochester) summarized the progress on the development of safer *Bacillus subtilis* host mutants and phages, especially ϕ 3, as vectors. New restriction nucleases, *Bgl-1* and *Bgl-2*, were also described.

The morning session on bacteriophage vectors was followed by a session on plasmid vectors that was chaired by D. Helinski (University of California, San Diego). Helinski presented the following properties as highly desirable characteristics of a safer plasmid vehicle: (a) Non-conjugative; (b) non-mobilizable or poorly mobilizable by a conjugative plasmid; (c) possesses little or no extraneous genetic information; (d) poorly recombines or does not recombine with the chromosome of the host cell; (e) provides no selective advantage to the host cell or the selective property is conditional; and (f) possesses mutations that restrict its maintenance to a specific host, prevent replication at mammalian body temperature and/or provide with the capability of killing any cell to which it might be transmitted other than the host cell. V. Hersfield (University of California, San Diego) described the properties of a variety of derivatives of the ColE1 derivatives, ColE1-*trp*, constructed in collaboration with C. Yanofsky and N. Franklin (Stanford University) provides the means to use the tryptophan genes of *E. coli* as a selective marker in transformation with recombinant DNA in situations where it is desirable to avoid antibiotic resistance genes. In addition, Hersfield described collaborative work with H. Boyer that resulted in the development of a mini-ColE1 plasmid and derivatives of this plasmid (mini-ColE1-*kan* and mini-ColE1-*trp*) as cloning vehicles. Finally, she described the temperature-sensitivity properties of *trp* and *kan* derivatives of a temperature-sensitive replication mutant of ColE1 isolated by J. Collins (Molecular Biology Institute, Stockholm) and hybrid ColE1 plasmids carrying the *EcoRI* generated *Cts* fragment of bacteriophage λ -*trp*61.

J. Carbon (University of California, Santa Barbara) described a replica plating method that greatly facilitates the detection of *E. coli* clones bearing ColE1 plasmids. The procedure, which utilizes the *F*₁ plasmid to promote the transfer of a hybrid ColE1 plasmid to a suitable auxotrophic recipient, was successful in identifying clones bearing hybrid plasmids carrying a number of different regions of the *E. coli* chromosome. The contributions of A. J. Clark and collaborators (University of California, Berkeley) were relevant to the problem of the mobilization and subsequent transfer of non-conjugative plasmids carrying foreign DNA of a potentially hazardous nature. Clark described the variations in transmission frequencies between the nonconjugative plasmids pSC101, pML31, pSC138 and a number of pSC101 hybrids containing various *EcoRI* fragments of *F* when the conjugal transfer of these plasmids was promoted by several different conjugative plasmids.

I. C. Gunsalus and collaborators (University of Illinois) and A. Chakrabarty (General Electric Research and Development Center)

described the properties of a variety of plasmids isolated from *Pseudomonas putida*. These contributions were followed by a discussion on the merits of developing plasmid-host systems involving *Pseudomonas* strains that naturally exhibit unusual growth requirements. Similar studies with plasmids isolated from *Bacillus megaterium* by B. Carlton (University of Georgia) from *B. subtilis* by P. Lovett (University of Maryland) and other naturally occurring *Bacillus* species by W. Goebel and K. Bernhard (Microbiology Institute, Wurzburg) were discussed and their further development as plasmid-host cloning systems was explored. It was clear from these presentations that considerable progress has been made recently in the identification and characterization of a variety of plasmid elements that occur naturally in *Pseudomonas* and *Bacillus* species. Several of the plasmids described show considerable promise as plasmid cloning systems involving a host other than *E. coli*.

A third session on the ecology and epidemiology of vector-host systems was chaired by S. Falkow (University of Washington). This workshop emerged, in part, from expressed fears that microorganisms containing cloned fragments of foreign DNA may potentially pose a threat to health or disrupt the normal ecological chain in some manner. Consequently, this session was devoted to a review of currently available information on the ecology and epidemiology of *E. coli* and related bacterial species since it was recognized that *E. coli* K-12 would be the prokaryotic host most commonly employed in the cloning of DNA molecules in the immediate future. F. Ørskov (Escherichia Reference Center, Copenhagen) reviewed the state of *E. coli* serotyping and what has been learned about the distribution of *E. coli* types in health and disease. Only certain *E. coli* types are generally recognized as good colonizers of the human gut and such strains come from a handful of the 160 well defined O (lipopolysaccharide) antigen types and invariably possess K (acidic polysaccharide capsule) antigens. Some serotypes apparently have become disseminated worldwide and possibly represent the proliferation of a bacterial clone because of, as yet unknown, selective pressures. In contrast, *E. coli* K-12 has no detectable O or K antigens and is considered to be rough. This may account, at least in part, for its demonstrate poor ability to colonize the human or animal gut. However, R. Freter (University of Michigan) pointed out that we still remain largely ignorant of the factors which control intestinal *E. coli* populations. Freter also noted that while adherence to the mucosal surface of the small intestine is important in the pathogenesis of *E. coli* diarrheal disease, the 'normal' long-lasting symbiotic relationship between a mammalian host and bacterium is established in the cecum and colon. It is in these locations that factors come into play to determine whether an *E. coli* strain passing through the intestine will become successfully implanted or whether it will be quickly eliminated in the feces. The factors controlling implantation include competition for substrates, inhibitors and the physiological state of the organism when it reaches the large bowel. For example, ingested *E. coli* previously grown under usual laboratory conditions fare poorly while cells of the same strain 'pre-adapted' in Eh, pH, etc., often colonize well. Freter has developed a continuous flow culture model which may be useful in studying the mechanisms of implantation. Falkow reviewed the pathogenicity of *E. coli*. *E. coli* causes diarrheal disease either by direct invasion of the bowel epithelium or by elaboration of enterotoxin(s). While invasive *E. coli* appear to owe their pathogenicity to a constellation of at least

five unlinked chromosomal gene clusters, toxigenic *E. coli* species generally owe their pathogenicity to the possession of two species, Ent and K. The introduction of Ent and K plasmids may be sufficient to convert a normal wild-type *E. coli* into a strain now capable of causing overt clinical disease. However, the introduction of these plasmids into *E. coli* K-12 sublines had no discernible effect on their ability to cause disease, although the K-12 strains could now better colonize calves. Despite the observation that *E. coli* K-12 did not appear to offer a significant hazard as a potential enteric pathogen even when it possessed well-defined determinants of pathogenicity it was emphasized by Ørskov, Freter and Falkow that *E. coli* K-12 strains carrying recombinant DNA molecules could still act as effective genetic donors *in vivo* and still posed a significant problem requiring control. E. Geldreich (U.S. Environmental Protection Agency, Cincinnati, Ohio) discussed the possible outcomes of the release of *E. coli* containing recombinant DNA molecules into the aquatic environment and concluded that total reliance cannot be placed on sewage treatment and the natural self-purification capacity of receiving waters to limit potential hazards. While these are realistic barriers to the dissemination of *E. coli* and associated fecal organisms via the water route, they are not infallible because of technological limitations, improper operational practices and system overloading. Finally, M. Starr (University of California, Davis) described the numerous genera of gram-negative bacteria found naturally occurring in the soil and on plants. He stated that most of these organisms do not appear to be a reasonable alternative to *E. coli* K-12 as a host for recombinant DNA molecules. Indeed, Starr pointed out that since such genera as *Erwinia*, *Rhizobium* and *Agrobacterium* are known to conjugate with *E. coli*, the potential dissemination of recombinant DNA molecule includes a greater spectrum of microorganisms than just enteric species.

The fourth session of the workshop, chaired by R. Curtiss III (University of Alabama), was concerned with the construction of safer bacterial hosts for DNA cloning. The goals in constructing safer host strains enumerated at the beginning of the session included introduction of mutations that would: (a) preclude colonization in normal ecological niches; (b) preclude cell wall biosynthesis except in specially defined media; (c) cause degradation of genetic information in normal ecological niches; (d) cause vectors to be host-dependent; (e) minimize transmission of recombinant DNA to other strains in normal ecological niches; (f) increase usefulness for recombinant DNA molecule research; and (g) permit monitoring.

Most of the progress in developing safer hosts has been achieved with *E. coli* K-12, although F. Young described a *B. subtilis* strain with a deletion for sporulation genes which readily undergoes autolysis. The strain also has defects in genes for purine and TTP biosynthesis and a mutation conferring a D-alanine requirement can be introduced to cause cell wall biosynthesis to be defective. This strain may be defective in transformation, however, and therefore might be useful only with a phage vector which has yet to be developed and/or discovered.

A. I. Bukhari (Cold Spring Harbor Laboratory) described the use of the *dapD8* mutation in *E. coli* K-12 to block cell wall biosynthesis and another non-reverting mutation which causes sensitivity to bile salts and detergents. The *dapD8* allele is the most stable *dap* point mutation known, although it does revert at frequencies of 10^{-3} to 10^{-5} .

The mutation conferring bile salts sensitivity was obtained after Mu-1 infection of an Hfr strain and, although exhibiting the theoretically useful properties of ease of DNA isolation and inability to survive in the intestinal tract, might be due to Mu insertion which would compromise its use for safe strain construction.

Curtiss reported on the work performed by him and his coworkers in constructing and testing numerous strains with different mutations. Survival of strains *in vivo* was tested by feeding rats 10^{10} cells in milk by stomach tube. *Apur* mutations did not reduce strain titers in feces whereas *ΔthyA*, *ΔthyA* *drm*, and *ΔthyA* *dra* mutations gave 10^2 -fold, 10^2 -fold and 10^5 -fold reductions, respectively, in strain titers in feces. Strains with *ΔthyA* mutations also exhibited thymineless death in *in vitro* tests. Since strains with *dapD8* allele can revert to *Dap*⁺, strains were constructed with both *dapD8* and *ΔbioH-asd* mutations. These strains have not been observed to revert to *Dap*⁺ but can survive passage through the rat intestine and in growth media lacking diaminopimelic acid but containing NaCl and 0.5% usable carbon sources. This survival was due to the production of the mucopolysaccharide, colanic acid, which permits many of the cells to grow and survive as spheroplasts. A *Δgal-chl*⁺ mutation (also deletes *lact*, *bio* and *uvrB* genes) was introduced which blocks colanic acid biosynthesis and leads to no detectable survivors in media lacking diaminopimelic acid or following passage through the rat intestine. The *dapD8* *ΔbioH-asd* *Δgal-chl*⁺ strains are more readily lysed, transform at higher frequencies and are conjugation-defective in matings with donors possessing conjugative plasmids in the P, W and O incompatibility groups but Con⁺ as recipients for F, I and T group plasmids when compared to the *dap*⁺ *gal*⁺ parent strain. Strains with *endA* mutations were also observed to exhibit increased transformation frequencies. Attempts to introduce temperature-sensitive *polA* alleles into strains to block replication of ColEI cloning vectors at elevated temperatures and to cause DNA degradation at elevated temperatures in the presence of *recA* and *ΔthyA* alleles often do not have the same properties in the constructed strains as in the strains in which the allele was originally induced. Many mutations causing a Con⁻ phenotype have been investigated, but many of these revert and/or do not exhibit a Con⁻ phenotype in matings with donors possessing conjugative plasmids of the incompatibility groups commonly found in enteric microorganisms. Some Con⁻ mutants exhibit increased sensitivity to bile salts; thus, the mutant described by Bukhari may also exhibit a Con⁻ phenotype. All of the strains constructed by the Curtiss group are SuII⁺ and most have mutations abolishing restriction alone or both restriction and modification. Thus, sufficient information is now known to construct a usable safer *E. coli* K-12 host. Curtiss and collaborators are now introducing *ΔthyA* and *dna* mutations into their *dapD8* *ΔbioH-asd* *Δgal-chl*⁺ *uvrB* *hcr* *nalA*⁺ (for ease in monitoring) Su⁺ λ⁺ 480⁺ strain to accomplish this objective.

The final session involved a general discussion of some of the major points raised previously in the workshop. There was general agreement at this session that both plasmid-host and phage-host systems have been developed that should meet the criteria of an EK2 system specified by the National Institutes of Health guidelines for research on recombinant DNA molecules. Additional testing is required to confirm the EK2 properties of these available systems, but it is anticipated that these vector-host systems will meet these tests.

Dr. Donald R. Helinski, University of California, San Diego.
Dr. Stanley Falkow, University of Washington.
Dr. Roy Curtiss III, University of Alabama.
Dr. Wacław Szybalski, University of Wisconsin.

APPENDIX D TO
APPENDIX D

SUPPLEMENTARY INFORMATION ON PHYSICAL
CONTAINMENT

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I. BIOLOGICAL SAFETY CABINETS

Biological Safety Cabinets suitable for confining operations involving recombinant DNA molecules are described below:

1. *Class I.* A ventilated cabinet for personnel protection only, with an unrecirculated inward flow of air away from the operator. The exhaust air from this cabinet may be filtered through a high-efficiency or high-efficiency particulate air (HEPA) filter before being discharged to the outside atmosphere. This cabinet is suitable for research work with the Center for Disease Control (CDC) classes of etiologic agents 1, 2 and 3 where no product protection is required. This cabinet may be used in three operational modes: (i) With an eight-inch high, full-width open front; (ii) with an installed front closure panel (having four, eight-inch diameter openings) without gloves; and (iii) with an installed front closure panel equipped with arm length rubber gloves. See Table I for ventilation requirements, agent use limitations, and minimum performance requirements.

2. *Class II.* A ventilated cabinet for personnel and product protection having an open front with inward air flow for personnel protection, and HEPA-filtered recirculated mass air flow for product protection. The cabinet exhaust air is filtered through a HEPA filter. Two models of this cabinet are available, Type 1 and Type 2.

(i) *Type 1.* The Type 1 recirculates approximately 70 percent of the air. The exhaust air from this cabinet may discharge

into the laboratory or be diverted out of the laboratory. This cabinet is suitable for CDC classes of etiologic agents 1, 2, and 3. Vapors or gases which are hazardous from a toxic, radioactive, or flammability standpoint should not be used in this cabinet because of the high quantity of recirculated air.

(ii) *Type 2.* The Type 2 cabinet recirculates approximately 30 percent of the air. The exhaust air from this cabinet is normally ducted out of the laboratory through a HEPA filter and, occasionally, an activated charcoal filter depending on the operation. The cabinet may be used with gases or vapors that are hazardous from a toxic, radioactive, or flammability standpoint. However, any consideration of use of such materials should be evaluated carefully from the standpoint of build-up to dangerous levels and problems of decontamination of the cabinet. See Table I for ventilation requirements, agent use limitations, and minimum performance requirements.

3. *Class III.* A closed front ventilated cabinet of gastight construction providing total protection for personnel and product from contaminants exterior to the cabinet. The cabinet is operated under a negative pressure of at least 0.5 inches water gauge. All supply air is HEPA-filtered. Exhaust air is HEPA-filtered or incinerated to protect the environment. This cabinet, fitted with arm length rubber gloves, provides the highest containment of these three classes of cabinets and is utilized for all activities involving high risk agents (i.e., CDC etiologic agents, class 4). See Table I for ventilation requirements, agent use limitations, and minimum performance requirements.

The integrity of any cabinet depends on initial and periodic evaluation to meet established performance tests. Table I outlines the minimum performance required to assure that the cabinets will provide protection of personnel and the environment.

TABLE I
BIOLOGICAL SAFETY CABINETS
SAFETY PERFORMANCE REQUIREMENTS AND SPECIFICATIONS
JUNE 1976

CABINET	USE CLASSIFICATION		PERFORMANCE REQUIREMENTS				
	DN ^a	CC ^b	FACE VELOCITY (linear feet per minute)	EXHAUST AIR (CFM) ^c		LEAK TIGHTNESS	EXHAUST FILTER EFFICIENCY
				4'hood	6'hood		
Class I	P1-P3	1-3	75	200	300	Not applicable	99.97%
Class II, Type 1	P1-P3	1-3	75	260	400	Gas tight; Leak rate < 1x10 ⁻⁵ cc/sec at 2"wg pressure	99.97%
Class II, Type 2	P1-P3	1-3	200	250	360	Pressure tight; No air/soap bubble at 2"wg pressure	99.97%
Class III	P4	4	Not applicable	4	4	Gas tight; Leak rate < 1x10 ⁻⁶ cc/sec at 3"wg pressure	99.97%

- a - For work with recombinant DNA molecules.
- b - Center for Disease Control (US Public Health Service).
- c - CFM=cubic feet per minute.
- d - Based on one volume of air change each 3 minutes, in the absence of unusual heat or moisture that would require more air changes.

APPENDIX D, Page D-4

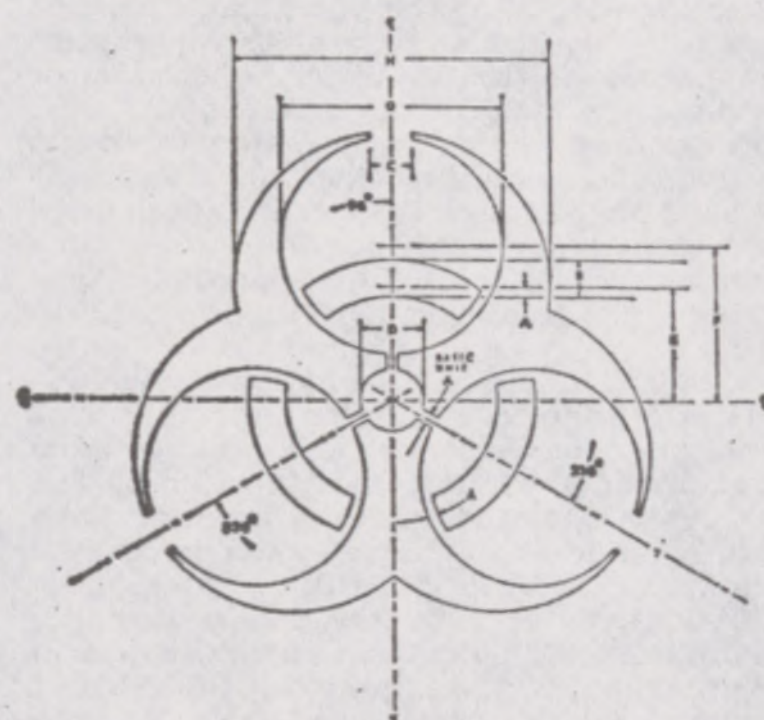
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II. UNIVERSAL BIOHAZARD WARNING SYMBOL (1)

The biological hazard warning symbol (biohazard symbol) specified herein shall be used to signify the actual or potential presence of a biohazard and to identify equipment, containers, rooms, materials, experimental animals or combinations thereof which contain or are contaminated with viable hazardous agents.

The biohazard symbol shall be designed and proportioned as illustrated here:



The symbol shall be as prominent as practical, and of a size consistent with the size of the equipment or material to which it is affixed, provided the proportions shown above are maintained, and, in any case, that the symbol can be easily seen from as many directions as possible.

Except when circumstances do not permit, the symbol shall be oriented with one of the three open circles pointed up and the other two forming a base.

The symbol color shall be a fluorescent orange or orange-red color.* Background color is optional as long as there is sufficient contrast for the symbol to be clearly defined.



Revised 9-9-66

*Day-Glo® Fire Orange of the Sylvania Brothers, Inc. is cited as an example, not an endorsement.

The biohazard symbol shall be used or displayed only to signify the actual or potential presence of biological hazard.

Appropriate wording may be used in association with the symbol to indicate the nature or identity of the hazard, name of individual responsible for its control, precautionary information, etc., but never should this information be superimposed on the symbol. (See next page)

ATTACHMENT 2, Page 2-8



ADMITTANCE TO AUTHORIZED PERSONNEL ONLY

Hazard identity: _____
 Responsible Investigator: _____
 In case of emergency call:
 Daytime phone _____ Home phone _____
 Authorization for entrance must be obtained from
 the Responsible Investigator named above.

III. LABORATORY TECHNIQUES FOR BIOHAZARD CONTROL

A. *Pipetting.* 1. No infectious or toxic materials should be pipetted by mouth (2, 3, 4).
 2. No infectious mixtures should be prepared by bubbling expiratory air through a liquid with a pipette (2, 3, 4).
 3. No infectious material should be blown out of pipettes (2, 3, 4).

4. Pipettes used for the pipetting of infectious or toxic materials should be plugged with cotton (2, 3, 4).
 5. Contaminated pipettes should be placed horizontally in a pan containing enough suitable disinfectant to allow complete immersion (2, 3, 4). They should not be placed vertically in a cylinder.

6. The pan and pipettes should be autoclaved as a unit and replaced by a clean pan with fresh disinfectant (2, 3, 4).
 7. Infectious material should not be mixed by alternate suction and expulsion through a pipette (2, 3, 4).
 8. Mark-to-mark pipettes are preferable to other types, as they do not require expulsion of the last drop (5).

9. Discharge should be as close as possible to the fluid or agar level, or the contents should be allowed to run down the wall of the tube or bottle whenever possible—
 not dropped from a height (5).
 10. A disinfectant-wetted towel over the immediate work surface is useful in some cases to minimize the splash from accidental droppage (9).

B. *Syringes and Needles* (9). 1. To lessen the chance of accidental injection, aerosol production or spills, avoid unnecessary use of the syringe and needle. For instance:
 (i) Use the needle for parenteral injections but use a blunt needle or a cannula on the syringe for oral or intranasal inoculations.
 (ii) Do not use a syringe and needle as a substitute for a pipette in making dilutions of dangerous fluids.

2. Use the syringe and needle in a Biological Safety Cabinet only and avoid quick and unnecessary movements of the hand holding the syringe.

3. Examine glass syringes for chips and cracks, and needles for barbs and plugs.

Note: This should be done prior to sterilization before use.

4. Use needle-locking (Luer-Lok® type) syringes only, and be sure that the needle is locked securely into the barrel. A disposable syringe-needle unit (where the needle is an integral part of the unit) is preferred.

5. Wear surgical or other type rubber gloves for all manipulations with needles and syringes.

6. Fill the syringe carefully to minimize air bubbles and frothing of the inoculum.

7. Expel excess air, liquid and bubbles from a syringe vertically into a cotton pledget moistened with the proper disinfectant, or into a small bottle of sterile cotton.

8. Do not use the syringe to expel forcefully a stream of infectious fluid into an open vial or tube for the purpose of mixing. Mixing with a syringe is condoned only if the tip of the needle is held below the surface of the fluid in the tube.

9. If syringes are filled from test tubes, take care not to contaminate the hub of the needle, as this may result in transfer of infectious material to the fingers.

10. When removing a syringe and needle from a rubber-stoppered bottle, wrap the needle and stopper in a cotton pledget moistened with the proper disinfectant. If there is danger of the disinfectant contaminating sensitive experiments, a sterile dry pledget may be used and discarded immediately into disinfectant solution.

11. Inoculate animals with the hand "behind" the needle to avoid punctures.

12. Be sure the animal is properly restrained prior to the inoculation, and be on the alert for any unexpected movements of the animal.

13. Before and after injection of an animal, swab the site of injection with a disinfectant.

14. Discard syringes into a pan of disinfectant without removing the needle. The syringe first may be filled with disinfectant by immersing the needle and slowly withdrawing the plunger, and finally removing the plunger and placing it separately into the disinfectant. The filling action clears the needle and dilutes the contents of the syringe. Autoclave syringes and needles in the pan of disinfectant.

15. Use separate pans of disinfectant for disposable and nondisposable syringes and needles to eliminate a sorting problem in the service area.

16. Do not discard syringes and needles into pans containing pipettes or other glassware that must be sorted out from the syringes and needles.

C. *Opening Culture Plates, Tubes, Bottles, and Ampoules.* 1. Plates, tubes and bottles of fungi may release spores in large numbers when opened. Such cultures should be manipulated in a Biological Safety Cabinet (6,15).

2. In the absence of definite accidents or obvious spillage, it is not certain that opening of plates, tubes and bottles of other microorganisms has caused laboratory infection. However, it is probable that among the highly infective agents, some infections have occurred by this means and are represented in the 80% for which no known act or accident is ascribable (3).

3. Water of syneresis in petri dish cultures is usually infected and forms a film between the rim and lid of the inverted

plate. Aerosols are dispersed when this film is broken by opening the plate. Vented plastic petri dishes where the lid touches the rim at only three points are less likely to offer this hazard (8,19).

4. The risk may also be minimized by using properly dried plates, but even these (when incubated anaerobically) are likely to be wet after removal from an anaerobic jar. Filter papers fitted into the lids reduce, but do not prevent, dispersal. If plates are obviously wet they should be opened in the Biological Safety Cabinet (8).

5. Less obvious is the release of aerosols when screw-capped bottles or plugged tubes are opened. This happens when a film of infected liquid which may collect between the rim and the liner is broken during removal of the closure (8).

6. Dried, infected culture material may also collect at or near the rim or neck of culture tubes and may be disposed into the air when disturbed (18). Containers of dry powdered hazardous materials, (e.g., Class 3 fungal agents in the spore phase of growth) should be opened only in a Biological Safety Cabinet (6, 14).

7. When the neck of an ampoule containing liquid is broken after nicking with a file, the snapping action creates aerosols. The following methods have been recommended:

(i) After nicking the ampoule with a file, wrap the ampoule in disinfectant-wetted cotton before breaking. Wear gloves (2).

(ii) The bottom of the ampoule should be held in several layers of tissue paper to protect the hands, and a file mark made at the neck. A hot glass rod should be carefully applied to the mark. The glass will crack, allowing air to enter the ampoule and equalize the pressures. After a few seconds the ampoule should be wrapped in a few layers of tissue and broken along the crack. The tissues and ampoule neck can then be discarded into disinfectant, and the contents of the ampoule removed with a syringe. If the ampoule contains dried cultures, about 0.5 cm³ of broth should be added slowly to avoid blowing dried material out. The contents may then be mixed without bubbling and withdrawn into a culture tube (8).

(iii) The researcher uses an intense, but tiny, gas-oxygen flame and heats the tip of the hard glass ampoule until the expanding internal air pressure blows a bubble. After allowing this to cool, he breaks the bubble while holding it in a large low temperature flame; this immediately incinerates any infectious dust which may come from the ampoule when the glass is broken (16). Preliminary practice with a simulant ampoule of the same type actually in use is necessary to develop a technique that will not cause explosion of the ampoule.

(iv) A simple device has been recommended consisting of a sleeve of rubber tubing into which the ampoule is inserted before it is broken (17,18).

D. *Centrifuging*. 1. A safety centrifuge cabinet or safety centrifuge cup (3,7,8,14,22) may be used to house or safeguard all centrifuging of infectious substances. When bench type centrifuges are used in a Biological Safety Cabinet, the glove panel should be in place with the glove ports covered. The centrifuge operation creates air currents that may cause escape of agent from an open cabinet (2,3,4,13).

2. In some situations, in the absence of O-ring cap sealed trunnion cups, specimens can be enclosed in sealed plastic bags before centrifugation (12).

3. Before centrifuging, inspect tubes for cracks, inspect the inside of the trunnion cup for rough walls caused by erosion or adhering matter, and carefully remove bits of glass from the rubber cushion (4,10).

4. A germicidal solution should be added between the tube and trunnion cup to disinfect the materials in case of accidental breakage. This practice also provides an excellent cushion against shocks that might otherwise break the tube (4,10).

5. Avoid decanting centrifuge tubes. If you must do so, afterwards wipe off the outer rim with a disinfectant; otherwise the infectious fluid will spin off as an aerosol (4, 10).

6. Avoid filling the tube to the point that the rim, cap or cotton plug ever becomes wet with culture (4, 10).

7. Screw caps, or caps which fit over the rim outside the centrifuge tube are safer than plug-in closures. Some fluid usually collects between a plug-in closure and the rim of the tube. Even screw-capped bottles are not without risk, however; if the rim is soiled some fluid will escape down the outside of the tube. Screw-capped bottles may jam in the bucket, and removing them is hazardous. Propping such bottles higher in the bucket with additional rubber buffers is mechanically unsound (8).

8. Kitchen foil is often used to cap centrifuge tubes. This creates more risk than the screw cap. Foil caps often become detached in handling and centrifuging (8).

9. The balancing of buckets is often mismanaged. Care must be taken to ensure that matched sets of trunnions, buckets and plastic inserts do not become mixed. If the components are not inscribed with their weights by the manufacturer, colored stains can be applied to avoid confusion. When the tubes are balanced, the buckets, trunnions and inserts should be included in the procedure; and care must be taken to ensure that the centers of gravity of the tubes are equidistant from the axis of rotation. To illustrate the importance of this, two identical tubes containing 20g of mercury and 20g of water respectively will balance perfectly on the scales; but their performance in motion is totally different, leading to violent vibration with all its attendant hazards (5).

10. Fill and open centrifuge tubes or trunnion cups in a Biological Safety Cabinet (10).

E. *High-Speed Centrifuges* (22). 1. In high-speed centrifuges the bowl is connected to a vacuum pump. If there is a breakage or accidental dispersion of infected particles the pump and the oil in it will become contaminated. A high efficiency filter should be placed between the centrifuge and the pump (8).

2. High speed rotor heads are prone to metal fatigue, and where there is a chance that they may be used on more than one machine each rotor should be accompanied by its own log book indicating the number of hours run at top or de-rated speeds. Failure to observe this precaution can result in dangerous and expensive disintegration. Frequent inspection, cleaning and drying are important to ensure absence of corrosion or other traumata which may lead to creeping cracks. Rubber O-rings and tube closures must be examined for deterioration and be kept lubricated with the material recommended by the makers. Where tubes of different materials are provided (e.g., celluloid, polypropylene, stainless steel), care must be taken that the tube closures designed specifically for the type of tube in use are employed. These caps are often similar in appearance, but are prone to leakage if applied to tubes of the wrong material. When properly designed tubes and rotors are well maintained and handled, leaking should never occur (5).

3. Cleaning and disinfection of tubes, rotors and other components requires con-

siderable care. It is unfortunate that no single process is suitable for all items, and the various manufacturers' recommendations must be followed meticulously if fatigue, distortion and corrosion are to be avoided. This is not the place to catalogue recommended methods, but one less well appreciated fact is worthy of mention. Celluloid (cellulose nitrate) centrifuge tubes are not only highly inflammable and prone to shrinkage with age and distortion on boiling, but can behave as high explosive in an autoclave (5). Large-scale zonal centrifugation requires special attention (11).

F. *Blenders, ultrasonic disintegrators, colloid mills, ball mills, jet mills, grinders, mortar and pestle*. All these devices release considerable aerosols during their operation. For maximum protection to the operator during the blending of infectious materials, the following practices should be observed:

1. Operate blending and cell-disruption and grinding equipment in a Biological Safety Cabinet (9).

2. Use safety blenders designed to prevent leakage from the rotor bearing at the bottom of the bowl (9).

3. In the absence of a leak-proof rotor, inspect the rotor bearing at the bottom of the blender bowl for leakage prior to operation. Test it in a preliminary run with sterile saline or methylene blue solution prior to use with infected material (9).

4. Sterilize the device and residual infectious contents promptly after use. Use a towel moistened with disinfectant over the top of the blender (9).

5. Glass blender bowls are undesirable for use with infectious material because of potential breakage. If used, they should be covered with a polypropylene jar to prevent dispersal of glass (8).

6. A new machine, the Colworth Stomacher (England), in which material is homogenized in a plastic bag in a closed container, would appear to be safer than some of the other blenders (8).

7. A heat-sealed flexible plastic film enclosure for a grinder or blender can be used, but it must be opened in a Biological Safety Cabinet (7).

8. Blender bowls sometimes require supplemental cooling to prevent destruction of the bearings and to minimize thermal efforts on the product (7).

9. Before opening the safety blender bowl, permit the blender to rest for at least one minute to allow settling of the aerosol cloud.

10. Clinical or other laboratories handling human blood should be aware of the aerosols produced by the microhaematocrit centrifuge, the autoanalyzer stirrer, and the microtonometer, inasmuch as it seems that airborne transmission of infectious hepatitis may occur in the laboratory (20).

G. *Miscellaneous precautions and recommendations*. 1. Water baths and Warburg baths used to inactivate, incubate, or test infectious substances should contain a disinfectant. For cold water baths, 70 percent propylene glycol is recommended (4, 10).

2. Deepfreeze, liquid nitrogen, and dry ice chests and refrigerators should be checked and cleaned out periodically to remove any broken ampoules, tubes, etc., containing infectious material, and decontaminated. Use rubber gloves and respiratory protection during this cleaning. All infectious or toxic material stored in refrigerators or deep-freezes should be properly labelled. Security measures should be commensurate with the hazards (4,10,21).

3. Freeze-dried culture ampoules should always be opened in a Biological Safety Cabinet. The ampoule should be wrapped in a disinfectant-soaked swab before breaking it open to minimize the risk of cutting the hands, and to a lesser extent of releasing

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aerosol of dried material. Whenever possible, ampoules should be filled with dry nitrogen after freeze-drying, thus avoiding implosion that may occur during the sealing as well as opening of evacuated ampoules. The whole process of freeze-drying itself should be performed in a Biological Safety Cabinet. Filtration of the effluent air from the vacuum pump is desirable either up (preferably), or down stream of the pump (5).

4. Ensure that all virulent fluid cultures or viable powdered infectious materials in glass vessels are transported, incubated, and stored in easily handled, nonbreakable leak-proof containers that are large enough to contain all the fluid or powder in case of leakage or breakage of the glass vessel (4,10).

5. All inoculated petri plates or other inoculated solid media should be transported and incubated in leak-proof pans or leak-proof containers (4,10).

6. Care must be exercised in the use of membrane filters to obtain sterile filtrates of infectious materials. Because of the fragility of the membrane and other factors, such filtrates cannot be handled as noninfectious until culture or other tests have proved their sterility (4,10).

7. Shaking machines should be examined carefully for potential breakage of flasks or other containers being shaken. Screw capped durable plastic or heavy walled glass flasks should be used. These should be securely fastened to the shaker platform. An additional precaution would be to enclose the flask in a plastic bag with or without an absorbent material.

8. No person should work alone on an extremely hazardous operation (4,10).

IV. PERSONAL HYGIENE, HABITS, AND PRACTICES

Personal hygienic practices in the laboratory are directed, in most part, toward the prevention of occupationally acquired physical injury or disease. To a less obvious extent, they can raise the quality of the laboratory work by reducing the possibilities for contamination of experimental materials. The reasons for many of the recommended precautions and practices are obvious, but, in some instances, amplification will permit a better review of the applicability to any one specific laboratory.

Consequently, what might be forbidden in one laboratory might be only discouraged in another, and be permissible in a third. Nevertheless, adherence to safe practices that become habitual, even when seemingly not essential, provides a margin of safety in situations where the hazard is unrecognized. The history of occupational injury is replete with examples of hazards unrecognized until too late. The following guidelines, recommendations, and comments are presented with this in mind:

1. Food, candy, gum, and beverages for human consumption will be stored and consumed only outside the laboratory (5, 10).

2. Foot-operated drinking fountains should be the sole source of water for drinking by human occupants of the laboratory (27).

3. Smoking is not permitted in the laboratory or animal quarters. Cigarettes, pipes, and tobacco will be kept only in clean areas (5, 10, 26).

4. Shaving and brushing of teeth are not permitted in the laboratory. Razors, toothbrushes, toiletry supplies, and cosmetics are permissible only in clean change rooms or other clean areas, and should never be used until after showering or thorough washing of the face and hands (27).

5. A beard may be undesirable in the laboratory in the presence of actual or potential airborne contamination, because it retains particulate contamination more persistently than clean-shaven skin. A clean-shaven face is essential to the adequate facial fit of a

face mask or respirator when the work requires respiratory protection (10,27,31).

6. Develop the habit of keeping hands away from mouth, nose, eyes, face, and hair. This may prevent self-inoculation (10,27).

7. For product protection, persons with long hair should wear a suitable hair net or head cover that can be decontaminated. This has long been a requirement in hospital operating rooms and in the manufacture of biological pharmaceutical products. A head cover also will protect the hair from fluid splashes, from swinging into Bunsen flames and petri dishes, and will reduce facial contamination caused by habitual repetitive manual adjustment of the hair (5).

8. Long-flowing hair and loose-flapping clothing are dangerous in the presence of open flame or moving machinery. Rings and wrist watches also are a mechanical hazard during operation of some types of machines (5, 10).

9. Contact lenses do not provide eye protection. The capillary space between the contact lenses and the cornea may trap any material present on the surface of the eye. Caustic chemicals trapped in this space cannot be washed off the surface of the cornea. If the material in the eye is painful or the contact lens is displaced, muscle spasms will make it very difficult, if not impossible, to remove the lens. For this reason, contact lenses must not be worn by persons exposed to caustic chemicals unless safety glasses with side shields, goggles, or plastic face masks are also worn to provide full protection. It is the responsibility of supervisors to identify employees who wear contact lenses (25, 26).

10. Personal items, such as coats, hats, storm rubbers or overshoes, umbrellas, purses, etc., do not belong in the laboratory. These articles should be kept elsewhere (25).

11. Plants, cut flowers, an aquarium, and pets of any kind are undesirable sources of yeast, molds, and other potential microbial contaminants of biological experimental materials (25).

12. Books and journals returnable to the institutional library should be used only in the clean areas as much as possible (10,27).

13. When change rooms with showers are provided, the employer should furnish skin lotion (27).

14. When employees are subject to potential occupational infection, the shower and/or face/hand-washing facilities should be provided with germicidal soap (8,27).

15. Personal cloth handkerchiefs should not be used in the laboratory. Cleansing tissue should be available instead.

16. Hand washing for personal protection:

(i) This should be done promptly after removing protective gloves. Tests show it is not unusual for microbial or chemical contamination to be present despite use of gloves, due to unrecognized small holes, abrasions, tears, or entry at the wrist.

(ii) Throughout the day, at intervals dictated by the nature of the work, the hands should be washed. Presence of a wrist watch discourages adequate washing of the wrist (10,25).

(iii) Hands should be washed after removing soiled protective clothing, before leaving the laboratory area, before eating, and before smoking. The provision of hand cream by the employer encourages these practices (5,8,10).

(iv) A disinfectant wash or dip may be desirable in some cases, but its use must not be carried to the point of causing roughening, desiccation or sensitization of the skin.

17. Anyone with a fresh or healing cut, abrasion, or skin lesion should not work with infective material unless the injured area is completely protected (8,25).

18. Persons vaccinated for smallpox may be shedders of vaccinia virus during the phase of cutaneous reaction. Therefore, vaccination requires permission of the appropriate supervisor, because two weeks' absence may be necessary before returning to work with normal cell cultures or with susceptible animals, especially the normal mouse colony (25).

19. The surgeon's mask of gauze or filter paper is of little value for personal respiratory protection (29). It is designed to prevent escape of droplets from the nose or mouth (23G). If biohazards demand respiratory protection, then nothing but a full face respirator or ventilated hood will suffice. A half-mask respirator does not protect the eyes, which are an unevaluated avenue of infection through the conjunctiva and the nasolacrimal duct (5,8).

20. Nonspecific contamination by environmental organisms from humans, animals, equipment, containers for specimens or supplies, and outside air is a complication that may affect or invalidate the results of an experiment. The human sources of this contamination are evaluated as follows:

(i) Sneezing, coughing and talking (23A, 24A). Sneezing, variously reported to generate as many as 32,000 or 1,000,000 droplets below 100 microns in diameter; coughing, which produces fewer and larger droplets; and talking, which has been reported to average only 250 droplets when speaking 100 words, show great differences between persons in regard to the number of microorganisms aerosolized. As a general rule, it may be said that these actions by normal healthy persons may play a less important role in transmission of airborne infection to humans or experimental materials than does liberation of microorganisms from human skin.

(ii) Dispersal of bacteria from human skin. There is a tremendous variation in the number of bacteria shed from the skin by a clothed subject. For instance, in one study, the number varied from 6,000 to 60,000 per minute (23C). These bacteria were released on skin scales which were of a size that could penetrate the coarse fabric used for the laboratory and surgical clothing in the test (23D). Dispersal of skin bacteria was several times greater from below the waist than from upper parts of the body (24D). Effective reduction is accomplished by use of closely-woven or impervious clothing fitted tightly at the neck, wrists, and ankles to prevent the clothing from acting as a bellows that disperses air carrying skin scales laden with bacteria (23B). Such clothing sometimes is too warm to work in. It was found that a significant reduction in dispersal of bacteria occurred with the wearing of close-fitting and closely-woven underpants beneath the usual laboratory clothing (23D). The purpose of this summary is to alert laboratory personnel to the existence of this source of contamination (9).

(iii) Prolific dispersal of bacteria occurs from infected abrasions, small pustules, boils, and skin disease (23F, 24B). Washing the lesions with germicidal soap will greatly decrease the number of organisms on the skin and dispersal into the air. Healthy nasal carriers who generate aerosolized staphylococci usually can be identified by the presence of heavy contamination of their fingers, face, and hair (23E). This point may be useful in investigating the source of staphylococcal contamination of cell lines.

(iv) Footwear. In moderate and high risk situations, shoes reserved for only laboratory use have been recommended as a precaution against transporting spilled infectious agents outside the laboratory. However, in experiments during which reduction of potential contamination of experimental materials is important, laboratory-only shoes can reduce the microbial load brought into the

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laboratory each day by street shoes. Shoes are efficient transporters. In one study, there were 4 to 850 times as many bacteria per square centimeter on the laboratory footwear as on the floor itself (30).

V. CARE AND USE OF LABORATORY ANIMALS (10,32-37)

A. *Care and handling.* 1. Special attention must be given to the humane treatment of all laboratory animals in accordance with the Animal Welfare Act of 1970. The implementing rules and regulations appear in the Code of Federal Regulations (CFR) Title 9, Chapter I, Subchapter A, Parts 1, 2, 3. Recommended provisions and practices that meet the requirements of the Act have been published by the U.S. Public Health Service (32).

2. There are specific minimum requirements (33) concerning the caging, feeding, watering, and sanitation for dogs, cats, guinea pigs, hamsters, rabbits, and nonhuman primates. To meet these requirements, the animal room supervisor must have a copy of 9 CFR Chapter I, Subchapter A, Parts 1, 2, 3.

3. Each laboratory should establish procedures to ensure the use of animals that are free of diseases prejudicial to the proposed experiments and free from carriers of disease or vectors, such as ectoparasites, which endanger other experimental animals or personnel (10).

B. *Cages housing infected animals* (10).

1. Careful handling procedures should be employed to minimize the dissemination of dust from cage refuse and animals.

2. Cages should be sterilized by autoclaving. Refuse, bowls and watering devices should remain in the cage during sterilization.

3. All watering devices should be of the "non-drip" type.

4. Cages should be examined each morning and at each feeding time so that dead animals can be removed.

5. Heavy gloves should be worn when feeding, watering, handling, or removing infected animals. Bare hands should NEVER be placed in the cage to move any object therein.

6. When animals are to be injected with biohazardous material, the animal caretaker should wear protective gloves and the laboratory workers should wear surgeons gloves. Animals should be properly restrained to avoid accidents that might result in disseminating biohazardous material, as well as to prevent injury to the animal and to personnel.

7. Animals exposed to biohazardous aerosols should be housed in ventilated cages, in gas-tight cabinet systems, or in rooms designed for protection of personnel by use of ventilated suits.

8. Animals inoculated by means other than by aerosols should be housed in equipment suitable for the level of risk involved.

9. Infected animals to be transferred between buildings should be placed in ventilated cages or other aerosol-proof containers.

10. The oversize canine teeth of large monkeys present a particular biting hazard; these are important in the potential transmission of naturally-occurring, and very dangerous, monkey virus infections. Such teeth should be blunted or surgically removed by a veterinarian.

11. Presently available epidemiological evidence indicates that infectious hepatitis may be transmitted from non-human primates (typically chimpanzees) to man. Newly imported animals may be naturally infected with this disease, and persons in close contact with such animals may become infected. After six months residence in this country, chimpanzees apparently no longer transmit the disease. A record should be maintained

for each newly imported animal. A sign should be posted at rooms housing these animals to warn that the animals are potentially infectious.

C. *General Guidelines that Apply to Animal Room Maintenance* (10). 1. Doors to animal rooms should be kept closed at all times except for necessary entrance and exit.

2. Unauthorized persons should not be permitted to enter animal rooms.

3. A container of disinfectant should be kept in each animal room for disinfecting gloves and hands, and for general decontamination, even though no infectious animals are present. Hands, floors, walls, and cage racks should be washed with an approved disinfectant at the recommended strength as frequently as the supervisor directs.

4. Floor drains in animal rooms, as well as floor drains throughout the building should be flooded with water or disinfectant periodically to prevent backup of sewer gases.

5. Shavings or other refuse on floors should not be washed down the floor drain because such refuse clogs the sewer lines.

6. An insect and rodent control program should be maintained in all animal rooms and in animal food storage areas.

7. Special care should be taken to prevent live animals, especially mice, from finding their way into disposable trash.

D. *Necropsy rules for infected animals* (10). 1. Necropsy of infected animals should be carried out by trained personnel in Biological Safety Cabinets with the hinged glass panel down. The glove port panel with or without attached gloves, and a respirator should be used at the discretion of the supervisor.

2. Surgeons gowns should be worn over laboratory clothing during necropsies.

3. Rubber gloves should be worn when performing necropsies.

4. The fur of the animal should be wetted with a suitable disinfectant.

5. Small animals should be pinned down or fastened on wood or metal in a metal tray.

6. Upon completion of necropsy, all potentially biohazardous material should be placed in suitable containers and sterilized immediately.

7. Contaminated instruments should be placed in a horizontal bath containing a suitable disinfectant.

8. The inside of the Biological Safety Cabinets and other potentially contaminated surfaces should be disinfected with a suitable germicide.

9. Grossly contaminated rubber gloves should be cleaned in disinfectant before removal from the hands, preparatory to sterilization.

10. Dead animals should be placed in proper leak-proof containers, autoclaved and properly tagged before being placed outside for removal and incineration.

VI. DECONTAMINATION AND DISPOSAL (7, 10, 38-42)

A. *Introduction.* Available data on the efficacy of various decontaminants for etiologic agents indicate that no major surprises will be forthcoming regarding the susceptibility of organisms containing recombinant DNA molecules. In the absence of adequate information, tests to determine the efficacy of candidate decontaminants should be conducted with the specific agent of interest. The goal of decontamination is not only the protection of personnel and the environment from exposure to infectious agents, but also the prevention of contamination of experimental materials by a variable, persistent, and unwanted background of microorganisms. This additional factor should be considered in selecting decontamination materials and methods.

B. *Decontamination Methods.* Physical and chemical means of decontamination fall into four main categories: Heat; Liquid Decontaminants; Vapors and Gases; and UV Radiation.

1. *Heat.* The application of heat, either moist or dry, is recommended as the most effective method of sterilization. Steam at 121 C under pressure in the autoclave is the most convenient method of rapidly achieving sterility. Dry heat at 160 to 170 C for periods of 2 to 4 hours is suitable for destruction of viable agents on impermeable non-organic material such as glass, but is not reliable in even shallow layers of organic or inorganic material that can act as insulation. Incineration is another use of heat in the decontamination of microorganisms and also serves as an efficient means for disposal.

2. *Liquid Decontaminants.* In general, the liquid decontaminants find their most practical use in surface decontamination and, at sufficient concentration, as decontaminants of liquid wastes for final disposal in sanitary sewer systems. There are many misconceptions concerning the use of liquid decontaminants. This is due largely to a characteristic capacity of such liquids to perform dramatically in the test tube and to fail miserably in a practical situation. Such failures often occur because proper consideration was not given to such factors as temperature, time of contact, pH, concentration, and the presence and state of dispersion, penetrability and reactivity of organic material at the site of application. Small variations in the above factors may make large differences in effectiveness of decontamination. For this reason, even when used under highly favorable conditions, complete reliance should not be placed on liquid decontaminants when the end result must be sterility.

There are many liquid decontaminants available under a wide variety of trade names. In general, these can be categorized as halogens, acids or alkalies, heavy metal salts, quaternary ammonium compounds, phenolic compounds, aldehydes, ketones, alcohols and amines. Unfortunately, the more active the decontaminant the more likely it is that the decontaminant will possess undesirable characteristics, such as the possession of corrosive properties. None is equally useful or effective under all conditions.

3. *Vapors and Gases.* A variety of vapors and gases possess decontamination properties. The most useful of these are formaldehyde and ethylene oxide. When these can be employed in closed systems and under controlled conditions of temperature and humidity, excellent decontamination can result. Vapor and gas decontaminants are primarily useful in decontaminating: (i) Biological Safety Cabinets and associated effluent air-handling systems and air filters; (ii) bulky or stationary equipment that resists penetration by liquid surface decontaminants; (iii) instruments and optics that might be damaged by other decontamination methods; and (iv) rooms and buildings and associated air-handling systems.

4. *Radiation.* The usefulness of ultraviolet (UV) irradiation as a decontaminant is limited by its low penetrating power. No information is available regarding the effectiveness of UV irradiation for decontaminating microorganisms containing recombinant DNA molecules. Dependence on UV must be based on the results of experiments imitating particular anticipated environmental conditions and applications. Ultraviolet light is generally of limited application and is primarily useful in air locks and animal holding areas for controlling low levels of airborne contaminants.

No one procedure or material will solve all decontamination problems. The only method of assuring the efficacy of selected methodologies is to critically examine the results

obtained in practical tests with the micro-organism(s) of interest.

C. Laboratory spills. A troublesome problem that may occur in the laboratory is the decontamination of an overt biological spill. The occurrence of a spill poses less of a problem if it occurs in a Biological Safety Cabinet provided splattering to the outside of the cabinet does not occur. Direct application of concentrated liquid decontaminant and a thorough wipe down of the internal surfaces of such cabinetry will usually be effective for decontaminating the work zone but gaseous decontaminants would be required to rid the interior sections of the cabinet of contaminants. Each researcher must realize that in the event of an overt accident, research materials such as tissue cultures, media, and animals within such cabinets may well be lost to the experiment.

The greater problem arises if the incident occurs in the open laboratory. All laboratory protocols should be designed to prevent such occurrences. The first action in the event of an overt laboratory spill is evacuation of the affected area to minimize the exposure of personnel involved. Next, the spill area must be isolated to prevent exposure of personnel and experimental materials beyond those involved in the immediate area of the spill. The procedures adopted must be rapidly effective and must not create additional aerosol or foster mechanical transfer of materials to unaffected areas. Personnel carrying out the procedures must be provided with protective clothing and equipment, including respiratory protection. Consideration must be given to the safe disposal of all materials and liquids resulting from cleanup procedures. Reentry of personnel to the area should be avoided until it can be reasonably established that the area has been effectively decontaminated. Further specific details are provided in Section VIII.

D. Disposal. Decontamination and disposal in infectious disease laboratories are closely interrelated acts in which decontamination constitutes the introductory phase of disposal. All materials and equipment used in research on recombinant DNA molecules will ultimately be disposed of; however, in the sense of daily use, only a portion of these will require actual removal from the laboratory complex or on-site destruction. The remainder will be recycled for use either within the same laboratory or in other laboratories that may or may not engage in DNA recombinant research. Examples of the latter that immediately come to mind are: Reusable laboratory glassware, instruments used in necropsy of infected animals, and laboratory clothing. Disposal should therefore be interpreted in the broadest sense of the word, rather than in the restrictive sense of dealing solely with a destructive process.

The principal questions to be answered prior to disposal of any objects or materials from laboratories dealing with potentially infectious microorganisms or animal tissues are:

1. Have the objects or materials been effectively decontaminated by an approved procedure?
2. If not, have the objects or materials been packaged in an approved manner for immediate on-site incineration or transfer to another laboratory?
3. Does disposal of the decontaminated objects or materials involve any additional potential hazards, biological or otherwise, to personnel either: (1) Those carrying out the immediate disposal procedures or (2) Those who might come into contact with the objects or materials outside the laboratory complex?

Laboratory materials requiring disposal will normally occur as liquid, solid, and animal room wastes. The volume of these

can become a major problem when there is the requirement that all wastes be decontaminated prior to disposal. It is most evident that a significant portion of this problem can be eliminated if the kinds of materials initially entering the laboratory are reduced. In any case, and wherever possible, materials not essential to the research should be retained in the nonresearch areas for disposal by conventional methods. Examples are the packaging materials in which goods are delivered, disposable carton-cages for transport of animals, and large carboys or tanks of fluids which can be left outside and drawn from as required. Reduction of this bulk will free autoclaves and other decontamination and disposal processes within the laboratory for the more rapid and efficient handling of materials known to be contaminated.

Inevitably, disposal of materials raises the question, "How can we be sure that the materials have been treated adequately to assure that their disposal does not constitute a hazard?" In the small laboratory, the problem is often solved by requiring that each investigator decontaminate all contaminated materials not of immediate use at the end of each day and place them in suitable containers for routine disposal. In larger laboratories where the mass of materials for disposal becomes much greater and sterilization and decontamination bottlenecks occur, materials handling and disposal will likely be the chore of personnel not engaged in the actual research. In either situation, a case can be made for establishing a positive method of designating the state of materials to be disposed of. This may consist of a tagging system stating that the materials are either sterile or contaminated.

Disposal of materials from the laboratory and animal holding areas will be required for research projects ranging in size from an individual researcher to those involving large numbers of researchers of many disciplines. Procedures and facilities to accomplish this will range from the simplest to the most elaborate. The primary consideration in any of these is to dispel the notion that laboratory wastes can be disposed of in the same manner and with as little thought as household wastes. Selection and enforcement of safe procedures for disposal of laboratory materials are of no less importance than the consideration given to any other methodology for the accomplishment of research objectives.

Materials of dissimilar nature will be common in laboratories studying recombinant DNA molecules. Examples are combinations of common flammable solvents, chemical carcinogens, radioactive isotopes, and concentrated viruses or nucleic acids. These may require input from a number of disciplines in arriving at the most practical approach for their decontamination.

E. Characteristics of chemical decontaminants in common use in laboratory operations. Every person actively working with viable microorganisms, no matter how remote the field of specialization, will, from time to time, find it necessary to decontaminate by chemical methods work areas and materials, equipment, and specialized instruments. Chemical decontamination is necessary because the use of pressurized steam, the most rapid and reliable method of sterilization, is not normally feasible for decontaminating large spaces, surfaces, and stationary equipment. Moreover, high temperatures and moisture often damage delicate instruments, particularly those having complex optical and electronic components.

Chemicals with decontaminant properties are, for the most part, available as powders, crystals, and liquid concentrates. These may be added to tap water for application as sur-

face decontaminants, and some, when added in sufficient quantity, find use as decontaminants of bulk liquid wastes. Chemical decontaminants that are gaseous at room temperatures are useful as space-penetrating decontaminants. Others become gases at reasonably elevated temperatures and can act as either aqueous surface or gaseous space-penetrating decontaminants.

Inactivation of microorganisms by chemical decontaminants may occur in one or more of the following ways: (1) Coagulation and denaturation of protein, (2) Lysis, (3) Binding to enzymes, or inactivation of an essential enzyme by either oxidation, binding, or destruction of enzyme substrate.

The relative resistance to the action of chemical decontaminants can be substantially altered by such factors as: Concentration of active ingredient, duration of contact, pH, temperature, humidity and presence of extrinsic organic matter. Depending upon how these factors are manipulated, the degree of success achieved with chemical decontaminants may range from minimal inactivation of target microorganisms to an indicated sterility within the limits of sensitivity of the assay systems employed.

There are dozens of contaminants available under a wide variety of trade names. In general, these decontaminants can be classified as halogens, acids or alkalies, heavy metal salts, quaternary ammonium compounds, phenolic compounds, aldehydes, ketones, alcohols, and amines. Unfortunately, the more active the decontaminant the more likely it will possess undesirable characteristics. For example, peracetic acid is a fast-acting, universal decontaminant. However, in the concentrated state it is a hazardous compound that can readily decompose with explosive violence. When diluted for use, it has a short half-life, produces strong, pungent, irritating odors, and is extremely corrosive to metals. Nevertheless, it is such an outstanding decontaminant that it is commonly used in germ-free animal studies despite these undesirable characteristics.

The halogens are probably the second most active group of decontaminants. Chlorine, iodine, bromine, and fluorine will rapidly kill bacterial spores, viruses, rickettsiae, and fungi. These decontaminants are effective over a wide range of temperatures. In fact, chlorine has been shown to be effective at -40 F. (On the other hand, phenols and formaldehyde have high temperature coefficients). The halogens have several undesirable features. They readily combine with protein, so that an excess of the halogen must be used if proteins are present. Also, the halogens are relatively unstable so that fresh solutions must be prepared at frequent intervals. Finally, the halogens corrode metals. A number of manufacturers of decontaminants have treated the halogens to remove some of the undesirable features. For example, sodium hypochlorite reacts with p-toluenesulfonamide to form Chloramine T, and iodine reacts with certain surface-active agents to form the popular iodophors. These "tamed" halogens are stable, non-toxic, odorless, and relatively noncorrosive to metals. However, the halogens are highly reactive elements, and, because they are reactive they are good germicides. When a halogen acts as a decontaminant, free halogen is the effective agent. Raising the pH or combining the halogen with other compounds to decrease the corrosive effect will also decrease the germicidal power. A trade-off situation occurs.

Ineffectiveness of a decontaminant is due primarily to the failure of the decontaminant to contact the microorganisms rather than failure of the decontaminant to act. If one places an item in

a liquid decontaminant, one can see that the item is covered with tiny bubbles. Of course, the area under the bubbles is dry, and microorganisms in these dry areas will not be affected by the decontaminant. Also, if there are spots of grease, rust or dirt on the object, microorganisms under these protective coatings will not be contacted by the decontaminant. Scrubbing an item when immersed in a decontaminant is helpful, and a decontaminant should have, and most do have, incorporated surface-active agents.

F. Properties of some common decontaminants—1. Alcohol. Ethyl or isopropyl alcohol in a concentration of 70-80 percent by weight is often used. Alcohols denature proteins and are somewhat slow in their germicidal action. However, they are effective decontaminants against lipid-containing viruses.

2. Ether and Chloroform. These compounds are not ordinarily used as decontaminants, but they do demonstrate the fact that lipid-containing viruses are inactivated by these organic solvents, whereas non-lipid-containing viruses are quite resistant.

3. Formaldehyde. Formaldehyde for use as a decontaminant is usually marketed as a solution of about 37 percent concentration referred to as formalin or as a solid polymerized compound called paraformaldehyde. Formaldehyde in a concentration of 5 percent active ingredient is an effective liquid decontaminant. It loses considerable activity at refrigeration temperatures and the pungent, irritating odors make formaldehyde solutions difficult to use in the laboratory. Formaldehyde vapor generated from formaldehyde solution is an effective space decontaminant for decontaminating rooms or buildings, but in the vapor state with water it tends to polymerize out on surfaces to form paraformaldehyde, which is persistent and unpleasant. Formaldehyde gas can be liberated by heating paraformaldehyde to depolymerize it. In the absence of high moisture content in the air, formaldehyde released in the gaseous state forms less polymerized residues on surfaces and less time is required to clear treated areas of fumes than formaldehyde released in the vapor state.

4. Phenol. Phenol itself is not often used as a decontaminant. The odor is somewhat unpleasant and a sticky, gummy residue remains on treated surfaces. This is especially true during steam sterilization. Although phenol itself may not be in widespread use, phenol homologs and phenolic compounds are basic to a number of popular decontaminants. The phenolic compounds are effective decontaminants against some viruses, rickettsiae, fungi and vegetative bacteria. The phenolics are not effective in ordinary usage against bacterial spores.

5. Quaternary Ammonium Compounds or Quats. After 30 years of testing and use, there is still a considerable controversy about the efficacy of the Quats as decontaminants. These cationic detergents are strongly surface-active and are effective against lipid-containing viruses. The Quats will attach to protein so that dilute solutions of Quats will quickly lose effectiveness in the presence of proteins. The Quats tend to clump micro-

organisms and are neutralized by anionic detergents, such as soap. The Quats have the advantages of being nontoxic, odorless, non-staining, noncorrosive to metals, stable, and inexpensive.

6. Chlorine. This halogen is a universal decontaminant active against all microorganisms, including bacterial spores. Chlorine combines with protein and rapidly decreases in concentration in its presence. Free, available chlorine is an active element. It is a strong oxidizing agent, corrosive to metals. Chlorine solutions will gradually lose strength so that fresh solutions must be prepared frequently. Sodium hypochloride is usually used as a base for chlorine decontaminants. An excellent decontaminant can be prepared from household or laundry bleach. These bleaches usually contain 5.25 percent available chlorine or 52,500 ppm. If one dilutes them 1 to 100, the solution will contain 525 ppm of available chlorine, and, if a nonionic detergent such as Naccanol is added in a concentration of about 0.7 percent, a very good decontaminant is created.

7. Iodine. The characteristics of chlorine and iodine are similar. One of the most popular groups of decontaminants used in the laboratory is the iodophors, and Wescodyne is perhaps the most popular. The range of dilution of Wescodyne recommended by the manufacturer is 1 oz. in 5 gal. of water giving 25 ppm of available iodine, and, in 5 gal. giving 75 ppm. At 75 ppm, the concentration of free iodine is .0075 percent. This small amount can be rapidly taken up by any extraneous protein present. Clean surfaces or clear water can be effectively treated by 75 ppm available iodine, but difficulties may be experienced if any appreciable amount of protein is present. For bacterial spores, a dilution of 1 to 40 giving 750 ppm is recommended by the manufacturer. For washing the hands, it is recommended that Wescodyne be diluted 1 to 10 or 10 percent in 50 percent ethyl alcohol (a reasonably good decontaminant itself) which will give 1,600 ppm of available iodine, at which concentration relatively rapid inactivation of any and all microorganisms will occur.

G. Vapors and gases. The use of formaldehyde as a vapor or gas has already been discussed. Other chemical decontaminants which have been used this way included ethylene oxide, peracetic acid, beta-propiolactone (BPL), methyl bromide, and ethylene amine. When these can be used in closed systems and under controlled conditions of temperature and humidity, excellent decontamination can be obtained. Residues from ethylene oxide must be removed by aeration; but otherwise it is convenient to use, versatile, and noncorrosive. Paracetic acid is corrosive for metals and rubber. BPL in the vapor form acts rapidly against bacteria, rickettsiae, and viruses. It has a half-life of 3.5 hours when mixed with water, is easily neutralized with water, and lends itself to removal by aeration. The National Institutes of Health does not recommend BPL as a decontaminant because it has been identified as a suspect carcinogen.

H. Residual action of decontaminants. As noted in the preceding discussion of decontaminant properties, many of the chemical decontaminants often have residual properties that may be considered a desirable feature in terms of aiding in the control of background contamination. One is cautioned, however, to consider residual properties carefully. Ethylene oxide used to sterilize laboratory shoes can leave residues which cause skin irritation. Animal cell cultures, as well as viruses of interest, are also inhibited or inactivated by decontaminants persisting after routine cleaning procedures. Therefore, reusable items that are routinely held in liquid decontaminant prior to autoclaving

and cleaning should receive particular attention in rinse cycles. Similarly, during general area decontamination with gases or vapors, it may be necessary to protect new and used clean items by removing them from the area or by enclosing them in gastight bags or by insuring adequate aeration following decontamination.

I. Selecting chemical decontaminants for research on recombinant DNA molecules. No single chemical decontaminant or method will be effective or practical for all situations in which decontamination is required. Selection of chemical decontaminants and procedures must be preceded by practical consideration of the purposes for the decontamination and the interacting factors that will ultimately determine how that purpose is to be achieved. Selection of any given procedure will be influenced by the information derived from answers to the following questions:

1. What is the target microorganism(s)?
2. What decontaminants in what form are known to, or can be expected to, inactivate the target microorganism(s)?
3. What degree of inactivation is required?
4. In what menstuum is the microorganism suspended; i.e., simple or complex, on solid or porous surfaces, and/or airborne?
5. What is the highest concentration of cells anticipated to be encountered?
6. Can the decontaminant either as an aqueous solution, a vapor, or a gas reasonably be expected to contact the microorganisms, and can effective duration of contact be maintained?
7. What restrictions apply with respect to compatibility of materials?
8. Does the anticipated use situation require immediate availability of an effective concentration of the decontaminant or will sufficient time be available for preparation of the working concentration shortly before its anticipated use?

The primary target of decontamination in the infectious disease laboratory is the microorganism under active investigation. Laboratory preparations or infectious agents usually have titers grossly in excess of those normally observed in nature. The decontamination of these high-titer materials presents certain problems. Maintenance systems for bacteria or viruses are specifically selected to preserve viability of the agent. Agar, proteinaceous nutrients, and cellular materials can be extremely effective in physically retarding or chemically binding active moieties of chemical decontaminants. Such interferences with the desired action of decontaminants may require the use of decontaminant concentrations and contact times in excess of those shown to be effective in the test tube. Similarly, a major portion of decontaminant contact time required to achieve a given level of agent inactivation may be expended in inactivating a relatively small number of the more resistant members of the population. The current state of the art provides little information on which to predict the probable virulence of these survivors. These problems are, however, common to all potentially pathogenic agents and must always be considered in selecting decontaminants and procedures for their use.

Microorganisms exhibit a range of resistance to chemical decontaminants. In terms of practical decontamination, most vegetative bacteria, fungi and lipid-containing viruses, are relatively susceptible to chemical decontamination. The non-lipid-containing viruses and bacteria with a waxy coating such as tubercle bacillus occupy a mid-range of resistance. Spore forms are the most resistant.

A decontaminant selected on the basis of its effectiveness against microorganisms on any range of the resistance scale will be ef-

fective against microorganisms lower on the scale. Therefore, if decontaminants that effectively control spore forms are selected for routine laboratory decontamination, it can be assumed that any other microorganisms generated by laboratory operations, even in high concentrations, would also be inactivated.

An additional area that must be considered and for which there is little definitive information available is the "inactivation" of nucleic acids. Nucleic acids often have better survival characteristics under adverse conditions than do the intact virions and cells from which they were derived. Strong oxidizers, strong acids and bases, and either gaseous or aqueous formaldehyde should react readily with nucleic acids. Their ability

to destroy the nucleic acid being studied, however, should be confirmed in the experimenter's laboratory. Because of innate differences in the chemistry of RNA and DNA the effectiveness of a decontaminant for one cannot be extrapolated to the other. For example, RNA molecules are susceptible to mild alkaline hydrolysis by virtue of the free hydroxyl group in the 2' position, whereas DNA molecules are not susceptible to mild alkaline hydrolysis.

Table II summarizes pertinent characteristics and potential applications for several categories of chemical decontaminants most likely to be used in the biological laboratory. Practical concentrations and contact times that may differ markedly from the recommendations of manufacturers of proprietary

products are suggested. It has been assumed that microorganisms will be afforded a high degree of potential protection by organic menstrooms. It has not been assumed that a sterile state will result from application of the indicated concentrations and contact times. It should be emphasized that these data are only indicative of efficacy under artificial test conditions. The efficacy of any of the decontaminants should be conclusively determined by individual investigators. It is readily evident that each of the decontaminants has a range of advantages and disadvantages as well as a range of potential for inactivation of a diverse microflor. Equally evident is the need for compromise as an alternative to maintaining a veritable "drug store" of decontaminants.

[illegible]

1. ☐ A.C. - not applicable ☐ A.C. - Not effective

2. ☐ The study results dependent on views

3. ☐ Neither flammable or explosive in 90% O₂ or flammable hydrocarbon use form.

4. ☐ At concentrations of 7 to 71% by volume in air, solid-vapour to open flame.

5. ☐ Protected from light and air.

6. ☐ By sale or mouth or both - refer to manufacturer's literature and/or health index.

7. ☐ No use limitations or labels listing all products available. Individual listings (if contained) do not constitute a rejection of any product by the BIA.

8. ☐ Refer to microcopy and camera lenses.

A. Introduction. Well-defined housekeeping procedures and schedules are essential in reducing the risks of working with etiologic agents and in protecting the integrity of the research program. This is particularly true in the biological laboratory operating under less than total containment concepts and in all areas used for the housing of animals, whether or not they have been intentionally infected. A well-conceived and well-executed housekeeping program limits physical clutter that could distract the attention and interfere with the activities of laboratory personnel at a critical moment in a potentially hazardous procedure, provides a work area that will not in itself be a source of physical injury or contamination, and provides an area that promotes the efficient use of decontaminants in the event of the inadvertent release of a harmful agent. Less immediately evident are the benefits of establishing, among personnel of widely varying levels of education, an appreciation of the nature and sources of biological contamination.

Housekeeping is an omnibus term that can be interpreted as broadly or as narrowly as one chooses. It can be seen that many of the procedures found under special headings, such as decontamination, disposal, and animal care, are, in reality, specific instructions for safely accomplishing otherwise routine housekeeping chores. In these safety suggestions for research on recombinant DNA molecules, it has been elected to address specifically only tasks of a janitorial nature under the subject of housekeeping.

The objectives of housekeeping in the biological laboratory are to:

1. Provide an orderly work area conducive to the accomplishment of the research program.
2. Provide work areas devoid of physical hazards.
3. Provide a clean work area with background contamination ideally held to a zero level but more realistically to a level such that extraordinary measures in sterile techniques are not required to maintain integrity of the biological systems being researched.
4. Prevent the accumulation of materials from current and past experiments that constitute a hazard to laboratory personnel.
5. Prevent the creation of aerosols of hazardous materials as a result of the housekeeping procedures used.

Procedures developed in the area of house-keeping should be based on the highest level of risk to which the personnel and integrity of the experiments will be subject. Such an approach avoids the confusion of multiple practices and retraining of personnel. The primary function, then, of routine house-keeping procedures is to prevent the accumulation of organic debris that (i) may harbor microorganisms that are a potential threat to the integrity of the biological systems under investigation, (ii) may enhance the survival of microorganisms inadvertently released in experimental procedures, (iii) may retard penetration of decontaminants, (iv) may be transferable from one area to another on clothing and shoes, (v) may, with sufficient buildup, become a biohazard as

a consequence of secondary aerosolization by personnel and air movement, and (vi) may cause allergenic sensitization of personnel, e.g., to animal danders.

Housekeeping in animal care units has the same primary function as that stated for the laboratory and should, in addition, be as meticulously carried out in quarantine and conditioning areas as in areas used to house experimentally infected animals. No other areas in the laboratory have the constant potential for creation of significant quantities of contaminated organic debris than do animal care facilities.

In all laboratories, efforts to achieve total decontamination and to conduct a major cleanup of the biological complex are normally undertaken at relatively long time intervals. Routine housekeeping must be relied on to provide a work area free of significant sources of background contamination. The provision of such a work area is not simply a matter of indicating in a general way what has to be done, who will do it, and how often. The supervisor must view each task critically in terms of the potential biohazard involved, decide on a detailed procedure for its accomplishment, and provide instructions to laboratory personnel in a manner that minimizes the opportunity for misunderstanding.

The following checklist outlines a portion of the items requiring critical review by the laboratory supervisor. It is not intended to be complete but is presented as an example of the detailed manner in which housekeeping in the biological laboratory complex must be viewed.

NOTICES

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Administration Areas
Aisles
Animal Food Storage
Animal Bedding Storage
Biological Safety Cabinets
Bench Tops and Other Work Surfaces
Ceilings
Change Rooms
Cleaning Solution Disposal
Cages and Cage Racks
Dry Ice Chests
Deep Freeze Chests
Entry and Exit Ways
Equipment Storage
Floors
Glassware
General Laboratory Equipment Cleanup
Hallways
Incubators
Instruments
Insect and Rodent Control
Light Fixtures
Mechanical Equipment Areas
Mops
Pipes—Wall and Ceiling Hung
Refrigerators
Showers
Supply Storage
UV Lamps
Vacuum Cleaners
Waste Accumulations
Waste Water Disposal
Others

Housekeeping in the laboratory is one of the avenues that leads to accomplishing the research program safely. It is important that housekeeping tasks be assigned to personnel who are knowledgeable of the research program and special hazards of the research environment. The recommended approach to housekeeping is the assignment of housekeeping tasks to the research teams on an individual basis for their immediate work areas and on a cooperative basis for areas of common usage. Similarly, animal caretaker personnel should be responsible for housekeeping in animal care areas. The laboratory supervisor must determine the frequency with which the individual and cooperative housekeeping chores need be accomplished. He should provide schedules and perform frequent inspection to assure compliance. This approach assures that research work flow patterns will not be interrupted by an alien cleanup crew, delicate laboratory equipment will be handled only by those most knowledgeable of its particular requirements, and the location of concentrated biological preparations and contaminated equipment used in their preparation and application will be known.

B. *Floor care.* Avoidance of dry sweeping and dusting will reduce the formation of nonspecific environmental aerosols. Wet mopping or vacuum cleaning with a high-efficiency particulate air (HEPA) filter on the exhaust is recommended.

Careful consideration must be given to design and quality in the selection of cleaning equipment and materials and in their use to prevent the substitution of one hazard for another.

In the absence of overt hazardous spills, the cleaning process commonly will consist of an initial vacuuming to remove all gross particulate matter and a follow-up wet mopping with a solution of chemical decontaminant containing a detergent. Depending on the nature of the surfaces to be cleaned and availability of floor drains, removal of residual cleaning solutions can be accomplished by a number of methods. Among these are: Pickup with a partially dry mop, pickup with a wet vacuum that has an adequately filtered exhaust, or removal to a convenient floor drain by use of a floor squeegee.

After cleaning up a spill of infected material, the residual solution should not be

discharged to a sanitary sewer until it has been autoclaved or given further chemical treatment, such as by the addition of sodium hypochlorite sufficient to provide a final concentration of 500 ppm chlorine. Most household bleaches are marketed with a chlorine content of 5.25%. These in a final dilution of 1:100, yield 525 ppm of available chlorine. After allowing a contact time of 15 minutes, these solutions may be flushed down any available drain. Chlorine solutions in these high concentrations may be too corrosive for general application to floors and equipment. In any event, if solutions are used in this way, after the contact time the area should be rinsed with water.

C. *Dry sweeping.*—While it is recommended that dry sweeping be minimized, this may be the only method available or practicable under certain circumstances. In such cases, sweeping compounds used with push brooms and dry-dust mop heads treated to suppress aerosolization of dust should be used.

Sweeping compounds available from the usual janitorial supply firms fall in three categories:

Wax-based compounds used on vinyl floors and waxed floor coverings.

Oil-based compounds for concrete floors.

Oil-based compounds with abrasives (such as sand) to achieve a dry scouring action where much soil is present.

Dry-dust mop heads can be purchased as treated disposable units or as reusable, washable heads that must be treated with appropriate sprays or by other means to improve their dust-capturing property.

D. *Vacuum cleaning.* In the absence of a HEPA filter on the exhaust, the usual wet and dry industrial-type vacuum cleaner is a potent aerosol generator. The HEPA-filtered exhaust used in conjunction with a well-sealed vacuum unit, however, can negate this factor because of its ability to pass large volumes of exhaust air while retaining particles with a minimum efficiency of 99.97 percent. Wet and dry units incorporating a HEPA filter on the exhaust are available from a number of manufacturers.

There are no particular requirements with respect to the manner in which the dry vacuuming is accomplished other than to emphasize that the objective is to remove all debris and particulate matter. The manufacturer's directions adequately detail the frequency of bag changes, filter changes, and mechanical adjustments.

Dry material vacuum-collected during these floor-cleaning activities is potentially contaminated, but the nature of the risk is probably greater to the experimenter than to the experimenter. It is wise to effect bag and filter changes and to clean out collection tanks in a manner that will avoid or minimize aerosolizing the contents of the vacuum cleaner.

A vacuum machine that collects debris in a disposable bag is preferable to machines that collect the major debris in a tank and on an exposed primary filter. Even though it may serve as a primary filter, the disposable bag must be removed with caution. A bellows effect may pump dust out of the bag if its intake opening is not sealed before moving it to a plastic bag for transfer out of the area. In any event, the outer surface of the disposable bag will probably bear some dust contamination, which also may occur on inner surfaces of the machine.

To avoid contaminating experimental materials, the emptying of vacuum collection tanks and changing of bags and filters are best done away from the immediate laboratory area, for example, in a small area that can be easily cleaned afterwards. The use of heavy rubber gloves is recommended when removing wastes from tanks in case broken glass is present. After making the filter changes, all external surfaces of the imme-

diately work area and the equipment should be wiped with a cloth moistened in decontaminant. The operator might plan for a change of laboratory clothing afterwards so as to minimize carrying contamination into other areas of the laboratory.

Avoid use of dry vacuum cleaning equipment in work with high risk agents in the open laboratory. Should it be necessary to use it, it is recommended that gaseous sterilization may be used to minimize aerosolization of microorganisms before waste is emptied from the vacuum container. Because complete penetration of sterilizing gases into the collected dry dust may be a problem, all wastes should be placed in a plastic bag, which then is tightly closed and incinerated or disposed of in an approved manner.

When dry vacuum cleaning equipment has been used within a gastight safety cabinet system, it can be treated in an attached double-door carboxyclave (an autoclave equipped with an ethylene oxide gas sterilization system) to allow for removal and emptying of the collection tank.

If a wet vacuum is to be used for pickup of the detergent-germicide solution from the floor, the manufacturer's recommendations on filter life should be followed. In addition, the operation of the vacuum should be closely observed for evidence of operating changes indicating restricted airflow or, conversely, increased flow indicating filter failure. Liquids collected in the vacuum cleaner after floor mopping will contain decontaminant materials. These liquids may be poured down a convenient floor drain, except in the case of cleanup wastes from an overt spill. The collected liquid should then be autoclaved or treated with chlorine solution before disposal.

Provisions should be made for regular decontamination of the entire vacuum cleaner with formaldehyde gas or vapor, or ethylene oxide. This should be done after use if the vacuum is used in any manner for cleanup of overt spills of infectious material.

E. *Selection of a cleaning solution.* The selection of a detergent-decontaminant combination for routine cleaning of the laboratory complex should be based on the requirements of the area of greatest potential for contamination by the widest spectrum of microorganisms. With rare exception, this will be identified as the animal holding area and the expected microorganisms may well include fungi, viruses, and the vegetative and spore forms of bacteria. A decontaminating solution for such a range of microorganisms would, however, be expensive and excessively corrosive for routine use. Except in those rare instances where it can be assumed that pathogenic spores are being shed by laboratory animals, the risks from the spores are more likely to affect the experiments than the personnel. The spores tend to be associated with organic debris from bedding and food, thus offering potential for removal or at least a large initial reduction in their numbers by vacuum cleaning. A wide range of cleaning solutions that are mildly sporicidal, reasonably residual, and are not destructive to the physical plant are available. Phenol derivatives in combination with a detergent have these characteristics and have been selected for routine use in a number of research facilities. There are numerous detergent-phenolic combinations available on the market. The phenols are one type of a broad spectrum of biocidal substances that include the mercurials, quaternary ammonium compounds, chlorine compounds, iodophores, alcohols, formaldehyde, glutaraldehyde, and combinations of alcohol with either iodine or formaldehyde. These have been discussed in Section VI.

The laboratory supervisor should make a selection from those types most readily avail-

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able which meet the general criteria of effectiveness, residual properties, and low corrosiveness.

F. Wet mopping—two-bucket method. Wet mopping of floors in laboratory and animal care areas is, from a safety standpoint, most conveniently and efficiently accomplished using a two-bucket system. The principal feature of such a system is that fresh detergent-decontaminant solution is always applied to the floor from one bucket, while all spent cleaning solution wrung from the mop is collected in the second bucket. Compact dolly-mounted double-bucket units with foot-operated wringers are available from most janitorial supply houses. A freshly laundered mop head of the cotton string type should be used daily. This requires that a mop with removable head be provided as opposed to a fixed-head type. In practice, the mop is saturated with fresh solution, very lightly wrung into the second bucket and applied to the floor using a figure eight motion of the mop head. After every four or five strokes, the mop head is turned over and the process continued until an area of approximately 100 ft² has been covered. After allowing a contact time of five minutes, the solution is removed with either a wet vacuum cleaner with HEPA-filtered exhaust or with the wrung-out mop. The mopping is continued in 100 ft² increments until the total floor area has been covered. Floor-cleaning procedures are most effectively completed after the majority of the work force has departed and should progress from areas of least potential contamination to those of greatest potential. Before a mop head is sent to a laundry, it should be autoclaved. Spent cleaning fluids are disposed of by flushing down the drain.

If the cleanup follows an overt spill of infectious material, the spent cleaning solution, after removal from the floor, should be autoclaved or treated with chlorine solution. Chlorine (as household bleach) should be added to give 500 ppm and held for a contact time of 15 minutes before dumping in the sanitary sewer.

G. Alternative floor cleaning method for animal care areas and areas with monolithic floors. The absence of permanently placed laboratory benches and fixed equipment, coupled with the mobility of modern cage racks, makes possible alternate floor-cleaning procedures in animal care facilities. As in all considerations of methodologies in biomedical laboratory facilities, it is necessary to assess the compatibility of procedures and facilities from the hazard point of view. The alternative floor-cleaning procedure to be discussed requires that floors are completely sealed or of monolithic construction so that liquid leakage to adjacent areas does not occur and that floor drains or wet vacuum cleaners are available.

Subsequent to the removal of all debris by dry vacuum, move the cage racks to one side of the room. Cover the floor of the remaining cleared portion of the room with detergent-decontaminant solution applied at a rate of approximately one gallon per 144 ft² from a one-gallon tank sprayer, using a setting on the nozzle which will cause the solution to flow on and not create a spray. The nozzle is placed close to the floor. Allow a fifteen-minute contact period; then push the cleaning solution to the floor drain with a large floor squeegee or pick it up with a wet vacuum. Allow the floor to air dry; move the cage racks into the cleaned area, and repeat the process for the remaining floor area. Floor drains in these areas should be rim-flush, at least six inches in diameter, and fitted with a screen or porous trap bucket to catch large debris that escapes the initial dry cleaning. Such screens and baskets should be emptied after treatment with a decontaminant. If space utilization does not require frequent floor washdown, pour a half-gallon of deter-

gent-decontaminant solution into the drain each week to keep the trap in the waste line filled against backup of sewer gases.

VIII. CLEAN-UP OF BIOHAZARDOUS SPILLS (8, 9, 10)

A. Biohazardous spill in a biological safety cabinet. Chemical decontamination procedures should be initiated at once while the cabinet continues to operate to prevent escape of contaminants from the cabinet.

1. Spray or wipe walls, work surfaces, and equipment with a 2 percent solution of an iodophor-decontaminant (Wescodyne or equivalent). A decontaminant detergent has the advantage of detergent activity, which is important because extraneous organic substances frequently interfere with the reaction between the microorganisms and the active agent of the decontaminant. Operator should wear gloves during this procedure.

2. Flood the top work surface tray, and, if a Class II cabinet, the drain pans and catch basins below the work surface, with a decontaminant and allow to stand 10–15 minutes.

3. Remove excess decontaminant from the tray by wiping with a sponge or cloth soaked in a decontaminant. For Class II cabinets, drain the tray into the cabinet base, lift out tray and removable exhaust grille work, and wipe off top and bottom (underside) surfaces with a sponge or cloth soaked in a decontaminant. Then replace in position and drain recontaminant from cabinet base into appropriate container and autoclave according to standard procedures. Gloves, cloth or sponge should be discarded in an autoclave pan and autoclaved.

B. Biohazard spill outside a biological safety cabinet. 1. Hold your breath, leave the room immediately, and close the door.

2. Warn others not to enter the contaminated area.

3. Remove and put into a container contaminated garments for autoclaving and thoroughly wash hands and face.

4. Wait 30 minutes to allow dissipation of aerosols created by the spill.

5. Put on a long-sleeve gown, mask, and rubber gloves before reentering the room. (For a high risk agent, a jumpsuit with tight-fitting wrists and use of a respirator should be considered).

6. Pour a decontaminant solution (5% iodophor or 5% hypochlorite are recommended) around the spill and allow to flow into the spill. Paper towels soaked with the decontaminant may be used to cover the area. To minimize aerosolization, avoid pouring the decontaminant solution directly onto the spill.

7. Let stand 20 minutes to allow an adequate contact time.

8. Using an autoclavable dust pan and squeegee, transfer all contaminated materials (paper towels, glass, liquid, gloves, etc.) into a deep autoclave pan. Cover the pan with aluminum foil or other suitable cover and autoclave according to standard directions.

9. The dust pan and squeegee should be placed in an autoclavable bag and autoclaved according to standard directions. Contact of reusable items with non-autoclavable plastic bags should be avoided—separation of the plastic after autoclaving can be very difficult.

C. Radioactive biohazard spill outside a biological safety cabinet. In the event that a biohazardous spill also involves a radiation hazard, the clean-up procedure may have to be modified, depending on an evaluation of the risk assessment of relative biological and radiological hazard.

Laboratories handling radioactive substances must have the services of a designated radiation protection officer available for consultation.

The following procedure indicates suggested variations from the biohazard spill pro-

cedure (above) that should be considered when a radioactive biohazard spill occurs outside a Biological Safety Cabinet.¹

1. Holding your breath, leave the room immediately and close the door.

2. Warn others not to enter the contaminated area.

3. Remove and put in a container contaminated garments for autoclaving and thoroughly wash hands and face.

4. Wait thirty minutes to allow dissipation of aerosols created by the spill.

*Before clean-up procedures begin, a radiation protection officer should survey the spill for external radiation hazard to determine the relative degree of risk.

5. Put on a long-sleeve gown, mask, and rubber gloves before reentering the room. (For a high risk agent, a jumpsuit with tight-fitting sleeves and a respirator should be considered).

6. Pour a decontaminant solution (5% iodophor or 5% hypochlorite are recommended) around the spill and allow to flow into the spill. Paper towels soaked with the decontaminant may be used to cover the area. To minimize aerosolization, avoid pouring the decontaminant solution directly onto the spill.

7. Let stand 20 minutes to allow adequate disinfectant contact time.

8. *In most cases, the spill will involve ¹⁴C or ³H, which present no external hazard. However, if more energetic beta or gamma emitters are involved, care must be taken to prevent hand and body radiation exposure. The radiation protection officer must make this determination before the clean-up operation is begun.

If the radiation protection officer approves, the bio-hazard-handling procedure may begin: Using an autoclavable dust pan and squeegee, transfer all contaminated materials (paper towels, glass, liquid, gloves, etc.) into a deep autoclave pan. Cover the pan with aluminum foil or other suitable cover and autoclave according to standard directions.

*If the radiation protection officer determines that radioactive vapors may be released and thereby contaminate the autoclave, the material must not be autoclaved. In that case, sufficient decontaminant solution to immerse the contents should be added to the wastes container. The cover should be sealed with waterproof tape, and the container stored and handled for disposal as radioactive waste. Radioactive and biohazard warning symbols should be affixed to the waste container. As a general rule, autoclaving should be avoided.

9. If autoclaving has been approved, the dust pan and squeegee should be placed in an autoclavable bag and autoclaved according to standard directions. Contact of reusable items with plastic bags should be avoided—separation of the plastic after autoclaving can be very difficult.

*A final radioactive survey should be made of the spill area, dust pan, and squeegee with a Geiger counter, or a smear should be taken and counted in a liquid scintillation counter.

IX. A SECONDARY RESERVOIR AND FILTRATION APPARATUS FOR VACUUM SYSTEMS

The aspiration of tissue culture media from monolayer cultures and of supernatants from centrifuged samples into collection vessels or reservoirs is a common procedure in many laboratories. To prevent the accidental contamination by aerosols or fluids of house vacuum systems or laboratory pumps, some investigators have installed side arm flasks containing cotton, sulfuric acid or decontaminant between the reservoir and the vacuum line. Cotton is not completely effective as a filtering agent,

¹ Changes in procedures have been starred and italicized.

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sulfuric acid will corrode pipes, and contaminants may lose their inactivating ability upon standing. The introduction of a cartridge-type filter that is moisture resistant and has a rated capacity to remove particles 350 nm (0.35u) or larger in size provides an effective barrier to virus aerosols.

The secondary reservoir and filtration apparatus can be assembled from readily available units as shown in Figure 1. A length of plastic tubing $\frac{1}{4}$ inch I.D. x $\frac{1}{16}$ inch wall is attached at one end of the reservoir and at the other end to the lower arm of a filtration and media storage flask. These flasks vary in capacity from 250 to 4000 ml, the choice of flask depending on available space and amount of fluid that could be accidentally aspirated. A second tube of the same dimensions is attached from the upper arm of the flask to the inlet port of the disposable filter assembly. The third tube is attached from the filter assembly to a vacuum source. The tubes are securely held to the filter by fittings supplied with the filter and the other tubing connections can be secured by worm drive hose clamps.

Ideally the flask should be placed higher than the reservoir of collection vessel. If fluid is accidentally drawn into the flask, the liquid can drain back into the reservoir by gravity if the connection at the vacuum line is broken. This prevents the loss of fluid which the investigator needs to retain.

Should the flask be used only for the recovery and storage of waste fluids, then the addition of a few grams of Dow Corning Antifoam A to the flask will reduce violent foaming of fluids aspirated into it. Such fluids can be decontaminated by introducing into the reservoir a final 5% concentration of an iodophor or other appropriate decontaminant, holding for 30 minutes and draining as above.

If the filter becomes contaminated or requires changing, the filter and flask can be safely removed by clamping the line between filter and vacuum source. The filter and flask should be autoclaved before the filter is discarded. A new filter can then be installed and the assembly replaced.

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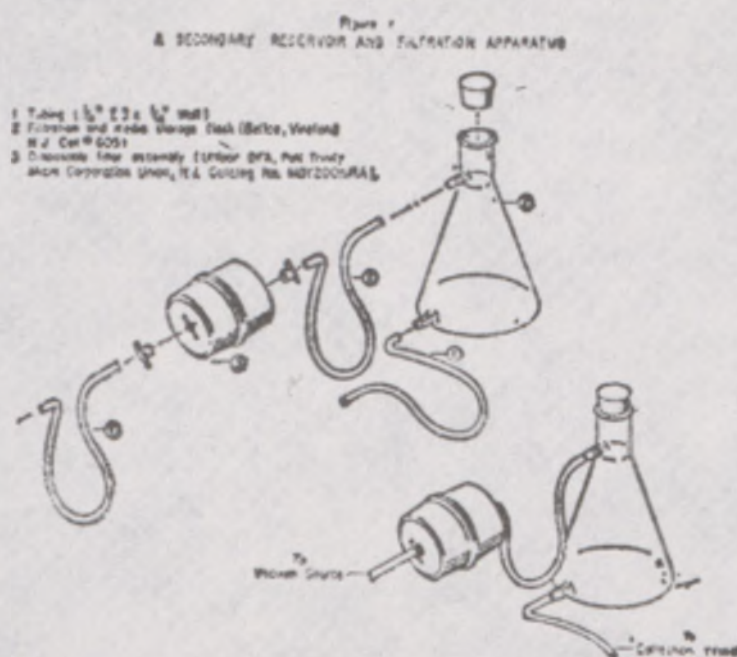


FIGURE 1

X. PACKAGING AND SHIPPING

A. Introduction. Federal regulations and carrier tariffs have been promulgated to ensure the safe transport of hazardous bio-

logical materials. The NIH Guidelines specify that all DNA recombinant materials will be packaged and shipped in containers that meet the requirements of these regulations and carrier tariffs. In addition when any portion of the recombinant DNA material is derived from an etiologic agent listed in paragraph (c) of 42-CFR 72.25 (which is included at the end of this section, page D-85) the labeling requirements in these regulations and carrier tariffs shall apply.

B. Packaging of recombinant DNA materials. 1. *Volume less than 50 ml.* Material shall be placed in a securely closed, watertight container [primary container (test tube, vial, etc.)] which shall be enclosed in a second, durable watertight container (secondary container). Several primary containers may be enclosed in a single secondary container, if the total volume of all the primary containers so enclosed does not exceed 50 ml. The space at the top, bottom, and sides between the primary and secondary containers shall contain sufficient nonparticulate absorbent material to absorb the entire contents of the primary container(s) in case of breakage or leakage. Each set of primary and secondary containers shall then be enclosed in an outer shipping container constructed of corrugated fiberboard, cardboard, wood, or other material of equivalent strength.

If dry ice is used as a refrigerant, it must be placed outside the secondary container(s).

Descriptions of this packaging method are given in Table III.

2. *Volumes of 50 ml or Greater.* Material shall be placed in a securely closed, watertight container (primary container) which shall be enclosed in a second, durable watertight container (secondary container). Single primary containers shall not contain more than 500 ml. of material. However, two or more primary containers whose combined volumes do not exceed 500 ml. may be placed in a single secondary container. The space at the top, bottom, and sides between the primary and secondary containers shall contain sufficient non-particulate absorbent material to absorb the entire contents of the primary container(s) in case of breakage or leakage. Each set of primary and secondary containers shall then be enclosed in an outer shipping container constructed of corrugated fiberboard, cardboard, wood, or other material of equivalent strength. A shock absorbent material, in volume at least equal to that of the absorbent material between the primary and secondary containers, shall be placed at the top, bottom, and sides between the secondary container and the outer shipping container. Not more than eight secondary shipping containers may be enclosed in a single outer shipping container. (The maximum amount of materials which may

be enclosed within a single outer shipping container should not exceed 4,000 ml.)

If dry ice is used as a refrigerant, it must be placed outside the secondary container(s). If dry ice is used between the secondary container and the outer shipping container, the shock absorbent material shall be placed so that the secondary container does not become loose inside the outer shipping container as the dry ice sublimates.

Descriptions of packages which comply with the regulations of the Department of Transportation (DOT) are given in Table IV.

C. Labeling of packages containing recombinant DNA materials. 1. Materials which do not contain any portion of an etiologic agent listed in paragraph (c) of 42 CFR 72.25.

Material data forms, letters, and other information identifying or describing the material should be placed around the outside of the secondary container. Place only the address label on the outer shipping container.

DO NOT USE THE LABEL FOR ETIOLOGIC AGENTS/BIOMEDICAL MATERIAL.

2. Materials which contain any portion of an etiologic agent listed in paragraph (c) of 42 CFR 72.25.

Material data forms, letters, and other information identifying or describing the material should be placed around the outside of the secondary container. In addition to the address label, the label for Etiologic Agents/Biomedical Material must be affixed to the outer shipping container. This label is described in paragraph (c)(4) of 42 CFR 72.25.

3. Materials which contain any portion of a plant pest (plant pathogens) which are so defined by the Department of Agriculture (USDA).

Material data forms, letters, and other information identifying or describing the material should be placed around the outside of the secondary container. In addition to the address label, the shipping labels furnished by the USDA as part of the General, Courtesy, or Special Permits required for research with and shipment of such agents shall be affixed to the outer shipping container.

D. Additional shipping requirements and limitations for recombinant DNA materials.—1. *Domestic Transportation.* Civil Aeronautics Board Rule No. 82 (Air Transport Association Restricted Articles Tariff 6-D) requires that a Shipper's Certificate, depicted below, be completed and affixed to all shipments which bear the ETIOLOGIC AGENT/BIOMEDICAL MATERIALS label required under the provisions of the Interstate Quarantine regulations (42 CFR 72.25(c)). The Certificate must be completed in duplicate and affixed to the outer shipping container.

This is to certify that the contents of this consignment are properly classified, described by proper shipping name and are packed, marked and labelled and are in proper condition for carriage by air according to all applicable carrier and government regulations. (For international shipments add "and to the IATA Restricted Articles Regulations") This consignment is within the limitations prescribed for: PASSENGER AIRCRAFT/CARGO ONLY (cross out nonapplicable).

Number of Packages	Specify Each Article Separately (Proper Shipping Name)	Classification	Net Quantity per Package
	ETIOLOGIC AGENT, n.o.s.	ETIO. AG.	

Shipper:

Date: _____

(Signature of Shipper)

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Shipments of recombinant DNA Materials exceeding 50 ml in volume and containing any portion of an etiologic agent listed in paragraph (c) of 42 CFR 72.25 are restricted, by DOT regulations, to transport by cargo only aircraft. When the volume of a single primary container exceeds the 50 ml limitation, this restriction must be indicated on the Shipper's Certificate by crossing out "Passenger Aircraft".

When dry ice is used as a refrigerant an "ORA—Group A—DRY ICE LABEL" should be affixed to the outer shipping container.

The amount of dry ice used and the date packed should be designated on the label.

2. *International Transportation.*—In addition to the packaging and labeling requirements of the regulations previously cited, international shipments of recombinant DNA materials in which any portion of the material is derived from an etiologic agent listed in paragraph (c) of 42 CFR 72.25 must have one or more of the following documents—depending on the country of destination:

(1) Parcel Post Customs Declaration (PS 2966) tag.

- (2) Parcel Post Customs Declaration (PS 2966-A) label.
- (3) International Parcel Post—Instructions Given by Sender (POD 2922) label.
- (4) Dispatch note (POD 2972) tag.
- (5) "Violet Label"
- (6) Shipper's Certificate specified in the current International Air Transport Association Tariff. Individual country requirements are listed in "International Postage Rates and Fees" (USPO Publication 51).

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TABLE III
Description of Packages for Material in Volumes less than 50 ml.

Volume (ml)	Primary Container	Packing	Secondary Container	Packing	Outer Shipping ^{d/} Container
15 or less	Sealed vial(s) or small glass test tube, screw cap ^a or stopper, taped	<u>a/</u>	Metal can 1" diam. x 7" O.D. metal screw cap	None Required	Fiberbody; metal screw cap, top and bottom; 1-1/2" diam. x 7 to 7-1/2" O.D.
30 or less	One 20 x 150 mm test tube, taped ^a stopper or multiple small vials	<u>a/</u>	Metal can 2-1/2" diam. x 6-1/2" high O.D. screw cap	None Required	Fiberbody; metal screw cap, top and bottom; 3-1/4" diam. x 7 to 7-1/2" O.D.
30 or less	Plastic ^a screw cap ^a bottle or Pyrex glass with skirt rubber stopper	<u>a/</u>	Metal can 2-1/2" diam. x 6-1/2" high O.D. screw cap	None Required.	Fiberbody; metal screw cap, top and bottom; 3-1/4" diam. x 7 to 7-1/2" O.D.
30 or less	Multiple watertight vials or ^a tubes, taped stoppers	<u>a/</u>	One or more friction-seal tin cans ^{b/} 306 x 400 or larger	<u>c/</u>	Fiberboard box

^aThe flexibility of the plastic bottle requires that a stopper or screw cap be secured in place by adhesive tape. The usual equivalent-size glass flat-sided prescription bottle is too fragile for use. For air transport, all stoppers, corks, and caps on primary containers must be secured in place with wire, tape, or other means, and all screw-capped containers of unfrozen liquid must be placed in 5 or 6 mil polyvinyl tubing heat-sealed at both ends to prevent atmospheric decompression that may result in leakage past the screw cap.

O.D. = outside dimensions.

a/ Nonparticulate absorbent material at top, bottom and sides that will completely absorb contents of the primary container(s).

b/ 610 x 708 and 804 x 908 are trade designations for outside dimensions of 6-10/16 inches diameter x 7-8/16" height, and 8-4/16" x 9-8/16".

c/ None required, but with the 306 x 400 cans or larger cans use sufficient nonparticulate shock-absorbent material to prevent rattling.

d/ If materials are to be refrigerated, it is recommended that an overpack be used to contain the refrigerant and the secured (original) outer shipping container. A leak proof outer container must be used for water ice. If dry ice is used the outer container must permit release of carbon dioxide. Interior supports must be provided to hold the container(s) in the original position(s) after wet or dry ice has dissipated.

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TABLE IV
Description of Packages for Material in Volumes of 50 ml or greater

Volume (ml)	Primary Container	Packing	Secondary Container	Packing		Outer Shipping Container	
				With Refrigerant	Without Refrigerant	With Refrigerant	Without Refrigerant
51 to 100 ml	Plastic ^a or Pyrex glass screw cap ^a bottle; rubber or skirt rubber stopper, taped ^a	<u>a/</u>	Consists of metal container & outer container specified in Table III	Styrofoam box shock-absorbent insulation	<u>c/</u>	Fiberboard box closely fitting the styrofoam box, taped shut	Corrugated fiberboard or cardboard box, taped shut
100 max.	One 100 ml plastic ^a screw cap ^a narrow neck bottle or Pyrex glass, taped ^a	<u>a/</u>	No. 3 crimp seal tin can 404 x 700 or a 1-gallon friction-seal tin can, 610 x 708, top soldered or clipped at 4 points <u>b/</u>	Styrofoam box shock-absorbent insulation	<u>c/</u>	Fiberboard box closely fitting the styrofoam box, taped shut	V3C cardboard box PSJ type, 9-3/16" x 9-3/16" x 11-1/4" high O.D. taped shut with 3" type PSJ tape
200 max.	Two 100 ml plastic ^a screw cap ^a bottles or Pyrex glass, taped	<u>a/</u>	No. 3 crimp seal tin can 404 x 700 or a 1-gallon friction-seal tin can, 610 x 708, top soldered or clipped at 4 points <u>b/</u>	Styrofoam box shock-absorbent insulation	<u>c/</u>	Fiberboard box closely fitting the styrofoam box, taped shut	V3C cardboard box PSJ type, 9-3/16" x 9-3/16" x 11-1/4" high O.D. taped shut with 3" type PSJ tape
250 max.	One 250 ml, plastic ^a narrow mouth screw cap ^a bottle or Pyrex glass skirted rubber stopper, taped ^a	<u>a/</u>	No. 3 crimp seal tin can 404 x 700 or a 1-gallon friction-seal tin can, 610 x 708, top soldered or clipped at 4 points <u>b/</u>	Styrofoam box shock-absorbent insulation	<u>c/</u>	Fiberboard box closely fitting the styrofoam box, taped shut	V3C cardboard box PSJ type, 9-3/16" x 9-3/16" x 11-1/4" high O.D. taped shut with 3" type PSJ tape
300 max.	Two 250 ml plastic ^a screw cap ^a bottles or Pyrex glass bottles, taped ^a	<u>a/</u>	2-gallon friction-seal tin can, 804 x 908, top soldered or clipped at 4 points <u>b/</u>	Styrofoam box shock-absorbent insulation	<u>c/</u>	Fiberboard box closely fitting the styrofoam box, taped shut	V3C cardboard box 12-1/4" x 12-1/4" x 10-3/16" high O.D. taped shut with 3" wide PSJ tape.
300 max.	300 ml Pyrex glass bottle, rubber-skirt stopper, taped, or 300 ml plastic ^a bottle, narrow or wide mouth, screw cap ^a , taped	<u>a/</u>	No. 12 crimp seal tin can 603 x 810 2-gallon friction-seal tin can, 804 x 908, top soldered or clipped at 4 points <u>b/</u>	Styrofoam box shock-absorbent insulation	<u>c/</u>	Fiberboard box closely fitting the styrofoam box, taped shut	V3C cardboard box 12-1/4" x 12-1/4" x 10-3/16" high O.D. taped shut with 3" wide PSJ tape. For the No. 12 can a cardboard box is ok taped shut

^aThe flexibility of the plastic bottle requires that a stopper or screw cap be secured in place by adhesive tape. The usual equivalent-size glass flat-sided prescription bottle is too fragile for use. For air transport, all stoppers, corks, and caps on primary containers must be secured in place with wire, tape, or other means, and all screw-capped containers of unfrozen liquid must be placed in 3 or 6 mil polyvinyl tubing heat-sealed at both ends to prevent atmospheric decompression that may result in leakage past the screw cap.

O.D. = outside dimensions.

a/ Nonparticulate absorbent material at top, bottom and sides that will completely absorb contents of the primary container(s).

b/ 610 x 708 and 804 x 908 are trade designations for outside dimensions of 6-10/16 inches diameter x 7-8/16" height, and 8-4/16" x 9-8/16".

c/ Shock absorbent material, in volume at least equal to that between the primary and secondary container(s), at the top, bottom, and sides between the secondary container and the outer shipping container. The shock absorbent material shall be so placed that the secondary container(s) does not become loose inside the outer shipping container as the water ice or dry ice is dissipated.

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ATTACHMENT I

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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ATLANTA, GEORGIA 30333
Telephone: (404) 633-3311, Ext. 3683

TITLE 42—PUBLIC HEALTH

Chapter I—Public Health Service, Department of Health, Education, and Welfare

SUBCHAPTER F—QUARANTINE, INSPECTION, LICENSING

PART 72—INTERSTATE QUARANTINE

Subpart C—Shipment of Certain Things

Section 72.25 of Part 72, Title 42, Code of Federal Regulations, is amended to read as follows:

§ 72.25 Etiologic agents.¹

(a) *Definitions.* As used in this section:

(1) An "etiologic agent" means a viable microorganism or its toxin which causes, or may cause, human disease.

(2) A "diagnostic specimen" means any human or animal material including, but not limited to, excreta, secreta, blood and its components, tissue, and tissue fluids being shipped for purposes of diagnosis.

(3) A "biological product" means a biological product prepared and manufactured in accordance with the provisions of 9 CFR Part 10, Licensed Veterinary Biological Products, 42 CFR Part 73, Licensed Human Biological Products, 21 CFR 130.3, *New drugs for investigational use in humans*, 9 CFR Part 103, Biological Products for Experimental Treatment of Animals, or 21 CFR 130.3(a), *New drugs for investigational use in animals*, and which, in accordance with such provisions, may be shipped in interstate traffic.

(b) *Transportation; etiologic agent minimum packaging requirements.* No person may knowingly transport or cause to be transported in interstate traffic, directly or indirectly, any material, including but not limited to, diagnostic specimens and biological products, containing, or reasonably believed by such person to contain, an etiologic agent unless such material is packaged to withstand leakage of contents, shocks, pressure changes, and other conditions incident to ordinary handling in transportation.

(c) *Transportation; etiologic agents subject to additional requirements.* No person may knowingly transport or cause to be transported in interstate traffic, directly or indirectly, any material, other than diagnostic specimens and biological products, containing, or reasonably believed by such person to contain, one or more of the following etiologic agents

unless such material is packaged in accordance with the requirements specified in paragraph (b) of this section, and unless, in addition, such material is packaged and shipped in accordance with the requirements specified in subparagraphs (1)–(6) of this paragraph:

BACTERIAL AGENTS

Actinobacillus—all species.
Arizona hinshawii—all serotypes.
Bacillus anthracis.
Bartonella—all species.
Bordetella—all species.
Borrelia recurrentis, *B. vincentii*.
Brucella—all species.
Clostridium botulinum, *Cl. chauvoei*, *Cl. haemolyticum*, *Cl. histolyticum*, *Cl. novyi*, *Cl. septicum*, *Cl. tetani*.
Corynebacterium diphtheriae *C. equi*, *C. haemolyticum*, *C. pseudotuberculosis*, *C. pyogenes*, *C. renale*.
Diplococcus (Streptococcus) pneumoniae.
Erysipelothrix insidiosa.
Escherichia coli, all enteropathogenic serotypes.
Francisella (Pasteurella) tularensis.
Haemophilus ducreyi, *H. influenzae*.
Herellea vaginicola.
Klebsiella—all species and all serotypes.
Leptospira interrogans—all serotypes.
Listeria—all species.
Mima polymorpha.
Moraxella—all species.
Mycobacterium—all species.
Mycoplasma—all species.
Neisseria gonorrhoeae, *N. meningitidis*.
Pasteurella—all species.
Pseudomonas pseudomallei.
Salmonella—all species and all serotypes.
Shigella—all species and all serotypes.
Sphaerophorus necrophorus.
Staphylococcus aureus.
Streptobacillus moniliformis.
Streptococcus pyogenes.
Treponema carereum, *T. pallidum*, and *T. pertenue*.
Vibrio fetus, *V. comma*, including biotype El Tor, and *V. parahemolyticus*.
Yersenia (Pasteurella) pestis.

FUNGAL AGENTS

Actinomyces (including *Nocardia* species, *Actinomyces* species and *Arachnia propionica*).
Blastomyces dermatitidis.
Coccidioides immitis.
Cryptococcus neoformans.
Histoplasma capsulatum.
Paracoccidioides brasiliensis.

VIRAL, RICKETTSIAL, AND CHLAMYDIAL AGENTS

Adenoviruses—human—all types.
Arboviruses.
Coxiella burnetii.
Coxsackie A and B viruses—all types.
Cytomegaloviruses.

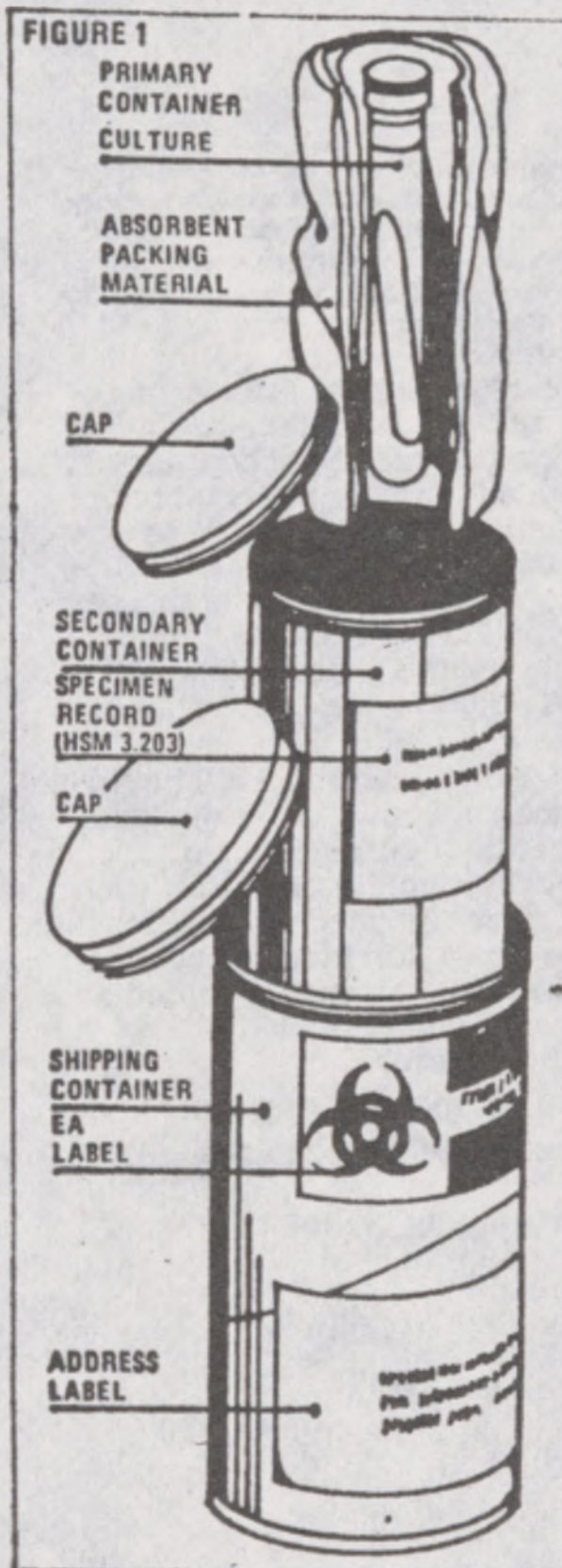
Dengue virus.
Echoviruses—all types.
Encephalomyocarditis virus.
Hemorrhagic fever agents, including *Crimean hemorrhagic fever (Congo)*, *Junin*, and *Machupo viruses*, and others as yet undefined.
Hepatitis-associated antigen.
Herpesvirus—all members.
Infectious bronchitis-like virus.
Influenza viruses—all types.
Lassa virus.
Lymphocytic choriomeningitis virus.
Marburg virus.
Measles virus.
Mumps virus.
Parainfluenza viruses—all types.
Polioviruses—all types.
Poxviruses—all members.
Psittacosis - Ornithosis - Trachoma-Lymphogranuloma group of agents.
Rabies virus—all strains.
Reoviruses—all types.
Respiratory syncytial virus.
Rhinoviruses—all types.
Rickettsia—all species.
Rubella virus.
Simian viruses—all types.
Tick-borne encephalitis virus complex, including *Russian spring-summer encephalitis*, *Kyasanur forest disease*, *Omsk hemorrhagic fever*, and *Central European encephalitis viruses*.
Vaccinia virus.
Varicella virus.
Variola major and *Variola minor viruses*.
Vesicular stomatitis virus.
Yellow fever virus.

(1) *Volume less than 50 ml.* Material shall be placed in a securely closed, watertight container (primary container (test tube, vial, etc.)) which shall be enclosed in a second, durable watertight container (secondary container). Several primary containers may be enclosed in a single secondary container, if the total volume of all the primary containers so enclosed does not exceed 50 ml. The space at the top, bottom, and sides between the primary and secondary containers shall contain sufficient nonparticulate absorbent material to absorb the entire contents of the primary container(s) in case of breakage or leakage. Each set of primary and secondary containers shall then be enclosed in an outer shipping container constructed of corrugated fiberboard, cardboard, wood, or other material of equivalent strength.

(2) *Volume 50 ml. or greater.* Packaging of material in volumes of 50 ml. or more shall include, in addition, a shock-absorbent material, in volume at least equal to that of the absorbent material

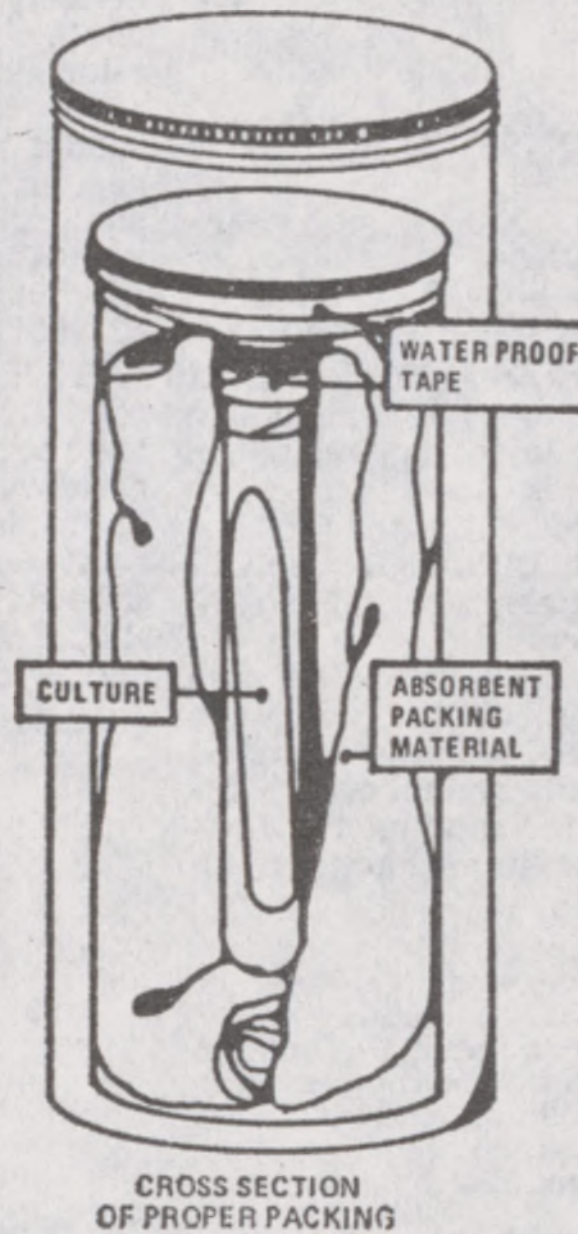
¹ The requirements of this section are in addition to and not in lieu of any other packaging or other requirements for the transportation of etiologic agents in interstate traffic prescribed by the Department of Transportation and other agencies of the Federal Government.

FEDERAL REGISTER, VOL. 41, NO. 176—THURSDAY, SEPTEMBER 9, 1976



PACKAGING AND LABELING OF ETIOLOGIC AGENTS

FIGURE 2



The Interstate Quarantine Regulations (42 CFR, Part 72.25 Etiologic Agents) was revised July 31, 1972 to provide for packaging and labeling requirements for etiologic agents and certain other materials shipped in interstate traffic.

Figures 1 and 2 diagram the packaging and labeling of etiologic agents in volumes of less than 50 ml. in accordance with the provisions of subparagraph (C) (1) of the cited regulation. Figure 3 illustrates the color and size of the label, described in subparagraph (C) (4) of the regulations, which shall be affixed to all shipments of etiologic agents.

For further information on any provision of this regulation contact:

Center for Disease Control
Attn: Biohazards Control Office
1600 Clifton Road
Atlanta, Georgia 30333
Telephone: 404 633 3311

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FIGURE 3



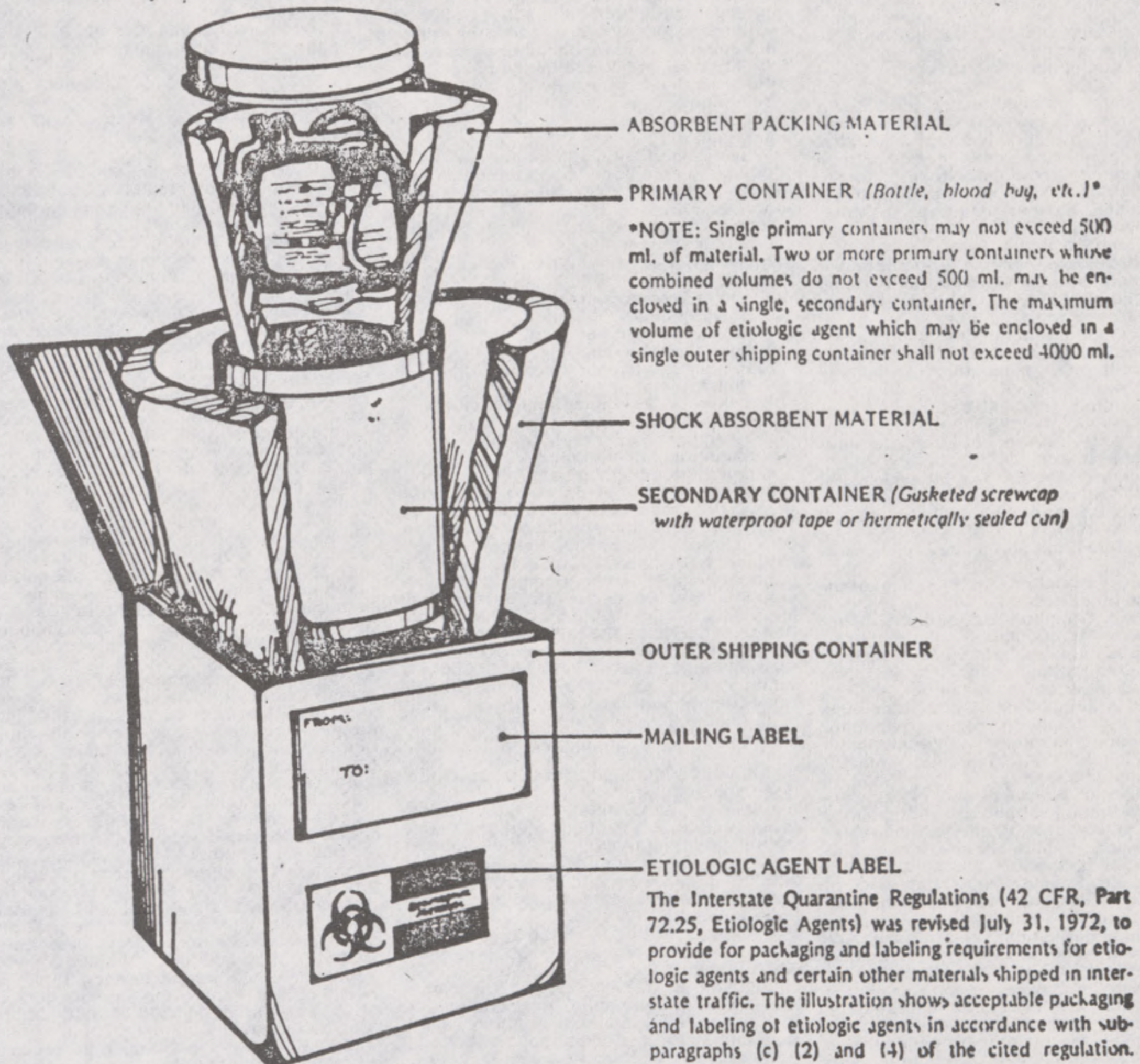
ETIOLOGIC AGENTS

BIOMEDICAL MATERIAL

IN CASE OF DAMAGE OR LEAKAGE
NOTIFY: DIRECTOR, CDC
ATLANTA, GEORGIA
404/633.5313

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PACKAGING AND LABELING OF ETIOLOGIC AGENTS



For further information on any provision of this regulation contact:

Center for Disease Control
Attn: Biohazards Control Office
1600 Clifton Road
Atlanta, Georgia 30333

Telephone: 404-633-3311

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XI. TRAINING AIDS, MATERIALS AND COURSES

- A. *Slide-tape cassettes*. 1. Assessment of Risk in the Cancer Virus Laboratory (\$10).
 2. Effective Use of The Laminar Flow Biological Safety Cabinet (\$10).
 3. Formaldehyde Decontamination of Laminar Flow Biological Safety Cabinets (\$10).
 4. Certification of Class II (Laminar Flow) Biological Safety Cabinets (\$13).
 5. Hazard Control in the Animal Laboratory (\$10).
 6. Basic Principles of Contamination Control (In preparation).
 7. Selection of a Biological Safety Cabinet (In preparation).

These slide tape cassettes are available for purchase from the National Audiovisual Center. The price for each is given above after the title. Send your order prepaid with a check or money-order made payable to National Archives Trust Fund and mail to: Sales Branch, National Audiovisual Center (GSA), Washington, D.C. 20409.

8. Research Laboratory Safety.

This slide tape cassette, stock number 176.79, is available for \$75 from the National Safety Council, 425 North Michigan Avenue, Chicago, Illinois 60611.

B. *Films*. 1. Air Sampling for Microbiological Particulates (M-926).

2. Handling the Laboratory Guinea Pig (T2618-X).

3. Handling the Laboratory Mouse (T2617-X).

4. Infectious Hazards of Bacteriological Techniques (M-382).

5. Laboratory Design for Microbiological Safety (M-1091).

6. Plastic Isolators: New Tools for Medical Research (M-599).

7. Safe Handling of Laboratory Animals (M-455).

8. Surface Sampling for Microorganisms (Rodac Method) (M-924).

9. Surface Sampling for Microorganisms (Swab Method) (M-925).

These films are available on loan without charge from: Media Resources Branch, National Medical Audiovisual Center (Annex), Station K, Atlanta, Georgia 30324. The same films (except 2 and 3) can be rented or bought from: National Audiovisual Center (GSA), (Rental Branch)—(Sales Branch), Washington, D.C. 20409.

C. *Courses*. 1. Biohazard and Injury Control in the Biomedical Laboratory. Presented by the University of Minnesota, School of Public Health and the National Cancer Institute, Office of Research Safety. Direct inquiries to Dr. Donald Vesley, University of Minnesota, School of Public Health, 1325 Mayo Memorial Building, Minneapolis, Minnesota 55455. June 22-24, 1976, Los Angeles, CA; October 26-28, 1976, Boston, MA; December 7-9, 1976, Bethesda, MD.

2. Biohazard Containment and Control for Recombinant DNA Molecules. Presented by the University of Minnesota, School of Public Health and the National Cancer Institute, Office of Research Safety. Direct inquiries as above. September 8-9, 1976, Stanford, CA; September 21-23, 1976, Cold Spring Harbor, NY.

3. Safety in Laboratory. Presented by National Institute of Occupational Safety and Health, Division of Training and Manpower Development, by special arrangement. Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

4. Laboratory Safety Management. Presented by the Laboratory and Training Division, Bureau of Laboratories, Center for Disease Control, Atlanta, Georgia, September 14-16, 1976 and September 13-15, 1977.

XII. OUTLINE OF A SAFETY AND OPERATION MANUAL FOR A P4 FACILITY

A. Purpose.

B. Policy.

C. Responsibility and Authority. 1. Management.

2. Supervisor.

3. Each Employee.

4. Facility Safety Officer.

5. Biohazard Safety Committee.

D. Facility Assignment Procedures.

E. Reporting of Major and Minor Accidents and Injuries, Exposure to Toxic or Infectious Materials, Unsafe Conditions and Property Damages, and Rendering First-Aid.

F. General Laboratory Safety. 1. Fire.

2. Equipment.

3. Physical.

4. Chemical.

5. Radiological.

G. Safety Procedures Associated with Biohazard Activities of the Laboratory. 1. Personnel Practices.

2. Operational Practices.

H. Medical Surveillance.

I. Facility Operations. 1. Personnel Access Procedures.

2. Access Procedures for Equipment Materials and Supplies.

3. Maintenance and Support.

4. Zone Classification.

5. Facility Monitoring Procedures.

6. Housekeeping.

J. Others. 1. Packaging and Shipment of Biohazardous Materials.

2. Emergency Procedures.

3. Insect and Rodent Control.

4. Orientation and Training.

Appendix D was prepared by a Working Group Consisting of: W. Emmett Barkley (Chairman), National Cancer Institute, NIH; Manuel S. Barbeito, National Cancer Institute, NIH; Everett Hanel, Jr., Frederick Cancer Research Center; George S. Michaelson, School of Public Health, University of Minnesota; Vinson R. Oviatt, Division of Research Services, NIH; Warren V. Powell, Division of Research Services, NIH; John Richardson, Center for Disease Control; James F. Sullivan, National Animal Disease Laboratories; and Arnold G. Wedum, Frederick Cancer Research Center.

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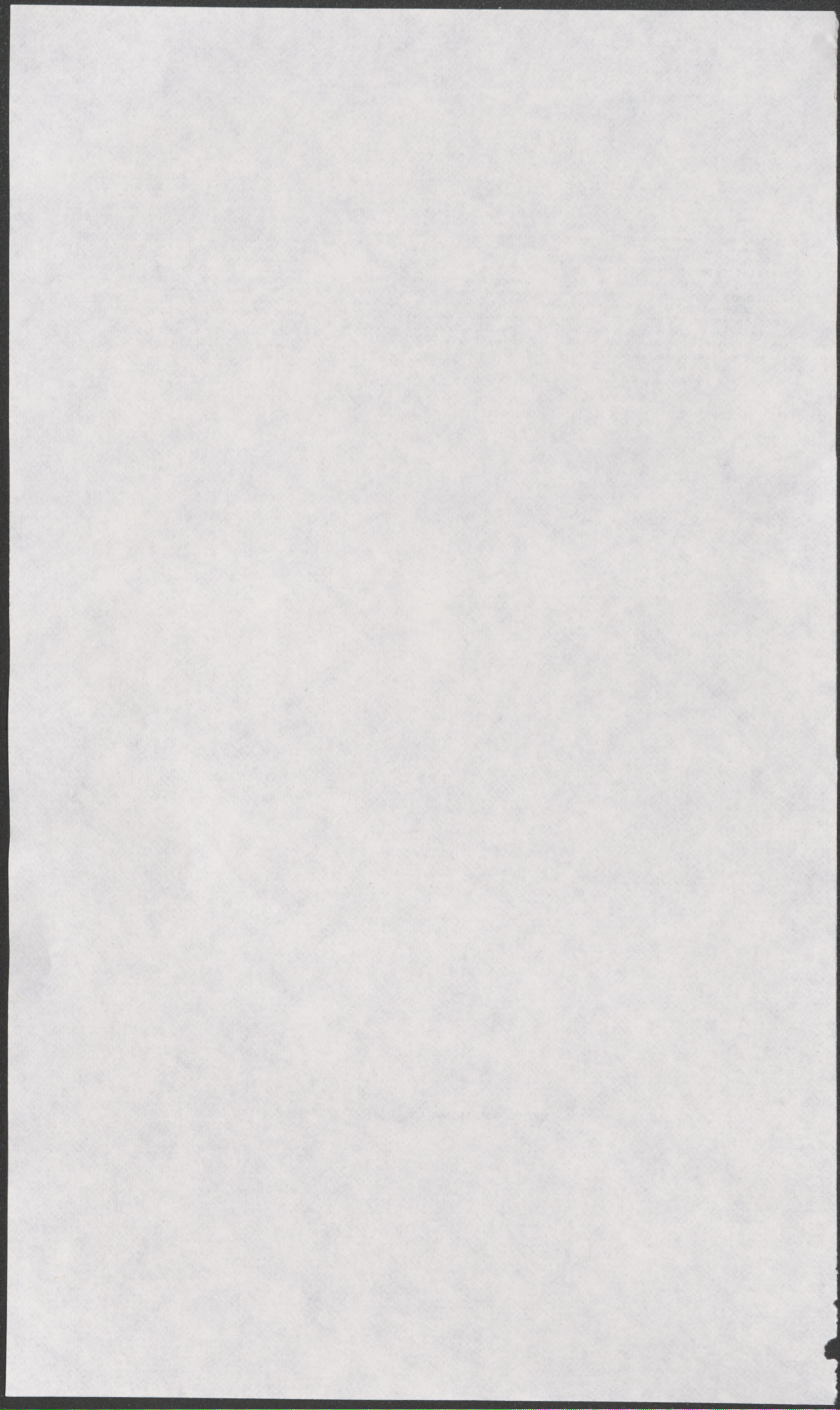
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APPENDIX 11

(Reproduced from Prism, November 1975, by permission of the publisher; the American Medical Association)

DNA SPLICING: WILL FEAR ROB US OF ITS BENEFITS?

We may be on the threshold of a technology of untold importance in diagnostic and therapeutic medicine, says this Nobel geneticist, if we have the courage to move ahead despite the risks involved.

(The Author: Joshua Lederberg, Ph.D., shared the Nobel Prize in medicine and physiology in 1958 for his work in genetics. In 1946, he and Professor E. L. Tatum showed that bacterial cells can transfer genetic material from one cell to another. Subsequently, Dr. Lederberg and D. N. Zinder discovered the phenomenon of transduction, the carriage of genes by viruses. Dr. Lederberg has been professor of genetics at Stanford University since 1959.)

Although our theoretical understanding of the cell has been completely transformed in the last 30 years, there has not yet been a corresponding advance in the practical application of our knowledge to medicine. Indeed, very little in the practice of medicine (even of clinical genetics) is directly related to the fundamental knowledge that DNA has a bihelical structure.

Nonetheless, our faith remains steadfast that further theoretical understanding of viruses, the neoplastic cell, the aging cell, the immune response mechanism, and the aberrant chromosome, will bring far-reaching changes to medicine. The human benefit from such understanding will someday surely match the theoretical impact that DNA study has already made on cell biology.

These expectations for a possibly long-delayed future benefit have been heightened and accelerated by new findings that give us much greater technical ability to manipulate microbial DNA. New methods of DNA splicing have already opened up many lines of investigation into the structure of eukaryotic (higher life form) chromosomes.

We can now fragment animal or human DNA into perhaps a million segments and transfer a single segment to a bacterial host for study in a microcosm or for production of large quantities of a specific DNA segment. This allows more elaborate analysis than has ever been possible with the enormously complex, original, unfragmented source material.

This technique of gene implantation can also be used to transfer the genetic information for a given product from the cell of one species to that of another; and this is the direction, in my own view, that will lead to a technology of untold importance in diagnostic and therapeutic medicine: the ready production of an unlimited variety of human proteins. Analogous applications may be foreseen in fermentation processes for the cheap manufacture of essential nutrients and in the improvement of microbes for the production of antibiotics and special industrial chemicals.

In the face of such a revolution, the primary concern of researchers in the field has been the public hazards that such a technology may create. While we may indeed inherit a Promethean dilemma, public policy decision can lead to social good only if we are equally well-informed about the potential risks and benefits of further work on DNA splicing. If substantial risk can be identified, there is no doubt of the need for ethical and operational safety standards; the only question must be whether the form and implementation of such standards are adequate.

Too often, the "easy" way to handle such a problem is to invoke a formal regulatory statute, ignoring how well the actual bureaucratic enforcement or policing of the rules meets the intended balance of risks and benefits. Before elaborating on the policy issues, it may be well for me to outline what is currently being done in DNA splicing, some promising applications, and also the risks of further work in this field.

DNA recombination, as the ultimate purpose of the sexual form of reproduction, is, of course, one of the major happenings in the natural world. Among higher life forms, DNA exchange is almost always limited to members of the same or closely related species. Bacteria and viruses, however, exhibit many exceptions to this rule, which perhaps reflects the fragility of the concept "species" when applied to these life forms.

For example, the entire group of enteric bacteria, including such forms as *Shigella*, *Escherichia coli*, *Proteus* and *Serratia*, can exchange genetic fragments without special intervention. Our own experiments in genetic exchange would not seriously increase the risks already latent in that natural process.

Convenient tools

An especially interesting and important level of genetic organization in bacteria is the plasmid: a bit of circular DNA that behaves like an extra chromosome and seems to survive in nature by virtue of its easy transmissibility from one bacterial strain to another. Many different kinds of plasmids are known; in medicine, the most prominent are those which confer transmissible antibiotic resistance on human pathogens, notably staphylococci and some enteric pathogens such as *Shigella*.

These plasmids are a by-product of the evolution of their host organisms: the spread of antibiotic-resistance plasmids is the most formidable bacterial response yet to our widespread use of antibiotics. Other plasmids are undoubtedly involved in altering the pathogenicity and host-specificity of various bacteria; therefore, in simple self-defense, we must learn all we can about them, without delay.

Plasmids have also achieved special prominence for a technical reason—they are especially convenient tools for DNA splicing and for the transmission of DNA segments from one species to another, particularly in conjunction with another elegant tool: the R- (for restriction) enzyme. (The R-nucleases are widely distributed among cell types; they may be an important mechanism by which a cell fends off any "foreign" DNA while protecting its own.)

Stanley N. Cohen, M.D., of the Department of Medicine, Stanford University, has used an R-enzyme to simplify a naturally occurring plasmid to the point where it consisted of a small circle of DNA, embracing the minimum amount of genetic information needed to replicate, plus a single R-enzyme recognition site.

This artificial plasmid, pSC-101, has been an important tool in DNA splicing research. When exposed to R-enzyme, the circle is cut into a single open length with sticky ends. It is then possible to insert other sticky-ended pieces of DNA from diverse sources into the plasmid, and finally to close it up with another enzyme, ligase. This process is the key to the convenient design and construction of new DNA molecules, which subsequently can be transferred to a bacterial host.

One important aspect of this research is that the new DNA does *not* have to come from the same bacterial species. For example, Dr. Cohen and his collaborators have already reported the successful transfer of DNA from a toad, *Xenopus*, to *E. coli* with evidence of the production of toad-like ribosomal nucleic acids in the modified bacteria.

In addition to these plasmids, bacterial viruses are being used in a similar fashion. Less elegantly, perhaps, segments of DNA from intact bacteria may also be used both for insertions and as the acceptors. So far, all of these techniques depend on the innate (and poorly understood) ability of bacterial cells to incorporate DNA furnished from without. There have been many published claims of similar phenomena with plant and animal cell acceptors, but to date the claims are unconfirmed.

The special power of the enzyme transfer techniques is that they depend on the basic chemical structure of DNA rather than on biological adaptation. Thus, laboratory manipulation may produce constructs that occur rarely, if ever, in the natural world. Most of these constructs would resemble hothouse plants, and be poorly adapted to competitive survival in the world outside the laboratory. But some, by chance, might be harbingers of new diseases, or the source of ecological upsets difficult to control—like the mongoose in Hawaii or the crabgrass in your lawn.

R-enzymes, mixed DNA, and acceptor bacteria surely bring about some DNA segment transfers in nature. Our knowledge of the extent of natural plasmid transmission among "unrelated" life forms was widened by recent discoveries of plasmids with extraordinarily broad host ranges. It is difficult, however, to assess just what *can* or *cannot* occur in nature.

Rapid advancement

DNA splicing is, however, merely the most powerful of several artificial techniques which bring together more-or-less natural assemblages of DNA. Indeed, it may prove to be less powerful than older methods (sexual crossing, transduction with bacteriophage, DNA-medicated transformation) for special constructions involving larger complexes than the segments yielded by R-enzymes.

These methods, in turn, are an extension of the artificial breeding of domestic animals and plants. In any event, the most efficient application of DNA splicing requires intimate knowledge of the genetic structure of both the donor and the acceptor strains, for which breeding methods are important if not indispensable.

Perhaps the single most important conclusion is that this technology is just in its infancy but has already advanced far—and that it is simple enough to be applied in any laboratory which can handle pure bacterial cultures. But it is just this simplicity, which makes for great convenience and speed of development, that has raised concern about the proliferation of such methods in the hands of people with perhaps less-than-mature professional and ethical judgment, and with insufficient skill to contain bacterial cultures in the laboratory.

Now that we have put the dangers of DNA splicing research into perspective, let us examine the promise that it holds. DNA segmentation and splicing is certain to play a vital role in the further domestication of microbes for such uses as the development of new antibiotics and the production of high-quality food protein supplements. However, the unique strength of this procedure is that it allows the large-scale production of gene products of a less easily domesticated species: man.

Human proteins already play a substantial role in medicine but a role which is hindered by scarce supply. Today, the most attractive candidates for such large-scale production are the human antibody globulins. Compared to the rare genetic defects in other proteins (as in the case of hemophilia), failure of error in the production of antibody globulin is quite prevalent and is known to play a major role in the breakdown of the body's defense against infectious disease, in autoimmune and allergic disease, and perhaps also in cancer.

The most comprehensive use for biosynthetic proteins would be in passive immunization against infectious disease. (Animal antisera were once used but had to be abandoned because of the anti-animal antibody that they provoked in man.) With wholesale production of biosynthetic proteins, passive globulin therapy could be targeted at those diseases for which either technical or social factors may bring about gaps in the protection provided by active immunization. Included in that group of diseases are influenza, hepatitis, smallpox, encephalitis, rubello, herpes, rabies, and perhaps also trypanosomiasis, malaria, schistosomiasis, tuberculosis, leprosy and many others.

Need for a ready defense

There is reason for special urgency in the development of a backup capability in passive immunization. Complacency about active immunization against diseases such as polio and the technical inadequacy of such vaccines as rubella and hepatitis have weakened our general posture of defense against viral pandemic. We have no assurance that the next influenza epidemic, slightly more virulent than the last one, will not take a million lives for lack of a ready defense.

A broader need for biosynthetic proteins lies in polyvalent prophylaxis for infants. The principal medical argument for breast feeding is that human milk provides the infant with colostrum and a continuing supply of maternal mixed globulins. In the future there might be a huge demand for polyvalent gamma globulin supplements for infants both in industrialized and in poorer countries. And an analogous veterinary use could bring about greater efficiency in livestock production.

Specific antibodies, of course, are already widely used as diagnostic reagents of high specificity and selectivity. But in sufficient quantity, blocking antibodies

might also play a useful role in helping protect transplanted tissues and organs from immunological attack by the new host. Conversely, tissue-specific ligating antibodies, although not necessarily cytotoxic themselves, may be useful in enhancing the cell-specific toxicity of certain cancer drugs. Cell-specific reagents would also be invaluable in diagnosis and in the specific separation of human cell types for either diagnostic or therapeutic applications.

Besides the specific antibody globulins, a number of important, but less specific, proteins (complement, properdin) play a major part in defense against infection. Fibrinolysin (plasmin) and urokinase (plasminogen-activator) represent a group of enzymes that experimentally have shown promise in the control of embolism. Besides these human proteins, many human hormones are also discouragingly scarce for use in clinical trials. The list of such bioproducts could be extended substantially. And perhaps the most important products are those that remain to be discovered.

Of course, microbial biosynthesis may well be supplemented by organic synthesis in human and hybrid somatic cell cultures and by cell-free ribosomal synthesis with m-RNA extracted from natural sources or synthesized. Each of these methods has its own peculiar difficulties and hazards, and the whole field will be advanced most rapidly by using the best available methods for any given problem.

At present, perhaps a half-dozen bacterial species are well enough understood to serve as prime vehicles in laboratory studies of DNA splicing. For safety and convenience, investigators have preferred not to use pathogenic forms. Yet many scientists are primarily concerned that DNA splicing may inadvertently generate a new pathogen inimicable to man or to some other species important to man's ecology. The most likely, but not necessarily the only, sources of such pathogenic genes are the organisms that most urgently need further study—the subtle and insidious killers not now amenable to medical treatment. These include slow virus infections that may be involved in a wide range of chronic diseases, including cancer and more familiar viruses, such as herpes, for which satisfactory vaccines are not available.

Speculating the hazards

The public debate over DNA splicing has focused on the possible hazards of new microorganisms, and away from their utilitarian prospects. The most urgent concern has been the danger of introducing potentially cancer-causing DNA into common bacteria. While this hazard is clearly speculative, the general territory is so poorly understood that no one can argue against the need for cautious laboratory procedures. A number of workers—particularly those whose special experience or training has been in fields other than medical microbiology—have confessed giving almost no thought in the past to safety; some of them are now among the most zealous in demanding tighter regulation of such research. And that zeal has spread to create a sincere, almost frantic effort to ferret out and identify the most remote, conceivable hazards.

Viewed as a rather public soul-searching and self-education, these discussions are invaluable. The main danger is that some political imperative may forge these tentative questions into iron-clad regulations which will be with us long after their origins have been forgotten. After all, similar questions can be raised about the widest range of human activities: should it be lawful to keep domestic cats when we suspect that they harbor toxoplasmosis, and possibly leukemia as well? Similarly, what assurance do we have that artificial pollination will not produce a weed that could ruin the wheat crop a decade from now? Closer to home, should we forbid international travel simply because our quarantine procedures do not guarantee that exotic diseases will be kept out?

For each of these cases, and many more, the apparently innocuous doctrine, "As long as there is any risk, don't do it!" can only bring a loss to human welfare. We must instead make every feasible effort to assess both the risks and the benefits of a given course of action—only then will we be able to find the optimal balance. But individuals can hardly determine the best policy about their own future—including their expectations for what medicine will offer for the infirmities of their own later years—without expert assessment.

Such assessments are difficult, problematical, and controversial. But a committee of the National Academy of Sciences has made some headway in trying to classify different categories of hazard. Where such hazard is reasonably predictable, the committee has recommended laboratory containment precautions akin to those appropriate for known pathogens. This applies, for example, to experiments in the recombination of known tumor virus DNA with bacterial plasmids.

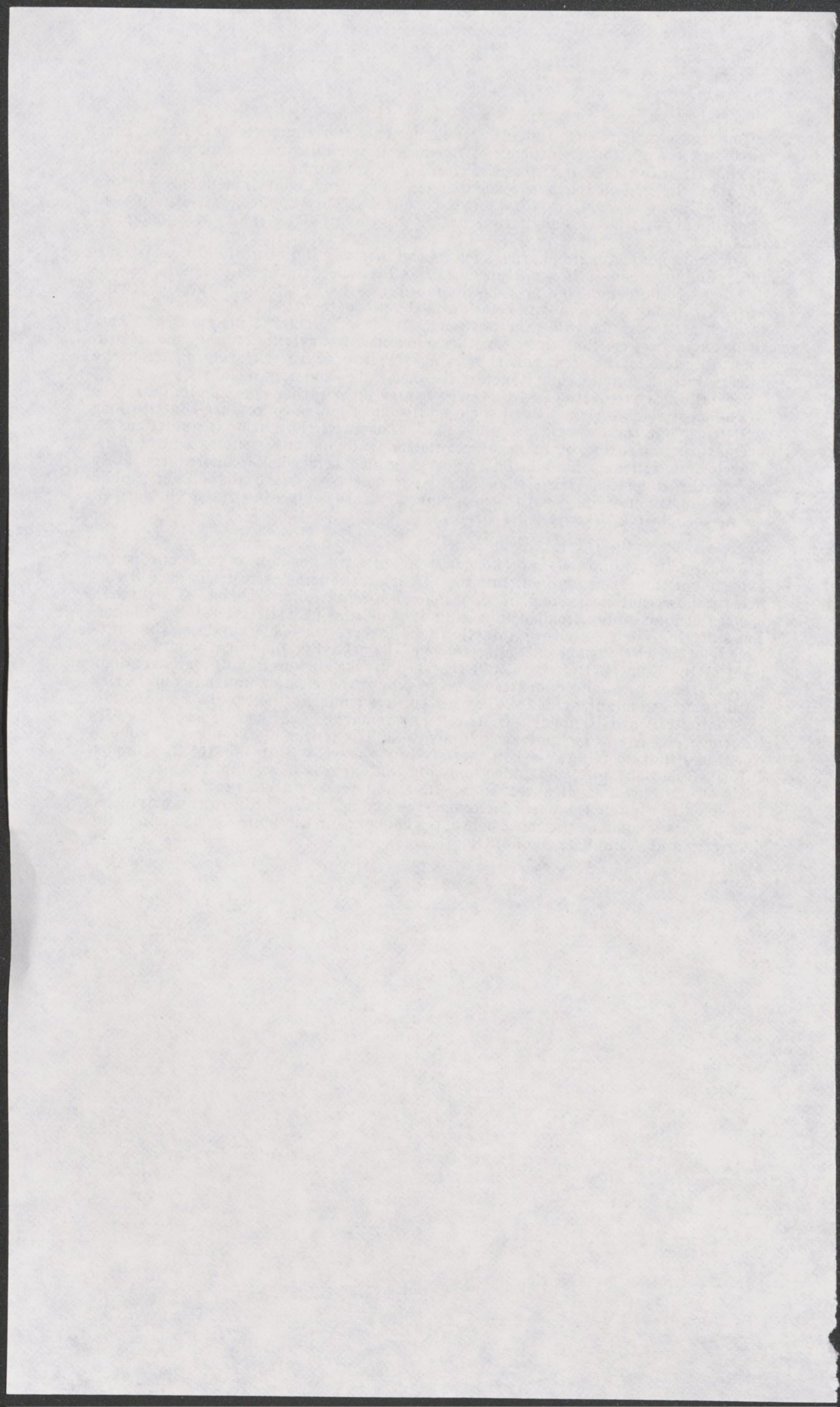
For more conjectural hazards, such as the introduction of antibiotic resistance into common, non-pathogenic species, the high security requirements recommended by the committee may be an inordinate burden for laboratories (who, in fact, will pay for them?) in relation to the prospective gains. The best strategy in such a case seems to be the development of safe vectors: plasmids and bacteria engineered so that they have little chance of surviving outside the laboratory. In fact, in the long run this is a safer procedure than relying upon the uncertainty of human compliance with fixed rules and regulations.

Remaining controversies in this area center upon rather complicated analyses of the most remote risks. Given some additional time, most research institutions will work out their own reasonable plans, based on the national guidelines. A premature imposition of external regulation will not only frustrate useful research, but will also hinder that research which is needed to more accurately assess the dangers. Those who consider themselves guardians of the public safety must count the costs to the public health of *impeding* research, as well as the speculative *hazards* of research.

Society's consent

This partly voluntary approach will not assure absolutely that no foolish experiment is ever attempted. But the history of human institutions should suffice to show that *no* system of sanctions can achieve such a goal. The human species is inevitably attended by contaminating and parasitic microbes—the person suffering from an enteric infection who fails to wash his hands or the influenza victim who insists on going to work is behaving unethically and to the peril of his fellows. But we would scarcely invoke serious regulatory sanctions in preference to public education, except where there is an unusual public risk with some attendant evidence that an enforced quarantine would be effective.

Senator Edward Kennedy (D-Mass.) has remarked that society must give its informed consent to technological innovation. The power of the purse is enough to enforce that doctrine; nor can there be any quarrel with it on ethical grounds. Informed consent surely includes knowing the hazards of saying no to the prospects of significant medical advances. DNA splicing research, far from being an idle scientific toy or the basis for expensive and specialized aid to the privileged few, promises some of the most pervasive benefits for the public health since the discovery and promulgation of antibiotics.



APPENDIX 12

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THE CASE AGAINST GENETIC ENGINEERING

(By George Wald)

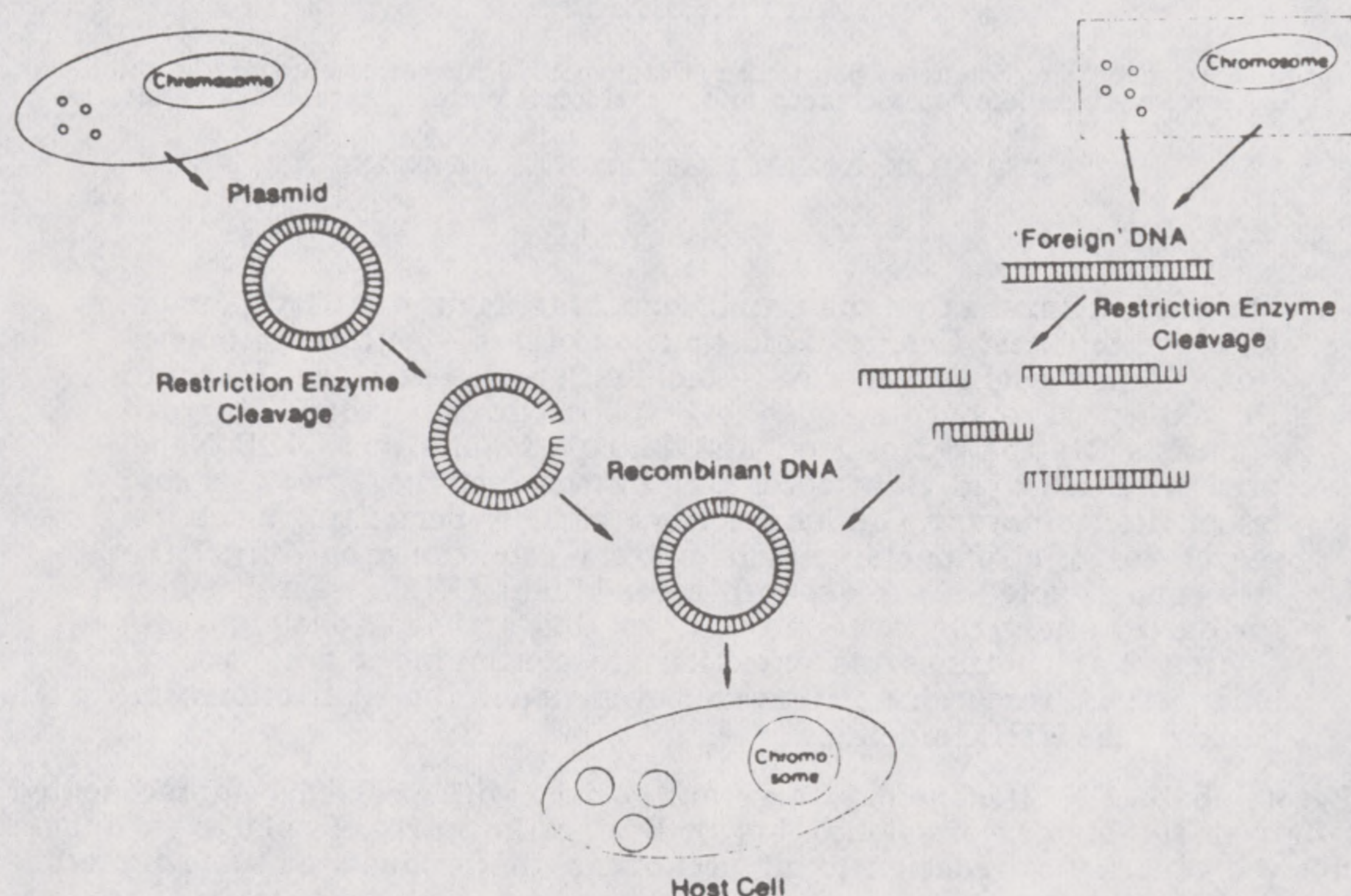
During hearings before the Cambridge, Massachusetts City Council, Harvard biologist George Wald—among others—testified in opposition to performing genetic recombination research at Harvard University. Proponents of the experiments included Harvard scientists Matthew Meselson and Mark Ptashne and MIT Nobel prize-winner David Baltimore. Despite the fact that the NIH had issued its voluntary Guidelines days earlier, permitting such research to go on under special laboratory conditions, on July 7 the city council voted a three-month recombinant DNA research moratorium to study the issue further. In this article, Nobel laureate George Wald outlines his objections to continuing genetic recombinant DNA research at Harvard, even under the restrictions imposed by the NIH Guidelines.

Recombinant DNA technology faces our society with problems unprecedented not only in the history of science, but of life on the Earth. It places in human hands the capacity to redesign living organisms, the products of some three billion years of evolution.

Such intervention must not be confused with previous intrusions upon the natural order of living organisms: animal and plant breeding, for example; or the artificial induction of mutations, as with X-rays. All such earlier procedures worked within single or closely related species. The nub of the new technology is to move genes back and forth, not only across species lines, but across any boundaries that now divide living organisms, particularly the most fundamental such boundary, that which divides prokaryotes (bacteria and bluegreen algae) from eukaryotes (those cells with a distinct nucleus in higher plants and animals). The results will be essentially new organisms, self-perpetuating and hence permanent. Once created, they cannot be recalled.

This is the transcendent issue, so basic, so vast in its implications and possible consequences, that no one is as yet ready to deal with it. We can't deal with it until we know a lot more; and to learn those things we would have to venture out into this no man's land. It is nothing like making new transuranic elements. New elements only add to the simple series of integral atomic numbers that underlie the Periodic System. Their numbers are limited and their properties highly predictable. Not so new organisms. They can be as boundless and unpredictable as life itself.

Technologically Redesigning Living Organisms



Recombinant DNA technology was launched in 1973 and 1974, largely through researches carried out in the laboratories of Stanley Cohen at Stanford University and Herbert Boyer at the University of California in San Francisco. A rapidly growing number of available restriction enzymes can be used to cut short specific segments of DNA usually containing several genes out of the chromosomes of any type of cell. These segments are then spliced with the help of the same and other enzymes, ligases, into viruses or the naturally-occurring small circular extra-chromosomal particles of DNA called plasmids. The plasmids can then be taken up by bacteria or animal or plant cells in which they reproduce, either in phase with the host cell or sometimes independently and many times faster. On occasion, the new genetic material fuses with the host chromosomes and reacts thereafter as a normal component of the host's genetic apparatus. In effect, such cells that have received foreign genes are new organisms, permanent hybrids of the host cells and whatever organism donated the transplanted genes. Their properties and capacities may differ profoundly from either host or donor.

—GEORGE WALD.

Up to now living organisms have evolved very slowly, and new forms have had plenty of time to settle in. It has taken from four to 20 million years for a single mutation, for example the change of one amino acid in the sequence of hemoglobin or cytochrome c, to establish itself as the species norm. Now whole proteins will be transposed overnight into wholly new associations, with consequences no one can foretell, either for the host organisms or their neighbors.

It is all too big, and is happening too fast. So this, the central problem, remains almost unconsidered. It presents probably the largest ethical problem that science has ever had to face. Our morality up to now has been to go ahead without restriction to learn all that we can about nature. Restructuring nature was not part of the bargain; nor was telling scientists not to venture further in certain directions. That comes hard. With some relief, most biologists turn away from so vast and uncomfortable an issue and take refuge in the still knotty but infinitely easier technical questions: not *whether* to proceed, but *how*. For going ahead in this direction may be not only unwise but dangerous. Potentially, it could breed new animal and plant diseases, new sources of cancer, novel epidemics.

We must never forget that the first intimation of these potential hazards came from workers in this field. All honor to them. Faced with unique problems, as they alone then realized, they did unprecedented things. They brought about a voluntary moratorium on certain, more clearly dangerous kinds of experiments. And now, after three years of debate, consultation and negotiation, the National Institutes of Health issued its Guidelines on June 23.

THE NOBEL LETTERS

During the hearings a number of leading biologists wrote letters to Cambridge Mayor Alfred E. Vellucci defending genetic recombinant research at Harvard. Below are excerpts from letters by three Nobel laureates.

In my view these Guidelines are far more stringent than is reasonably necessary for the protection of public health. In every case where reasonable doubt could be entertained, it has been resolved in a way that imposes the most serious and conservative protective requirements. Most of the risks in question are purely conjectural and no substantive basis can be found for the dire prediction that the public health could be endangered by recombinant organisms. Nevertheless, the Guidelines in their present form have accepted every such speculation as if it were accepted reality. In summary, even the most cautious view of the NIH Guidelines should give citizens ample assurance that they go far beyond what is necessary to protect their health.

Elsewhere I have commented that the very act of setting up such elaborate precautions would frighten people because they go so far beyond what we do in other spheres of life. This seems to have happened in the present case—it is the very security precautions having been doubled and redoubled that has generated an unjustifiable fear. On the other side of the coin. I take the opportunity to indicate that research in this area has the potential for the most extraordinary contributions to medical advance and I would hope that Cambridge, Massachusetts would be proud to be the seat of major accomplishments in this direction.

JOSHUA LEDERBERG,
Stanford University Medical School.

In terms of our present knowledge, I feel that there are no real accidental dangers involved in research on animal virus and vertebrate cell DNAs under the NIH Guidelines. The specific dangers that have been suggested involve combinations of events that are either known not to occur or occur only at very low probabilities. Therefore, the likelihood of the occurrence of any specific danger is so low that it can be considered zero. In fact, I consider that the Guidelines are probably too restrictive in terms of our present knowledge of animal virus and vertebrate DNAs.

Furthermore, I consider it ineffectual to regulate on a local level research involving possible infectious entities. Unless there is national, and preferably international, regulation, local regulation would not serve to protect the inhabitants of that locale.

In addition, I have found the members of the Department of Biochemistry and Molecular Biology, Harvard University, conservative in respect to possible safety hazards from research with animal viruses and vertebrate cells.

As taxpayers and governmental officials, you have a responsibility to insure public health and safety, but you also have a responsibility to promote the public welfare. It is conceivable that the technique of recombinant DNA may lead to major benefits in terms of public health and welfare. Therefore, a balance must be made between the "zero" likelihood of harm and the possibility of beneficial results.

HOWARD M. TEMIN,
University of Wisconsin Medical Center.

I implore you to encourage the progress of the planned facilities for genetic research at Harvard and to do your utmost to foster a spirit which advances this exceedingly important direction in medical science.

The new NIH Guidelines to which these Harvard facilities and investigators will adhere go far beyond reasonable needs for personal and public safety. I

assure you that the current hazards in many chemical, bacteriological, biological and physical laboratories in Cambridge, public and private, are far greater than those anticipated in recombinant DNA research.

I realize you have heard a different point of view from some Harvard and MIT scientists who have testified before you. I believe their views are not based on sound scientific evidence and are highly exaggerated. In my estimation, they represent a tiny fraction of the scientific community.

I implore you again not to suppress the serious and responsible search for new knowledge. If scientific inquiry is stifled in Cambridge, it will be done in Waltham, Palo Alto or Moscow. In 1976, please do not squander your most precious human resources.

ARTHUR KORNBERG,
Stanford University Medical Center.

"And God blessed Noah and his sons, and said to them, 'Be fruitful and multiply, and fill the Earth. The fear of you and the dread of you shall be upon every beast of the Earth, and upon every bird of the air, upon everything that creeps on the ground and all the fish of the sea; into your hand they are delivered. Every moving thing that lives shall be food for you; and as I gave you the green plants, I give you everything.' "

—GENESIS.

One can hardly read the Guidelines, or the careful and sensitive statement by Donald Frederickson, the Director of NIH, on releasing them, and not be impressed with the goodwill and concern that animate them. Yet there is much in this enterprise and in the Guidelines themselves that troubles me greatly.

First and foremost: the very existence of the Guidelines begs the central question, whether this kind of research should proceed at all. The experiments are quite simple and straightforward. Can they be stopped? Perhaps they can. If one could neither publish the results nor exploit them commercially there would be little incentive to do them.

As for the Guidelines themselves, the first thing to understand is the context of utter ignorance of what to expect in which they had to be formulated. The Guidelines begin by saying: 'At present the hazards may be guessed at, speculated about, or voted upon, but they cannot be known absolutely in the absence of firm experimental data—and, unfortunately, the needed data were, more often than not, unavailable.'

Physical containment.—The purpose here is to keep the recombinants from escaping the laboratory. The Guidelines list four levels of containment labeled P1 to P4; but in effect there are only two levels, a lesser—P3—and a greater—P4. This classification is itself deceptive, for it makes the prevalent P3 facility sound better than it is, three quarters of the way to the top, whereas in fact it is the lowest level of containment. P1 is just a laboratory, P2 the same laboratory with a warning sign on the door. A young woman demonstrating a P2 experiment at an open hearing before the Cambridge City Council made a point of putting on the prescribed laboratory coat; but she had long, loose, abundant hair that could have carried more bacteria or viruses than a dozen lab coats.

A P3 facility such as has just been authorized at Harvard employs various devices intended to minimize the escape of recombinants. Yet the reason proponents of the facility at Harvard gave for building it within our Biological Laboratories, close to the laboratories of prospective users—though the building is half a century old and infested with ants and cockroaches—was that workers in the facility would be the principal means of spreading contamination, and hence should have to move as short distances as possible. I think it is probably correct that the laboratory personnel will be the principal means of spreading any potential infection. But in that case, wherein lies the containment? Why the elaborate and costly precautions within the facility?—the small unit at Harvard is estimated to cost more than \$800,000. And what matter whether distances between the labs are short or long? All these workers move freely throughout the building and the city: they meet with us, eat with us, and—most importantly—they teach classes of young students. I see no reason to believe that P3 containment, even if conscientiously enforced, can effectively contain.

Biological containment.—One of the most unsettling aspects of present recombinant DNA research is that the host organism that receives the plasmids that

carry foreign genetic material is almost always the colon bacillus, *Escherichia coli*, a constant inhabitant of the human bowel. To do potentially hazardous experiments, why pick an organism that lives in us? The reason is that we know more about *E. coli* than about any other living organism. Yet what is to keep some hybridized *E. coli* turned pathogenic from infecting its conventional human hosts? Or transferring those plasmids to human cells?

Hence the stress on the assurance that all recombinant experiments with *E. coli* will use the K12 strain, which, we are told, can exist only under special laboratory conditions and neither survives nor reproduces in the human gut. The use of this strain is the "biological containment."

In this connection Stanley Falkow of Seattle, Washington, submitted to the NIH Recombinant DNA Advisory Committee a highly informative report on the ecology of *E. coli*. According to Falkow, almost innumerable serologically distinct strains of *E. coli* inhabit the human colon from time to time, the population constantly changing. The more persistent (resident) strains last several months, other (transient) strains only a few days. The statement that the K12 strain does not survive in the human bowel rests primarily on observations by E. S. Anderson and H. Williams Smith that this strain "is a poor colonizer of the human alimentary tract." Smith found a mean survival time of about three days, Anderson about six days. Anderson also found that it "multiplied to some extent in two of eight subjects." Hardly an impressive statistic! Furthermore he could detect plasmid transmission from K12 to other enteric flora when it was fed "in substantially high numbers."

Falkow confirms these observations, and adds another that is singularly important: Working with calves, he found that introducing certain plasmids into K12 increased its survival and multiplication in the gut many times over. He concludes that "it may not be too farfetched to suggest that some DNA recombinant molecules could profoundly affect the ability of this *E. coli* strain to survive and multiply in the gastrointestinal tract"

These are oddly inadequate data to carry such weight. We would like to know much more. How does K12 get along in persons whose colons are relatively empty of bacteria and hence offer it little competition?—such as newborn infants, or persons who have just been treated with sulfa drugs or antibiotics? So-called biological containment seems to me as problematical as P3 physical containment.

Enforcement.—The Guidelines are just that, hence wholly voluntary. The only penalty now available for simply disregarding them is the possible withholding of federal research support. Obviously this applies only to research dependent on federal funds. It leaves out completely the rapidly growing industrial exploitation of recombinant DNA technology.

Benefits and risks.—I have up to now said almost nothing of the potential benefits of this technology. I think that the most certain benefits to come out of it would be scientific: increased understanding of important biological phenomena, such as the mechanisms that turn specific gene activities on and off, that trigger cell multiplication and differentiation, that regulate cell metabolism. We are also offered the prospect of large practical benefits: teaching cereal plants to fix their own nitrogen from the air, new bacterial syntheses of drugs and hormones, the hope that increased understanding of cancer may lead to its cure. I cannot think of a single instance of such developments, scientific or practical, that does not also involve large potential risks.

Consider cancer. If indeed it turns out that recombinant DNA research will improve our understanding of cancer, that would still be far from showing us how to cure it. In spite of many statements, as vague as they are optimistic, that the cure of cancer lies in this direction, it is hard to see how that is to happen. Any such hope must be balanced against the real possibility that recombinant DNA experiments may induce new cancers. If right now I had to weigh the probabilities of either event I would guess that recombinant DNA research carries more and earlier risks of causing cancers than hope of curing them.

Add that about 80 percent of cancer in this country is now believed to be of environmental origin. The largest single cause of lung cancer is smoking, but one is free to smoke or not. About 40 percent of those environmental cancers happen in the work places, through involuntary exposure to a rapidly increasing variety of toxic materials in industrial use. If one were really concerned about cancer, there is the obvious place to attack it, with sure and immediate results.

Or consider a frankly industrial development. General Electric is reportedly

trying to patent a newly assembled strain of *Pseudomonas* bacteria that can wholly digest crude oil. It was developed there by Ananda Chakrabarty by transferring plasmids from several strains, each of which could digest oil partially, into a single strain that can do the whole job. It is pointed out that this organism could be very useful for cleaning up oil spills. Very true; but how about oil that has not spilled?—oil still in the ground, or on the way, or stored? Can this organism be contained, kept from destroying oil we want to use? Or will we need to begin to pasteurize oil?

The corporate connection.—As early as February 1974 *Fortune* magazine hailed the coming importance of genetic recombination in industrial developments. "The best microbes are freaks," it said and "many scientists see an important industrial role ahead for the powerful new methods of transferring genetic material from one cell to another." It named a number of them, including a few who are already directing corporate activities.

The industrial exploitation of recombination technology raises special problems, for in that, as any other business enterprise, the major goal is to maximize profits and, frequently in the past, public and worker safety and health have been subordinated to that end. Last May representatives of about twenty drug and chemical companies met with NIH Director Frederickson to discuss the proposed Guidelines. They expressed "general support," but made three points: (1) the fear that voluntary Guidelines might lead to enforceable regulations, (2) for reasons of competition, the companies could not afford to reveal what recombinant DNA experiments they were performing and (3) they found other features of the Guidelines onerous, for example the restrictions on large-volume experiments, which of course are less easily contained, but which they require in testing procedures for commercial feasibility.

The dilemma of the NIH.—The recombinant DNA development faces NIH with an interesting predicament. Anything I say of this is said sympathetically, for under Donald Frederickson's perceptive leadership it is doing as well as could be hoped. Yet is it possible for the same agency both to promote and regulate? The old Atomic Energy Commission, set up originally to regulate, turned instead to promoting nuclear power, and that eventually destroyed it. It has been replaced by two separate agencies, one for research and development, the other for nuclear regulation.

NIH, on the contrary, set up to promote scientific and medical research, is now being forced into regulation. Its entire impulse, as that of all other institutions concerned with research, is to avoid regulation, to maintain full freedom of inquiry. Probably that is why it can bring itself only to promulgate voluntary guidelines. Surely it recognizes the previous history of ineffectuality of voluntary self-regulation in other areas. For the NIH Guidelines to be enforced, academically and particularly industrially, they would have to become regulations, backed by legislation, with adequate provisions for licensing, inspection and supervision. The NIH would like to avoid such measures and so, as a scientist, would I. Yet this situation seems to demand them, and I fear that scientists and science will eventually have to suffer because of them.

What to do.—First, I think it essential to open a wide ranging and broadly representative discussion of the central issue: whether artificial exchanges of genetic material among widely different living organisms should be permitted.

Second, in consideration of the potential hazards and our present state of ignorance, I would confine all recombinant DNA experimentation that transcended species boundaries to one or a few national or regional laboratories where they can be adequately confined and supervised. There, every attempt should be made to define the hazards that are now only guessed at. If trouble should arise, I would expect it to involve first the workers in such laboratories and their families whose health should be carefully monitored. Until such trials have told us better what to expect, this kind of investigation should have no place in crowded cities or educational institution.

Third, industrial research and development in this area need most of all to be brought under control. The usual secrecy that surrounds industrial research is intolerable in a province that can involve such serious consequences and hazards. The need for licensing, inspection and supervision will probably require national legislation. Hearings in the Congress should begin at once to consider these issues.

As I write these words, they trouble me greatly. I fear for the future of science as we have known it, for humankind, for life on the Earth. My feelings are ambivalent, for the new technology excites me for its sheer virtuosity and its

intellectual and practical potentialities; yet the price is high, perhaps too high. We are at the threshold of a great decision with large and permanent consequences. It needs increasing public attention here and worldwide, for it concerns all humankind. That will take time, during which we can try to learn, as safely as that can be managed, more of what to expect, of good and ill. Fortunately there is no real hurry. Let us try, with goodwill and responsibility, to work it out.

THE DEFENSE DOESN'T REST

One of the leading advocates of recombinant DNA research is Mark Ptashne of Harvard's Biological Laboratories. The Sciences gave him an opportunity to reply to George Wald's case against genetic engineering at Harvard.

George Wald's plea that "artificial exchanges of genetic material among widely different organisms" should be banned from "crowded cities or educational institutions" is based on a curious mixture of fantasy, misinformation, and irrelevancies. Consider the following:

1. Wald notes that the Guidelines specify four levels of physical containment, P1 to P4. He states that "P1 is just a laboratory, P2 the same laboratory with a warning sign on the door," and "P3 . . . is the lowest level of containment," and "I see no reason to believe that P3 containment, even if conscientiously enforced, can effectively contain."

In fact, a P2 lab, as specified in the NIH Guidelines, does have a sign on the door, but in addition, it is subject to the following regulations, among others: all liquid and solid wastes are incinerated or otherwise decontaminated before removal from the lab; reusable equipment (glassware, etc.) is prohibited and biological safety cabinets must be used for all operations that generate aerosols. Hospital laboratories are typical examples of P2 facilities, and they are used for routine culture of agents as dangerous as those which cause anthrax, pneumonia, plague, measles, mumps, influenza, gonorrhea, etc. P3 specifies more sophisticated construction, requiring—among other features—a constant negative air pressure so that air flows from the corridor to the lab when the doors are opened. Wald is apparently unaware of just how well P3 laboratories do contain. For example, W. Emmett Barkley, Director of Research Safety of the National Cancer Institute, points out that experience shows that the most highly infectious biological agents may be used in a properly run P3 laboratory with minimal risk. He estimates that, on average, workers in such laboratories incur about two infections for every 100 person-years of work—and this with the most highly infectious agents known. Moreover, many years of experience with P3 facilities at the Center for Communicable Diseases in Atlanta, and at Fort Dietrick, and the laboratories of the National Institute of Health in Maryland show that, even in those rare cases of infection of a laboratory worker caused by human error, secondary spread to people outside the lab is virtually nonexistent. According to studies conducted in Barkley's office by Barkley, Arnold Weedum and others, there is no evidence that proper handling of even the most dangerous organisms under P3 conditions—or in many cases under less restrictive conditions—endangers the surrounding community. Wald's statement that P3 labs do not contain is simply false. Of course the designations P2, P3, or P4 may be misused, but then even ordinary chemicals present in any biochemical lab can be misused, and in the latter case with immediate and serious danger. It must not be forgotten that recombinant DNA experiments which present some plausible scenario for significant danger have been banned altogether by the Guidelines, and many experiments are confined to the extraordinarily protective environment defined as P4.

2. Wald objects to the use of *E. coli* in recombinant DNA experiments. He notes that *E. coli* is a "constant inhabitant of the human bowel" and he asks ". . . what is to keep some hybridized *E. coli* turned pathogenic from infecting its human host?" Wald implies that *E. coli* turns pathogenic at the drop of a gene. He is apparently unaware of the years of sophisticated experimentation that have been devoted to analyzing the factors required to render *E. coli* pathogenic. In fact, despite these efforts, no one yet has managed to transfer any gene or set of genes from a pathogenic *E. coli* to *E. coli* K12, the commonly used laboratory strain, and render that strain pathogenic. This is not surprising: pathogenic organisms are highly evolved to occupy a very specialized niche, and it is no easy matter to confer those multiple properties required for pathogenicity on a non-

pathogenic bacterium grown for many generations in the laboratory. The scenario behind Wald's query involves a series of extremely improbable events. We would have to imagine a segment of foreign DNA—representing about .1 percent of the DNA of the bacterium into which it is placed—rendering K12 pathogenic. The K12 would then have to colonize the human gut (which K12 does not ordinarily do), and survive excretion and a sojourn outside the gut *en route* to infect another person or animal. As far as we know, the probabilities of any one of these events occurring is extremely small, and the aggregate probability, vanishingly small. Wald formulates his questions in such a way as to simply ignore these issues.

3. Wald questions the concept of "biological containment." He asserts that "... all recombinant experiments with *E. coli* will use the K12 strain ..." and he goes on to cite, among other reports, the fact that when K12 is fed to human beings in large numbers it can be detected for some days in the intestinal tract. He points out that plasmid transmission has been detected from one bacterium to another *in vivo* when bacteria carrying these plasmids are ingested in large numbers. Wald's characterization of biological containment is rudimentary. In fact, most experiments done in P3 and P4 laboratories would require use of specially enfeebled strains—for example, mutants of K12—that have been demonstrated to survive only 10^{-2} times as well as ordinary K12 in laboratory conditions. Tests performed with candidates for such strains have revealed no survival in the animal gut, even when ingested in extremely high numbers. Moreover, the plasmids used in these experiments are of the non-transmissible type. The transfer resulted quoted by Wald were obtained with plasmids that transfer at very high frequency. In fact, no one, to my knowledge, has demonstrated transfer of a non-transmissible plasmid *in vivo* from K12, even under strong selective conditions.

4. Wald believes that "recombinant DNA technology faces our society with ... [unprecedented] ... problems," because "the nub of the new technology is to move genes back and forth, not only across species lines, but across any boundaries that now divide prokaryotes from eukaryotes." The dogmatic statement of fact that so moves Wald is highly debatable. It is well known that among prokaryotes *in vivo*, DNA passes not only across species lines but also across genus and family lines, and it is far from obvious that DNA does not frequently pass the "prokaryotic-eukaryotic" barrier as well. Many biologists believe that some of the organelles of higher cells, such as mitochondria and chloroplasts, are descendants of bacteria that existed as symbiotes of eukaryotic cells. It has been estimated that the Earth's human population alone excretes some 10^{22} bacteria per day. *E. coli* absorbs foreign DNA in the laboratory quite readily when treated with calcium ion, and the frequency with which such conditions arise in the gut, or with which mutants arise that are competent to accept foreign DNA under ordinary conditions, is probably not much below 10^{-6} . Other common strains of bacteria, such as *Haemophilus*, are competent, under almost all conditions, to absorb foreign DNA. Of course, host restriction will decrease the efficiency of any initial transfer, but once DNA is past this barrier it is no longer recognizable as foreign. Wald's scenario for disaster assumes that the addition of a bit of foreign DNA would render a bacterium a strongly virulent pathogen. It is likely that such a recombinant, with a marked selective advantage over ordinary bacteria, would not have been produced and selected for by nature? Wald apparently does not take his "barrier" argument very seriously, because he freely asks, "Yet what is to keep some hybridized *E. coli* from transferring those plasmids to human cells?"

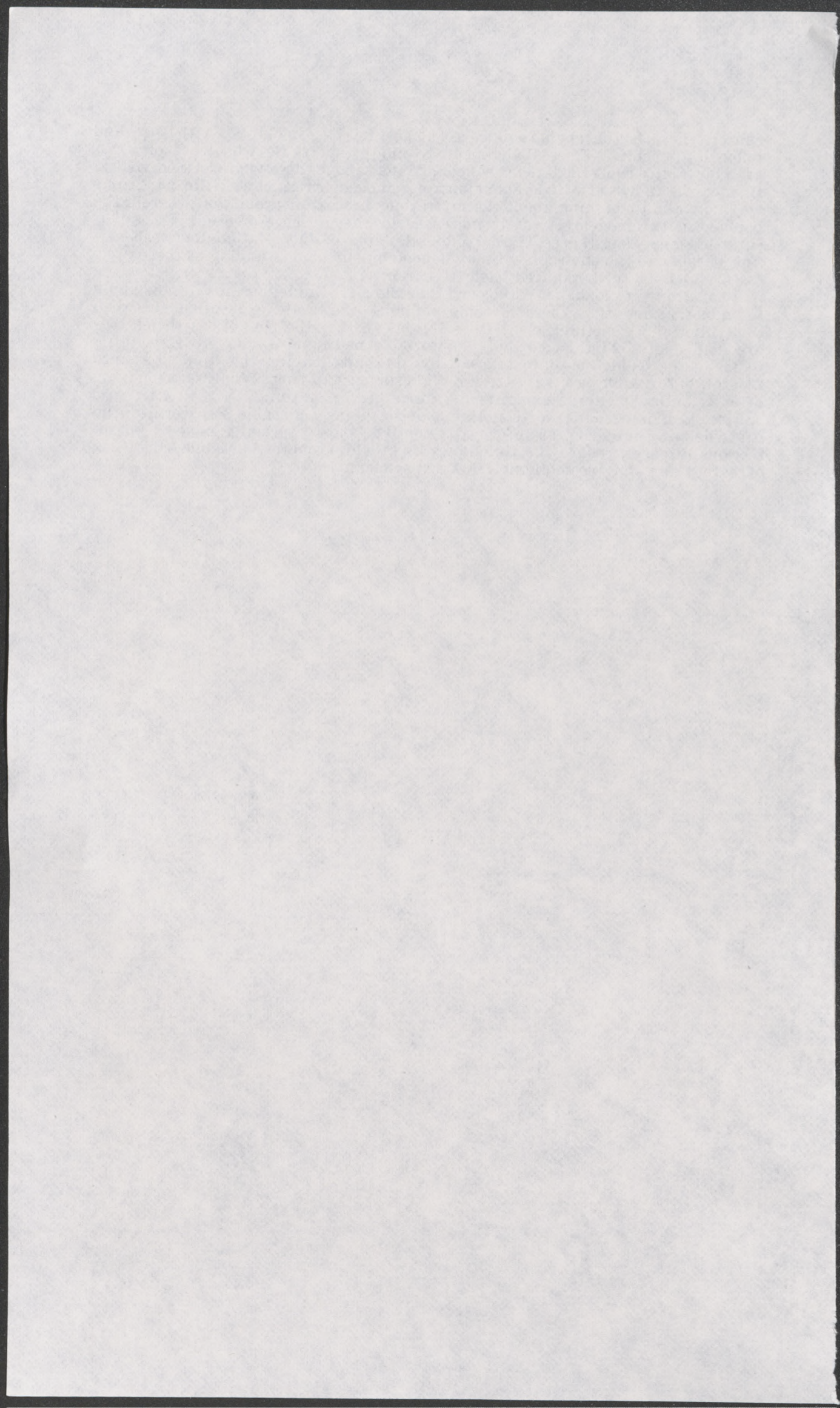
5. Wald states: "I think that the most certain benefits to come out of [this technology] would be scientific: increased understanding of important biological phenomena, such as the mechanisms that turn specific gene activities on and off, that trigger cell multiplication and differentiation, that regulate cell metabolism." He adds: "I would guess that recombinant DNA research carries more and earlier risk of causing cancers than hope of curing them." Wald presents not a shred of argument or evidence that would make plausible the extraordinary statement that recombinant experiments might cause cancers. The first part of Wald's statement is in fact a good summary of what most workers in the field believe to be the likely benefits of this work.

6. Wald has added a series of diversions, the relevancy of which I cannot determine. It is no news to most of us that smoking causes lung cancer, but what are we to make of the admonition: "If one were really concerned about

cancer, there is the obvious place to attack it [i.e., smoking], with sure and immediate results." Does Wald mean to imply that those who work on DNA are not "really concerned about cancer?" What about those who work on vision? In fact we know very little about how carcinogens cause cancer—in particular we know almost nothing about the mysterious process of promotion wherein the potency of carcinogens is vastly increased by the presence of otherwise apparently harmless substances. A real understanding of the relations between carcinogenesis and the environment may depend on our understanding of these processes which in turn requires basic research.

What are we to make of Wald's cry that the NIH Guidelines do not now apply to industry, and that there is some ominous "corporate connection" between something and something else? Does this mean that the Guidelines themselves are inadequate? At this moment Senators Kennedy and Javits are attempting to make the Guidelines into federal law. Perhaps making the Guidelines into federal, enforceable law will satisfy Wald, or perhaps not. What Wald may be after is outlawing these experiments altogether by statute.

Finally, it is perhaps worth noting that so far as I am able to ascertain, the overwhelming majority of informed scientists, most especially experts on infectious diseases, regard the Guidelines as providing more than sufficient levels of safety for the recombinant DNA experiments.



APPENDIX 13

RECOMBINANT DNA—ON OUR OWN

The recombinant DNA issue will not go away. It is but the churning edge of a turbulent sea of concerns to come, as mankind again extends its dominion, this time to redirect the course of biological evolution. And as we find our course in this changed world, we should not expect that the ways of science will remain unchanged.

It is the success of science that has ended its pleasant isolation from the strident conflict of interests and the often passionate clash of values. The great discoveries in molecular and cellular biology—in particular the elucidation of the structure and functions of the nucleic acids—have provided us with a definitive understanding of the nature of life. Earlier in this century splendid discoveries in physics and chemistry provided us with a definitive understanding of the nature of matter. From that understanding has come the technology to reshape the inanimate world to human purpose. And many are less than pleased with the consequences. Now the description of life in molecular terms provides the beginning of a technology to reshape the living world to human purpose, to reconstruct our fellow life forms—each, as are we, the product of three billion years of evolution—into projections of the human will. And many are profoundly troubled by the prospect.

With the advent of synthetic biology we leave the security of that web of natural evolution that, blindly and strangely, bore us and all of our fellow creatures. With each step we will be increasingly on our own. The invention and introduction of new self-reproducing, living forms may well be irreversible. How do we prevent grievous missteps, inherently unretraceable? Can we in truth foresee the consequences, near- and long-term, of our interventions? By our wits mankind has become the master of the extant living world. Will short-sighted ingenuity now spawn new competitors to bedevil us?

The apparent significance of the potential hazard of recombinant DNA depends markedly on the perspective in which the issue is seen. Viewed narrowly the potential hazard seems slight. Most of the novel microorganisms will likely be innocuous. A few, by careful design and selection, will be of value for human purpose. A few might inadvertently be perilous. The chance of release of these organisms is statistically small although it can hardly be null. The chance of a series of events necessary to produce a plague seems slim, in any one experiment.

Viewed broadly, however—over long years, in numerous environs, with countless experiments—a far larger penumbra of hazard appears. Nature has developed strong barriers against genetic interchange between species. What do we know of the consequence of breaching these barriers? In particular and specifically, what may in time ensue if we introduced genetic intercourse between ourselves (and our biological relations) and the ubiquitous microorganisms with which we live so intimately?

We can have no assurance that science will not bring us into a more dangerous world. The search for knowledge has often been hazardous; many explorers have faced great perils. Now the hazards can encompass the planet, and we may not continue to rely upon the resilience of nature to protect us from our follies.

New circumstances bring new perspectives. As scientists we have had the rare luxury to pursue truth, unhampered by conflicts of compassion. Caution has been an unfamiliar virtue while boldness and curiosity have been hallowed. As we cut free the strands of our inheritance, a different blend of virtues may be in order and other traditions may be helpful.

We should not underestimate these stakes, now and in time to come. We will need to establish in each time a sense of limits commensurate with our finite vision and shaped by our sense of the moral—limits within which we believe we can explore without fear and with decency, and beyond which we should

tread most gingerly. These limits will change continually as knowledge grows. In their definition and redefinition we should involve all who can help and respect all of those affected.

As scientists who seek to understand nature, we should not unthinkingly and irreversibly perturb it. As human beings we have a responsibility always to be concerned for our fellows and our fellow creatures and the future generations.

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APPENDIX 14

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PUBLIC LECTURE, HARVARD SCIENCE CENTER: DARWIN, PASTEUR, AND THE ANDROMEDA STRAIN

Recent developments in molecular genetics have made it easy to insert small fragments of genetic material (DNA) from any organism, including man, into tiny self-replicating units of DNA from bacteria, called plasmids. These can be reintroduced into bacteria, such as the common *E. coli* of the human gut, which can then be used to manufacture large quantities of the inserted DNA in pure form. The possibilities opened up by this technique have aroused enormous interest among biologists but have also generated wide public concern, focused on two potential risks. The first is the immediate risk of harm from some of the novel organisms produced. It is useful to consider this risk in terms of three probabilities: the probability of producing a pathogenic organism, the probability of its infecting an exposed laboratory worker, and the probability of its spread in the community. The second risk is a more conjectural, long-term one: that our interference with evolution, by recombining DNA from distant sources, will eventually create unforeseeable disasters.

Both these issues raise ethical questions, on which a public consensus is the ultimate arbiter. But a rational decision requires an informed public—and despite claims that we are entirely in the dark in this novel territory, we actually possess a good deal of relevant information. It is this knowledge—in microbiology, epidemiology, and evolutionary theory—that I wish to review. For the extensive public discussions of the hazards have been built largely on the assumption that any novel organism we may produce is likely to survive and spread, and this assumption ignores what was Darwin's great discovery: the dominating role of natural selection in determining what survives, multiplies, and evolves. Working with the invisible organisms that were not part of Darwin's world, Pasteur made essentially the same discovery, though it was expressed in different terms: he showed that bacteria do not arise by spontaneous generation but are ubiquitous, and the kinds that grow out in any medium are the ones that are selected by that medium. For example, the same mixture of contaminants from the air grows out one kind of organism in grape juice, producing an alcoholic fermentation, and another kind in milk, producing a lactic acid fermentation.

Unfortunately, the evolutionary considerations that I shall invoke cannot provide the hard data that we have become accustomed to in modern experimental biology, and a skeptic might dismiss the arguments as mere handwaving. But then nearly all of Darwin's arguments, based on inferences about the past and not on verifiable experiments, could be similarly dismissed. And I would remind you that Darwin's theory remains the most profound generalization in biology—unifying the field, enormously supported today by the evidence for continuous evolutionary progression in DNA sequences, and rich in implications for our understanding of man.

Let us start by reviewing some principles from evolution and microbiology that seem pertinent to the problem of estimating the risks of recombinant DNA research.

I. BACKGROUND

A. Microbiological and evolutionary principles

(1) *The meaning of species.*—As evolution proceeded from prokaryotes (i.e., bacteria with a single chromosome) to eukaryotes (i.e., higher organisms, with a more complex genetic apparatus), it created the process of sexual reproduction, which reassorts genes and thus provides vastly increased genetic diversity for natural selection to act on. But while diversity is necessary for evolution, un-

limited combinations from the pool of genetic material in the living world would not be useful, for a successful organism must have a reasonably balanced set of genes. Hence the development of sexual reproduction was accompanied by the development of species: groups of organisms that reproduce only by mating with other members of the same group, and not with members of other species. Some closely related species produce hybrid offspring, such as a mule, that are viable but not fertile, while more distant crosses produce no offspring at all. The evolutionary value of such fertility barriers is clearly to avoid useless production of grossly unfit, non-viable progeny.

Unlike eukaryotes, prokaryotes ordinarily reproduce by the asexual process of cell division, which means that the genetic properties of a strain remain constant for generation after generation, except for rare mutations or rare gene transfers. The gene transfers, which are usually mediated by plasmids or viruses, do not show a sharp species boundary: they simply become less efficient the greater the evolutionary separation between the donor and the recipient. Prokaryotes therefore have no true species: they have an almost continuous spectrum of genetic patterns, and the borders between what we call bacterial species are arbitrary and often controversial. *E. coli*, for example, is not a homogeneous species. It is the name given to a range of strains with certain common features and also with a variety of differences—in surface molecules, nutrition, growth rate, sensitivity to inhibitors, etc. These differences determine the relative Darwinian fitness of various strains for various environments.

(2) *Bacterial ecology*.—Every living species is adapted to a given range of habitats. The set of bacterial strains called *E. coli* thrive only in the vertebrate gut. They survive temporarily in water but quickly die out. (Indeed, for that reason the *E. coli* count of a pond or a well is a reliable index of its continuing fecal contamination.) In the gut there is intense Darwinian competition between strains, depending on such variables as growth rate, nutritional requirements, ability to scavenge limited food supplies, adherence to the gut lining, and resistance to antimicrobial factors in the host. Hence most novel strains are quickly extinguished. It is the kind of selection by competition envisaged by Darwin for higher organisms, but it happens in days rather than in eons, because the generation time of many bacteria is only 20 minutes and the selection pressures are often intense.

This effect of the environment in the gut (i.e., type of food and physiological state) on the normal flora is readily recognized. For example, when breast feeding is replaced by solid food the character of the stool changes dramatically, as lactic acid bacteria, which produce sweet-smelling products, are replaced by *E. coli* and other foul organisms. And in an experimental example, early in this century, Mechnikov romantically hoped to promote longevity by reversing the process, by supplying a large number of lactic acid bacteria, in the form of yogurt, to displace the presumably toxic foul organisms. The experiments were a dismal failure, but perhaps a commercial success. In a third, more recent example we frequently see the normal bacterial population of the gut disturbed by administration of antibiotics, and it has not proved possible, despite commercial interest, to accelerate recovery by administering desired strains. It is clear that in the gut the environment plays a dominating role in determining what strains persist.

(3) *Pathogenesis*.—Only an incredibly small fraction of all bacterial species can cause disease. The rest play essential roles in the cycle of nature, in which CO_2 from the air is fixed in plants or bacteria by photosynthesis, the plants are eaten by animals, the animals and plants return to the soil after death, and there microorganisms digest the dead organic matter and return the carbon to the atmosphere as CO_2 .

Infectious bacteria differ from each other in several distinct respects: infectivity (i.e., the infectious dose, ranging from a few cells of the tularemia bacillus to around 10^6 cells of the cholera vibrio); specific distribution of the organism in the body; virulence (i.e., the severity of the disease once the infection has overcome natural resistance); and communicability from one individual host to another (including length of survival in nature). As with any complex property, these attributes depend on the coordinate, balanced activity of many genes, which are capable of independent variation. It is especially important to distinguish the ability to produce a serious disease from the ability to spread. For example, the tetanus bacillus is a normal, non-invasive inhabitant of the gut, but it can cause fatal illness when trauma gives it access to a susceptible tissue.

(4) *Stabilizing and diversifying selection.*—When an organism grows continuously in a relatively constant environment natural selection has a stabilizing effect, weeding out the variants that deviate too far in any direction from the well adapted norm. But when the environment is changed the same basic process of natural selection has another, diversifying effect: the new circumstances select for the preferential survival and reproduction of variants with increased fitness for those circumstances. This Darwinian process explains the fluctuation in the properties of bacterial cultures that confused the early workers. For example, when pathogenic bacterial strains from infected hosts are isolated in the laboratory and then repeatedly transferred in artificial culture media they face an abrupt change of environment, and they rapidly develop improved adaptation to the new environment at the expense of decreased adaptation to the old one (i.e., they lose virulence).

The mechanism is now clear, and it does not involve any directive effect of the environment on the shifting bacterial population. Instead, rare mutants of all kinds are constantly appearing in the successive generations—in fact, as much as 10% of the cells in each generation may have a change in one of the several million bases of the cell's DNA, though most of these mutations are not recognized because their effects are either too small to be seen or too large to yield a viable cell. Among the viable progeny those that are better adapted to the new culture medium (i.e., that can grow slightly faster, or can grow slightly longer with a limited food supply) outgrow the original strain.

We can see a similar effect of the wide use of antibiotics in man and in domesticated animals, except that the environment being changed is now the animal host rather than a laboratory culture medium: the result has been increased prevalence of drug resistance among some of the microbes that normally inhabit or that occasionally infect those hosts. The key is again selection: unless the drug is present in the environment to exert a selection pressure the introduction of even large numbers of a variant with specific drug resistance will not lead to its spread unless the variant is as well adapted as its competitors.

It is clear that natural selection plays an overwhelming role in evolution. With bacteria its role was long unrecognized: the population shifts seemed too rapid for an undirected process, and the existence of genes and mutations in bacteria were not recognized until the 1940's. But by now selection has become the foundation of bacterial ecology.

B. Benefits of recombinant DNA research

Before going on to analyze the hazards we should take a brief look at some of the benefits, which must also be considered in any decision.

Synthesis of recombinant DNA in vitro is not just a toy to satisfy the curiosity of investigators. It is an extraordinarily powerful and simple tool for studying the structure and function of mammalian DNA, and it has rapidly become as indispensable as radioactive isotopes or the electron microscope. In particular, we do not understand the regulation of mammalian genes nearly as well as that of bacterial genes: the cells are harder to work with in many ways, and they contain DNA equivalent to several million genes, or about a thousand times the amount in a bacterium. The recombinant DNA technique, which can purify fragments containing a single gene and its regulatory elements, provides an enormous simplification of the system and thus promotes its analysis. In addition, the value of such purification has recently been enormously enhanced by the development, by W. Gilbert and by F. Sanger, of an extremely simple technique for determining the sequence of short fragments of DNA, up to two hundred bases long. In two days one can now completely determine such a sequence, which previously took two years; hence we can anticipate rapid progress in determining the chemical structure of innumerable mammalian genes.

While no one can foresee all the consequences of a basic discovery, the history of molecular biology assures that these new developments in handling DNA will lead to great advances in our understanding of mammalian gene regulation, the key to normal development and differentiation and also to the defective regulation of cell growth in cancer. One can also safely predict the use of such bacteria for producing medically valuable human cell products, such as insulin and other protein hormones, specific antibodies to replace deficiencies, specific antigens for immunization against tumors, and the specific genes or their products that may ultimately be used to treat hereditary enzyme deficiencies.

In addition to these practical benefits, I need hardly emphasize for this audience the enormous cultural importance of encouraging free inquiry, and the potential loss to society from a precedent of curtailing such inquiry. At the same time, it has always been clear that the right to freedom of inquiry has limits, just like the right to freedom of expression. One such limit is cruelty: a medical experimenter must recognize that he is dealing with human subjects and not with objects. Another limit is unacceptable hazard, whether to individuals, to the population, or to the environment: hence the acceptance of regulations and licensing requirements for research with radioactive materials. In turning now to the question of hazard I would suggest that we cannot pretend to compare risks and benefits as closely as we can compare costs and benefits: we must rather ask whether a particular set of risks is acceptable, in terms of the increment that it may add to the risks that we already live with. For a demand for absolute freedom from risk would be a prescription for paralysis.

II. HAZARDS

In trying to estimate the immediate hazards we must consider, as I mentioned earlier, three probabilities: that experiments with a given kind of DNA will produce a dangerous organism, that that organism will infect a laboratory worker, and that the organism will escape and spread in the community or the environment. For it is easy to draw up a scary hypothetical scenario, if one's imagination need not be limited by considerations of probability. But any realistic discussion must consider probabilities.

A. DANGER OF PRODUCING A HARMFUL ORGANISM

If one deliberately transfers into *E. coli* a bacterial gene for toxin production the probability of its having the expected phenotypic effect on the cell, and producing its toxin as long as it survives in the new host, is very high. If one introduces the total genome of a tumor virus the hazard will be less, for it would require release of the viral DNA and its infection of host cells; but while that probability may be very low, we cannot assume that it is negligible. Both these kinds of experiments are appropriately prohibited in the NIH Guidelines today.

I would like to concentrate on a kind of experiment that is allowed but is causing great concern and is restricted to quite special facilities: the so-called "shotgun" experiment, in which one transfers random fragments of DNA from mammalian cells. Here it is clear that the probability of isolating a strain with a gene for a toxic product, or with the genes of a tumor virus, is exceedingly low.

Evolutionary considerations provide an additional and independent approach to the question whether shotgun experiments are likely to create novel and harmful microbes. In my opinion it is exceedingly doubtful that our new-found ability to introduce mammalian DNA into bacteria in the laboratory will create a truly novel class of organisms, for evolution had an earlier crack at the problem. It is known that bacteria can take up naked DNA from solution and, in fact, two different strains of pneumococcus have been shown to be able to produce a third, recombinant strain in an animal body, by release of DNA from a lysed cell of one strain and its uptake by an intact cell of the other. Moreover, bacteria in the gut are constantly exposed to fragments of host DNA that are released as the cells lining the gut die; while bacteria growing in carcasses have a veritable feast.

The efficiency of such uptake of mammalian DNA by bacteria is undoubtedly very low. However, because of the extraordinarily large scale of the exposure in nature, recombinants of this general class must have been formed innumerable times over millions of years and thus have been tested in the crucible of natural selection. Moreover, such organisms are undoubtedly also being formed in nature today. If they had high survival value we would be recognizing short stretches of mammalian DNA in *E. coli*. We do not. In addition, if the naturally occurring recombinants included serious pathogens, as is feared from artificial recombinants, we would be seeing epidemics of serious disease due to *E. coli*. We do not. If, on the other hand, naturally occurring recombinants are appearing and even causing disease, but are escaping our attention, we would have to ask how much our laboratories could add, since nature experiments with about 10^{22} bacterial cells produced in the human species per day.

As an additional danger, it has been suggested that terrorists might deliberately create harmful recombinant bacteria, as a powerful new tool. But it is hard to see why a terrorist would be interested in an *E. coli* strain containing, say, a gene for botulinus toxin, when that gene is already housed in the naturally occurring *Clostridium botulinum*, a well adapted organism with proven survival value. With that organism the terrorist could manufacture, at the cost of a few dollars, enough botulinus toxin to poison all the inhabitants of a large city.

B. Danger of laboratory infection

In moving now from the probability of inadvertently producing a harmful organism to the probability of its causing a laboratory infection, let us assume the worst case: an *E. coli* strain producing a potent toxin absorbable from the gut, such as botulinus toxin. (This experiment is at present prohibited). Such a strain would present a real danger of laboratory infection. But there are a number of reasons to expect it to be less, with even this worst hypothetical recombinant pathogen, that with the pathogens that are handled every day in diagnostic and research laboratories.

(a) The known laboratory infections (about 6,000 recorded in the history of microbiology) have been largely due to organisms that cause respiratory infections, spread by droplets (mostly before safety cabinets were introduced in the 1940's). Because enteric infections occur through swallowing of contaminated food or other material, even the most virulent enteric pathogens are relatively safe to handle in the laboratory with simple precautions, such as not putting food or a cigarette on the laboratory bench.

(b) Strain K12 of *E. coli*, used in almost all genetic work, has been transferred for at least 30 years in the laboratory, during which it has become much better adapted to artificial media than to the human gut. In fact, recent tests showed that after a large dose in man (much larger than what one would expect from a laboratory accident) this strain disappeared from the stools within a few days. Its problems of survival are analogous to those of a delicate hothouse plant thrown out to compete with the weeds in a field.

(c) The addition of a block of foreign DNA to an enteric organism will ordinarily decrease its adaptation to survival in the gut and hence its probability of spreading. For at the least, replication of useless DNA exacts a metabolic price for an organism; while if the DNA is active its products are likely further to disturb the metabolic balance.

(d) A very large safety factor is added by the provision for biological containment in the present Guidelines. All work with mammalian DNA must be carried out only in a strain derived from *E. coli* K12 (the class called EK2) that has a drastically impaired ability to multiply, or to transfer its plasmid, except under very special conditions provided in the laboratory. For example, in the presently certified EK2 strain the defects include loss of the ability to synthesize an essential wall component. The strain is maintained in the laboratory by supplying the missing component, which is not found in the gut. Cells growing without that component quickly burst, because they grow without forming more wall; hence survival is less than 10^{-8} in 24 hours.

We thus see that with a strain known to have added the gene for a potent toxin in a serious laboratory infection requires the compounding of four low probabilities. With strains from shotgun experiments we have a fifth, very low probability, already mentioned: that an apparently harmless mammalian tissue will yield a dangerous product.

I conclude that in the kinds of experiments now permitted (which exclude the introduction of a known gene for a potent toxin or a known tumor virus) the danger of a significant laboratory infection is vanishingly small compared with the dangers encountered every day by medical microbiologists working with virulent pathogens. And such dangers must ultimately be balanced against the potential benefits, both practical and cultural. In the United States, up to 1961, of the 2400 recorded cases of laboratory infections 107 were fatal—over half of these from diagnostic laboratories. On the other side, millions of lives were saved by bacteriological research and diagnosis.

But even if the risks in recombinant DNA research are much smaller than the public has been led to believe, it is important to keep all the probabilities low. In particular, even if a toxin-producing strain would survive only very briefly in the gut, a large enough dose might meanwhile produce enough toxin to cause disease. Hence it is important for molecular biologists working in this area to

learn, and to use, the standard techniques of medical microbiology, at least until we have acquired much more experience with the organisms. Indeed, the enforcement of such practices could be a major benefit from the current discussion.

C. Danger of spread

I now come to the most important point of all, with respect to protecting the public interest. The difference between the danger of causing a laboratory infection and the further danger of unleashing an epidemic is enormous. In our government's bacteriological warfare laboratories at Camp Detrick, working for 25 years on the most communicable and virulent pathogens known, 423 laboratory infections were seen. Moreover, most of these infections were picked up by the respiratory route. Yet despite our very imperfect control of respiratory transmission there was not a single case of secondary spread to a member of the family or to any person outside the laboratory. Similarly, in the Communicable Disease Center of the U.S. Public Health Service 150 laboratory infections were recorded, with one case of transmission to a spouse. Elsewhere in the world there have been about two dozen laboratory-based microepidemics recorded, each involving a few outsiders.

With enteric pathogens the danger of secondary cases is minimal, for with this class of agents modern sanitation provides infinitely better control than we can provide for respiratory infection: in contrast to influenza, the appearance of a case of typhoid in a home does not lead to an epidemic. Enteric epidemics appear only when sanitation is poor or has broken down, or when a symptom-free carrier with filthy personal habits serves as a food handler; and such epidemics are always small (except when sewage freely enters the water supply).

There is no doubt that this epidemiological information is pertinent to the recombinants that we are discussing. For despite widespread apprehension about the presumed biparental chimeras with totally unknown properties, the fact is that these recombinants are genetically 99.9 percent *E. coli*, with about 0.1 percent foreign DNA added. It is exceedingly improbable that such an organism could have a radically expanded habitat, no longer confined to the gut. It is even harder to see that the organism would be more communicable, or more virulent, than our worst enteric pathogens, which cause typhoid and dysentery. The Andromeda Strain remains entertaining science fiction.

I conclude that if by remote chance a recombinant strain should be pathogenic, and if it should cause a laboratory infection, that infection would give an early warning, which would decrease the chance of spread.

Moreover, if a case should appear outside the laboratory the enteric habitat of *E. coli* provides powerful protection, in a country with modern sanitation, against the chain of transmission required for an epidemic.

We must therefore ask whether the problem merits deep concern by the general public, any more than the problem of how laboratories performing diagnostic work or research on known pathogens should be operated. To produce a serious epidemic by introducing fragments of mammalian DNA into *E. coli* would require the compounding of five low probabilities. By any reasonable analysis the risk seems very much less than that from pathogens that are being cultivated in laboratories all the time.

D. Tumor viruses

Tumor viruses present a special problem. Unlike other viruses, whose entry in an adequate dose regularly causes disease in a susceptible host, tumor viruses do not cause a tumor regularly after infection but require special circumstances. Indeed, their frequent presence in apparently normal animal tissues is the main source of the fear of shotgun experiments. Moreover, whether they make any contribution to human cancer is still quite unknown. Nevertheless, if they should do so it would be after a latent period of years. Hence any conceivable infection by a bacterium containing a tumor virus genome would lack the early warning of the toxin producers.

However, all other aspects of the problem remain the same. And this loss of one protective feature is balanced by the fact that these viruses, by definition, have their own means of spread. Indeed, in general the natural spread of viruses is even more effective than that of bacteria, each infected animal cell producing thousands of infectious virus particles. Moreover, since viral DNA in a bacterium would have to get out of its host cell and enter human cells through an extremely inefficient process, it is hard to imagine that that naked DNA would be more hazardous than the same DNA in its own infectious, viral coat, adapted by

evolution for entering animal cells. In addition, if we fear the danger of such indirect uptake of unrecognized tumor virus DNA from normal mammalian tissue, one must ask whether the direct ingestion of such tissue, e.g., in steak cooked rare, may not present at least as great a danger.

It therefore seems fair to ask whether there is greater danger if we use the recombinant DNA technology to help us to understand tumor viruses, or if we presumably play safe and inhibit that research. For if we choose the latter we meanwhile allow the tumor viruses to spread as they presently do in nature, under circumstances where we really do not understand their relation to human tumors at all. If I may engage in a bit of speculation, I would suggest that ordinary blood transfusions probably have a much higher risk of exposing us to tumor-producing agents. For since tumors are not detected until they reach a substantial size, the probability that the average transfusion has come from an early tumor patient is not negligible: it may be as high as 0.1 or 1 percent. The choice between cancer cells injected into one's bloodstream, and tumor virus genes in bacteria in one's gut, would not seem difficult.

E. The NIH guidelines

Though extensive discussion preceded formulation of the Guidelines I believe it did not include nearly enough input from experts in infectious disease and in evolution, who could have debated the real hazards rather than unlimited hypothetical scenarios. And in the light of what I see as the technical realities I would regard the present Guidelines as excessively conservative. On the other hand, I would also regard them as a reasonable response to the level of public anxiety that has been raised, though they make the research substantially more expensive. And in the face of the alleged dangers that have been described I cannot blame the public for having a high level of anxiety. But I do blame the New York Times for publishing in their Sunday Magazine last August a one-sided presentation by a molecular biologist who displayed extraordinarily little understanding of either microbiology or evolution. In speaking of *E. coli* as though it were a standard, uniformly distributed organism, which would carry with it through the world any additional genes that we insert, he ignored the most important factor of all: natural selection. He also made the remarkable statement that the insertion of tumor viruses into bacteria may make them infectious. And his scary scenarios concluded with the suggestion that scientists working in this field may produce yet another Andromeda strain—as though the first strain existed in fact rather than in fancy.

Given the present level of public anxiety, scientists in this field seem quite willing to accept the Guidelines. But I hope it will not be too long before these rules are modified in the light of further experience. For since the technique is potentially useful for a large number of investigators, the requirement for elaborate facilities will add up to a very large expense. There must be some limits to the laudable principle of erring on the side of caution.

III. INTERVENTION IN EVOLUTION

The hazard that we have been discussing—that of creating novel, dangerous organisms—is a legitimate cause for public concern; there is no question about society's right to limit hazardous activities. However, when we move to the question whether our increasing power to manipulate genetic material creates long-term evolutionary dangers we are moving into quite a different area, involving the concept of dangerous knowledge rather than dangerous actions. The most prominent exponent of this view is Robert Sinsheimer, of Caltech. Perhaps we can clarify the issue by trying to translate into more specific terms some of the general sources of apprehension that he has expressed in various publications.

1. Dr. Sinsheimer questions our moral right to breach the barrier between prokaryotes and eukaryotes, since we simply cannot foresee the consequences. This argument seems to turn voluntary principles through 180 degrees. Evolution is concerned with selection for fitness, in the Darwinian sense, and the barriers that it has established between species are designed to avoid wasteful matings, i.e., matings whose products would be monstrosities, in the sense of being unable to survive, rather than monsters, in the sense of taking over. Since survival of an organism depends upon a balanced genome, evolution proceeds in small steps, no one of which will excessively unbalance the genome in one respect while improving its adaptation in another. And since crosses between even closely related species are excluded in nature on these grounds, it is exceedingly unlikely that arti-

ficial transfers of genes between eukaryotes and prokaryotes would pass the test of Darwinian fitness.

2. "This is the beginning of synthetic biology." I wonder whether this statement can really be defended, considering that man has been domesticating animals and plants by selective breeding since neolithic times, and has also been cloning vegetables by grafting.

3. "The power to change the evolutionary process is as significant as cracking the atom." But atoms are not subject to extinction by Darwinian selection. Stores of nuclear weapons are likely to be more permanent than any dangerous organism that might reach the world from a laboratory working with recombinant DNA. Similarly, the statement by George Wald that "a living organism is forever" is dramatic, but it disregards two powerful evolutionary predictions: first, that natural selection will rapidly extinguish all evolutionary departures except for the infinitesimal fraction that have improved their adaptive fitness; and second, that the recombination of genes from distant sources has an exceedingly small probability of improving fitness.

4. "We no longer have the absolute right of free inquiry." But we never had: as I noted above, dangerous procedures have always been subject to limitations. But to invoke dimly foreseen, undefined dangers seems to be starting on the slippery slope of excluding dangerous ideas.

5. Power over nucleic acids, as over the atomic nucleus, "might drive us too swiftly toward some unseen chasm. . . . We should not thrust inquiry too far beyond our perception of its consequences." While we have become increasingly aware of the costs and dangers of technology, and should increase our alertness to these problems as they become visible, I would paraphrase this statement and suggest that we should not thrust our limitations on research too far beyond our perceptions of its hazards. Some claim that scientists are arrogant and wish to steam ahead regardless of the consequences. But considering the history of the benefits of science, and the sad history of Italy's elimination from the race by Pope Urban VIII after its head start under Galileo, perhaps it is more arrogant for a handful of opposed scientists, having presented their arguments, to try desperately to place severe restrictions on recombinant DNA research.

6. Finally, Sinsheimer suggests that this is the beginning of a genetic engineering that will ultimately extend to man. In contrast to the vagueness of the preceding propositions, this one is concrete, and one can wrestle with it. Moreover, I suspect that it lies at the heart of his anxiety, and that of much of the audience.

This is too large a topic to consider in detail here. In 1970 it received extensive discussion, which then subsided but has been reactivated by the very different question of genetic engineering in bacteria. I would only point out briefly that the medical aim of genetic engineering in man is gene therapy for diseases due to single defective genes, with a well defined chemistry. I believe we are still a long way from being able to introduce DNA in the reliable, controlled way that would be required. But even if this guess is wrong, it is clear that success in such therapy would still leave us very far from being able to manipulate in any useful way the large number of genes, all still undefined, that affect the structure and function of the brain. Moreover, in an already developed organism no conceivable manipulation of DNA could prescribe the wiring diagram of the already formed brain. Hence the possibility that a tyrant could use genetic engineering to manipulate personalities seems still too remote to justify present concern. In addition, I would question whether the technological imperative would necessarily (or even likely) lead us to use genetic technology to manipulate human personalities if we could. If the simple but effective techniques of selective breeding and artificial insemination are not used to influence the gene pool, one must question what motivation would lead society to use the much more elaborate techniques that might emerge from current research.

Philosophical questions about the effect of science and technology on man's fate do not start with recombinant DNA but go back to Galileo. We cannot unlearn the scientific method, and if we restrict it in one place it will turn up in another. In a world that has only recently come to realize how large (and often unexpected) a price we are paying for various aspects of technology, it is only too easy to take the benefits of science and technology for granted, and to object to the new problems that they are raising. But in the long run it is difficult to see how we can plot a more prudent course than to try to recognize the hazards of

specific possible applications as they arise, to seek a reasonable balance between the demand for freedom of action and the demand for protection from excessive risks, and to seek orderly and responsible methods for involving the public in matters that so deeply affect its interests.

I share Sinsheimer's concern for the future, and his passionate advocacy of vigilance. But the vigilance must be directed at specific definable applications. Vigilance concerning new knowledge that might someday be misused is, to me, a threat to freedom of inquiry, and I believe a threat to human welfare. If we are entering dangerous territory in exploring recombinant DNA, we may enter even more dangerous territory if we start to limit inquiry on the basis of our incapacity to foresee its consequences.

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