

y 4
Sci 2
95/WW

GOVERNMENT

Storage

DOCUMENTS
[COMMITTEE PRINT]

MAR 30 1979

OVERSIGHT

FARRELL LIBRARY
KANSAS STATE UNIVERSITY

ALTERNATIVE BREEDING CYCLES FOR
NUCLEAR POWER:

AN ANALYSIS

REPORT

PREPARED FOR THE

SUBCOMMITTEE ON FOSSIL AND NUCLEAR ENERGY
RESEARCH, DEVELOPMENT AND DEMONSTRATION

OF THE

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

SECOND SESSION

BY THE

CONGRESSIONAL RESEARCH SERVICE

LIBRARY OF CONGRESS

Serial WW

VOLUME VI



OCTOBER 1978

Printed for the use of the Committee on Science and Technology

[COMMITTEE PRINT]

OVERSIGHT

ALTERNATIVE BREEDING CYCLES FOR
NUCLEAR POWER:

AN ANALYSIS

REPORT

PREPARED FOR THE

SUBCOMMITTEE ON FOSSIL AND NUCLEAR ENERGY
RESEARCH, DEVELOPMENT AND DEMONSTRATION

OF THE

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

SECOND SESSION

BY THE

CONGRESSIONAL RESEARCH SERVICE
LIBRARY OF CONGRESS

Serial WW

VOLUME VI



OCTOBER 1978

Printed for the use of the Committee on Science and Technology

U.S. GOVERNMENT PRINTING OFFICE

WASHINGTON : 1978

COMMITTEE ON SCIENCE AND TECHNOLOGY

OLIN E. TEAGUE, Texas, *Chairman*

DON FUQUA, Florida
WALTER FLOWERS, Alabama
ROBERT A. ROE, New Jersey
MIKE McCORMACK, Washington
GEORGE E. BROWN, Jr., California
DALE MILFORD, Texas
RAY THORNTON, Arkansas
JAMES H. SCHEUER, New York
RICHARD L. OTTINGER, New York
TOM HARKIN, Iowa
JIM LLOYD, California
JEROME A. AMBRO, New York
ROBERT (BOB) KRUEGER, Texas
MARILYN LLOYD, Tennessee
JAMES J. BLANCHARD, Michigan
TIMOTHY E. WIRTH, Colorado
STEPHEN L. NEAL, North Carolina
THOMAS J. DOWNEY, New York
DOUG WALGREN, Pennsylvania
RONNIE G. FLIPPO, Alabama
DAN GLICKMAN, Kansas
BOB GAMMAGE, Texas
ANTHONY C. BEILENSON, California
ALBERT GORE, Jr., Tennessee
WES WATKINS, Oklahoma
ROBERT A. YOUNG, Missouri

JOHN W. WYDLER, New York
LARRY WINN, Jr., Kansas
LOUIS FREY, Jr., Florida
BARRY M. GOLDWATER, Jr., California
GARY A. MYERS, Pennsylvania
HAMILTON FISH, Jr., New York
MANUEL LUJAN, Jr., New Mexico
CARL D. PURSELL, Michigan
HAROLD C. HOLLENBECK, New Jersey
ELDON RUDD, Arizona
ROBERT K. DORNAN, California
ROBERT S. WALKER, Pennsylvania
EDWIN B. FORSYTHE, New Jersey

CHARLES A. MOSHER, *Executive Director*
HAROLD A. GOULD, *Deputy Director*
PHILIP B. YEAGER, *Counsel*
JAMES E. WILSON, *Technical Consultant*
WILLIAM G. WELLS, Jr., *Technical Consultant*
RALPH N. READ, *Technical Consultant*
ROBERT C. KETCHAM, *Counsel*
JOHN P. ANDELIN, Jr., *Science Consultant*
JAMES W. SPENSLEY, *Counsel*
REGINA A. DAVIS, *Chief Clerk*
PAUL A. VANDER MYDE, *Minority Staff Director*

SUBCOMMITTEE ON FOSSIL AND NUCLEAR ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION

WALTER FLOWERS, Alabama, *Chairman*

MARILYN LLOYD, Tennessee
THOMAS J. DOWNEY, New York
DOUG WALGREN, Pennsylvania
BOB GAMMAGE, Texas
WES WATKINS, Oklahoma
MIKE McCORMACK, Washington
DALE MILFORD, Texas
RAY THORNTON, Arkansas
JAMES H. SCHEUER, New York
RICHARD L. OTTINGER, New York
ROBERT (BOB) KRUEGER, Texas
ROBERT A. ROE, New Jersey
GEORGE E. BROWN, Jr., California
TOM HARKIN, Iowa
JIM LLOYD, California
ROBERT A. YOUNG, Missouri

GARY A. MYERS, Pennsylvania
HAMILTON FISH, Jr., New York
BARRY M. GOLDWATER, Jr., California
MANUEL LUJAN, Jr., New Mexico
HAROLD C. HOLLENBECK, New Jersey
ROBERT K. DORNAN, California
EDWIN B. FORSYTHE, New Jersey
LOUIS FREY, Jr., Florida

SUBCOMMITTEE STAFF

ROBERT C. KETCHAM
THOMAS N. TATE
MARTHA KREBS-LEIDECKER
JOHN V. DUGAN

JAMES H. TURNER, Jr.
NANCY SMITH
CAROLYN CRAWFORD
VIVIAN TESSIERI

LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, D.C., November 1, 1978.

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

DEAR MR. CHAIRMAN: As part of the Subcommittee's continuing oversight activity, I am pleased to transmit an analysis entitled "Alternative Breeding Cycles for Nuclear Power" prepared by the Congressional Research Service of the Library of Congress.

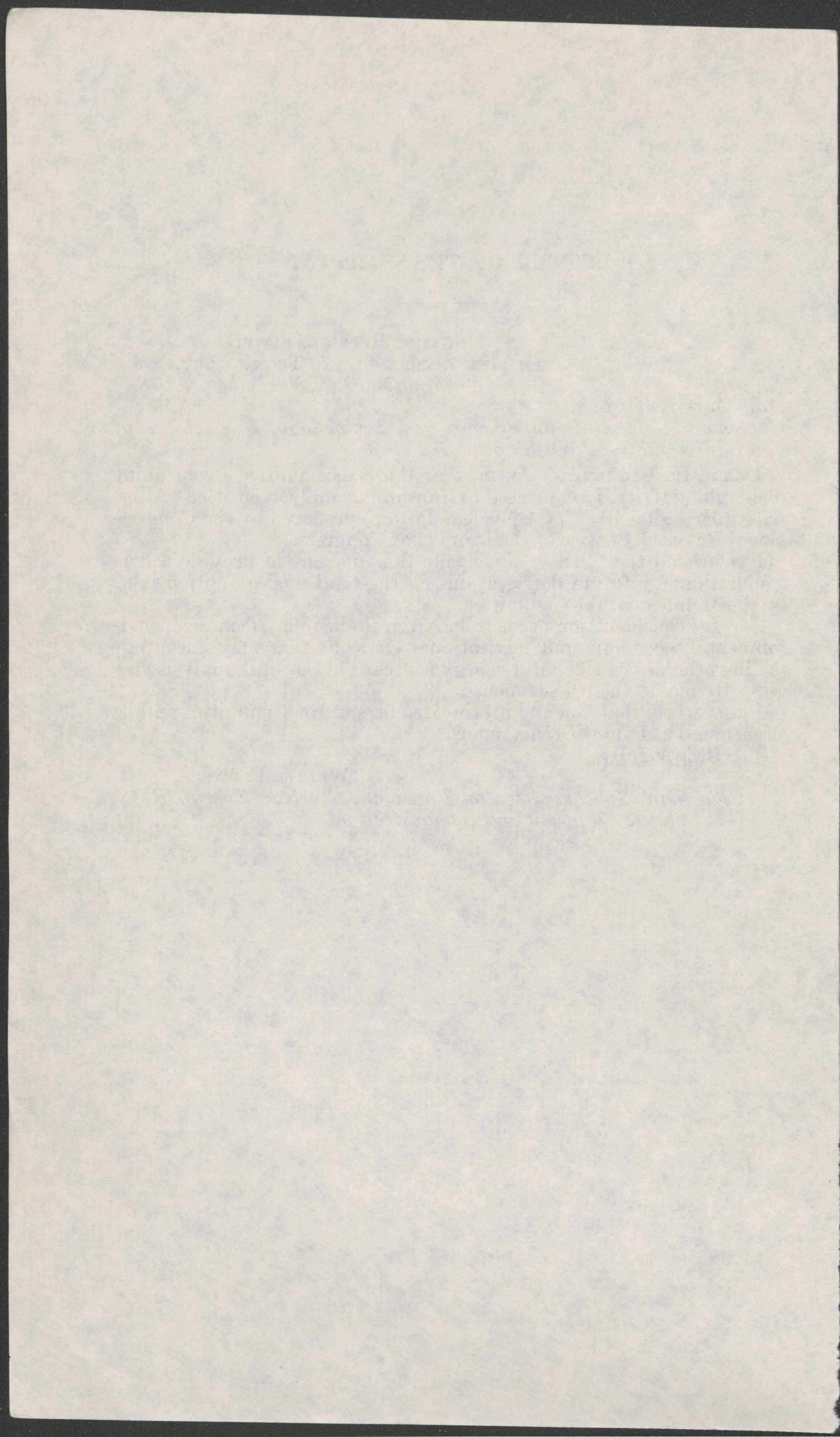
I requested the CRS to undertake this analysis to provide a firm foundation for future deliberations on the total nuclear option issue by the Members of the Committee.

Careful consideration needs to be given to the many technical, environmental, economic and institutional tradeoffs that may encourage or limit the use of this vital energy source. This careful analysis successfully makes these assessments.

I am certain that you and all the Members of the Committee will be as enthused as I am with this report.

Respectfully,

WALTER FLOWERS,
*Chairman, Subcommittee on Fossil and Nuclear Energy Re-
search, Development and Demonstration.*



LETTER OF SUBMITTAL

OCTOBER 31, 1978.

HON. WALTER FLOWERS,
*Chairman, Subcommittee on Fossil and Nuclear Energy Research,
Development and Demonstration, Committee on Science and Tech-
nology, U.S. House of Representatives, Washington, D.C.*

DEAR MR. CHAIRMAN: In response to your request, I am submitting a full analysis of Alternative Breeding Cycles for Nuclear Power.

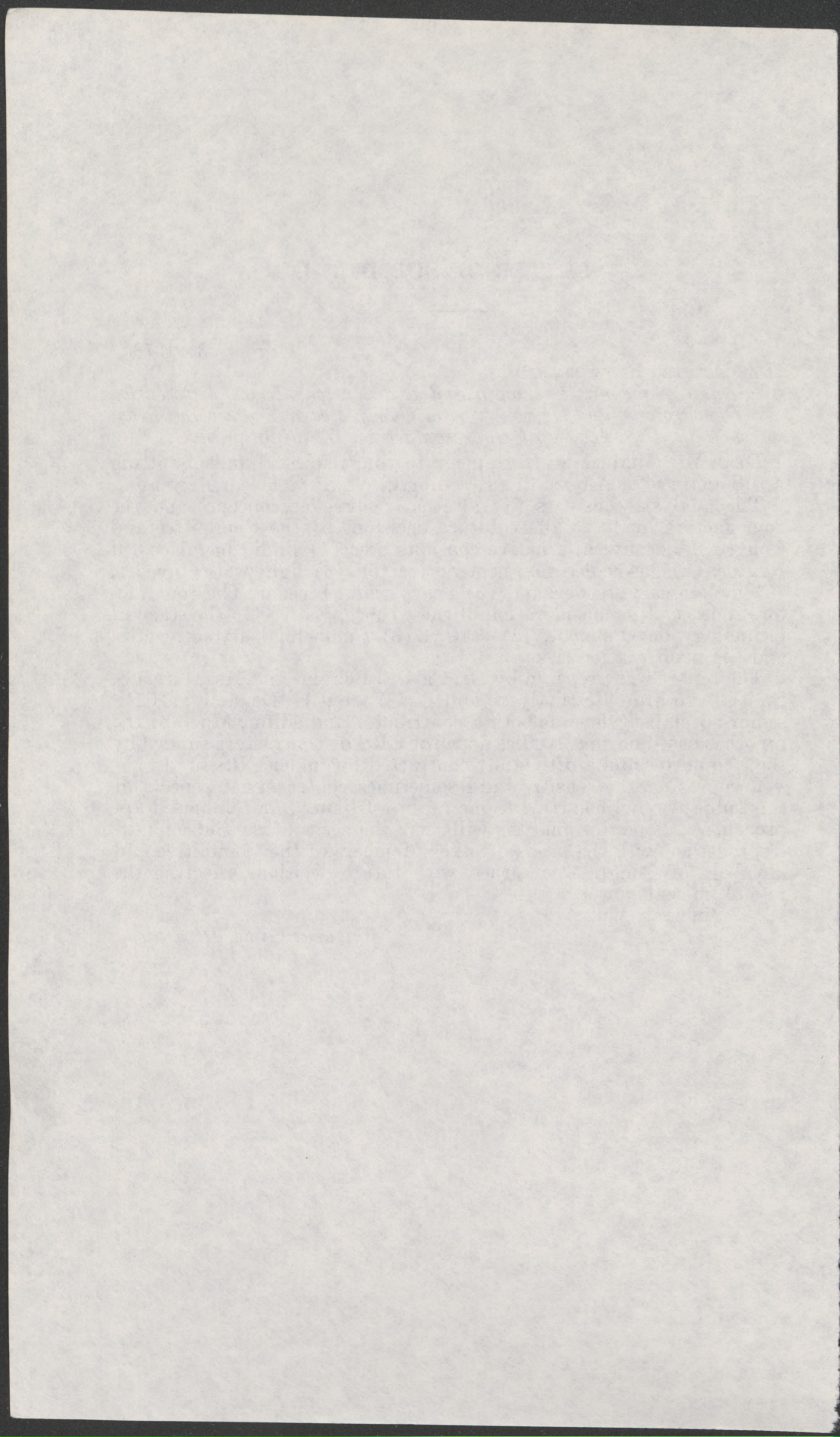
The analysis considers five alternative breeder concepts and the four factors likely to affect future decisions by the Committee and Congress. The five alternative concepts are: (1) liquid metal cooled reactor, (2) gas cooled fast neutron reactor, (3) light water breeder, (4) molten salt breeder, and (5) heavy water breeder. The four factors concerned in consideration of these concepts are: (1) the stage of technology development, (2) safety, (3) commercial attractiveness, and (4) proliferation risks.

The report was prepared by Dr. Carl E. Behrens and Ms. Marcia S. Smith, who are CRS analysts, and Dr. Warren H. Donnelly, a CRS senior specialist who was both a contributor and editor. Much of the report is based on four studies done for CRS by contractors funded by the Committee and a fifth study contracted for under CRS funds.

Recognizing the sensitive and sometimes controversial aspects of this subject, CRS has tried to maintain a balanced and unbiased approach. We hope this analysis will serve the needs of the Subcommittee, together with the needs of other Members of the Committee and Members of Congress concerned with future decisions affecting the fate of nuclear power.

Sincerely yours,

GILBERT GUDE, *Director.*



CONTENTS

	Page
Letter of transmittal.....	iii
Letter of submittal.....	v
I. Summary.....	1
Technological status.....	1
Safety considerations.....	2
Commercial considerations.....	3
Proliferation considerations.....	3
Matters for congressional attention.....	4
The basis for choice among alternative breeders.....	4
Strategy for research, development, and demonstration.....	5
Foreign breeder R. D. & D.....	5
U.S. nonproliferation R. & D.....	5
Proliferation analysis and assessment.....	5
II. Purpose and basis.....	7
III. Reasons for current attention to alternative breeder reactors.....	9
Proliferation: definition and status.....	9
The dangers of proliferation.....	11
A bit of history.....	11
Routes to nuclear weapons.....	15
IV. Technological and safety aspects of alternative breeders.....	17
Introduction and summary.....	17
Nuclear fuels.....	18
Uranium versus thorium.....	18
Oxide, carbide, and metal fuels.....	20
Safety aspects of breeder reactors.....	21
General.....	21
Radioactive inventory of the core.....	21
Barriers to the release of radioactivity.....	22
Mechanisms for breaching barriers.....	22
Inherent and engineered safety systems.....	23
Risk determination criteria.....	23
Summary.....	24
Description of alternative breeder reactors.....	24
Fast versus thermal breeders.....	25
The liquid metal fast breeder reactor (LMFBR).....	25
Program status.....	25
Advantages.....	26
Disadvantages.....	26
Technology.....	26
Safety.....	28
The gas cooled fast reactor (GCFR).....	30
Program status.....	30
Advantages.....	30
Disadvantages.....	31
Technology.....	31
Safety.....	31
The light water breeder reactor (LWBR).....	32
Program status.....	32
Advantages.....	32
Disadvantages.....	32
Technology.....	32
Safety.....	32

VIII

	Page
The molten salt breeder reactor (MSBR)	34
Program status	34
Advantages	34
Disadvantages	34
Technology	34
Safety	35
The heavy water breeder reactor (HWBR)	37
Program status	37
Advantages	37
Disadvantages	37
Technology	37
Safety	39
Foreign breeder programs	39
Britain	40
France	41
West Germany	42
Japan	43
Soviet Union	43
V. Commercial considerations of alternative breeder technologies— the utility environment	45
Background	45
Economic difficulties	45
Environment and embargo	46
Four kinds of uncertainty	47
Load growth	47
Scheduling	47
Costs	48
National policy	48
Breeder options	48
Breeder options	49
VI. Proliferation considerations	53
The linkage of nuclear weapons and nuclear power	53
The spectrum of proliferation risks	54
The presumed ease of making nuclear explosives	55
Materials for nuclear weapons and explosives	56
Alternative breeder cycles as a technological fix	57
VII. Proliferation risks of alternative breeder cycles	61
Fuel cycles for alternative breeders	61
Vulnerability of alternative breeder cycles	62
The once-through fuel cycle	63
Diversion from uranium mills	63
Diversion from enrichment	63
Technological surprise in enrichment	64
Diversion from spent fuel	64
The light water reactor with reprocessing and recycle	66
The standard LMFBR	67
The gas cooled fast reactor	69
The light water breeder reactor	69
The light water breeder reactor, prebreeding cycle	71
The molten salt breeder reactor	73
The heavy water breeder reactor	75
Decreasing proliferation risks of alternative breeders	75
Technological measures	75
Coproprocessing	76
Civex	76
Alternative fuels for breeder cycles	77
Organizational measures	78
International management and control	78
Safeguards	79
National safeguards systems	79
IAEA safeguards systems	80
Comparison of proliferation risks for alternative breeder cycles	83
Risks of subnational theft	84
Risks of national diversion	86
Summary comparison	89

IX

	Page
VIII. The legislative basis for U.S. non-proliferation policies.....	91
Major legislation.....	91
The Atomic Energy Act of 1954 as amended.....	91
The Energy Reorganization Act of 1974.....	92
The Nuclear Non-Proliferation Act of 1978.....	92
Implications for alternative breeder reactors.....	93

LIST OF TABLES

1. Potential weapons countries, April 1977.....	10
2. Difference in breeding ratio and doubling time for five breeder reactor fuel cycles.....	19
3. Breeding ratio and doubling time in LMFBRs with different fuel forms.....	20
4. Hypothetical energy sources in reactor accidents.....	23
5. Summary of breeder reactor safety information.....	24
6. LMFBR summary.....	25
7. Safety characteristics of loop- and pool-type LMFBRs.....	30
8. GCFR summary.....	30
9. LWBR summary.....	32
10. MSBR summary.....	34
11. HWBR summary.....	37
12. Foreign LMFBR programs.....	40
13. Commercial characteristics of alternative breeder cycles.....	51
14. Usability of nuclear materials for nuclear weapons or explosives.....	56
15. Nuclear materials in alternative breeder fuel cycles.....	57
16. Nuclear materials in parts of fuel cycles for alternative breeder reactors.....	63
17. Levels of protection for plutonium from associated radioactivity of spent fuel or chemical form.....	66
18. Summary of technological measures to reduce proliferation risks of alternative breeder fuel cycles.....	76
19. Possible alternative fuel cycles for use with LMFBR.....	78
20. Proliferation risk aspects for subnational theft from alternative breeder cycles.....	85
21. Proliferation risk aspects for government diversions from alternative breeder cycles.....	87
22. Statutes containing provisions relating to nuclear energy and non-proliferation.....	92

LIST OF FIGURES

1. Schematic diagram of loop-type LMFBR.....	27
2. Schematic diagram of pool-type LMFBR.....	28
3. Simplified flow diagram of GCFR demonstration plant.....	31
4. Shippingport plant operation cycle with LWBR.....	33
5. Conceptual design of a 1,000 MWe MSBR.....	36
6. CANDU reactor core.....	38
7. Extractable world plutonium.....	59
8. Basic elements of nuclear power fuel cycles.....	62
9. Annual quantities of nuclear materials for LMFBR fueled with plutonium and depleted uranium (full recycle).....	68
10. Annual quantities of nuclear materials for LWBR fuel cycle.....	70
11. Nuclear materials in prebreeder fuel cycle.....	72
12. Daily quantities of nuclear materials for MSBR fuel cycle.....	74

APPENDICES

Appendix I. Acronyms and glossary.....	95
Appendix II. Supplemental information.....	97
Introductory note.....	97
Effects of nuclear weapons and explosives.....	97
Nuclear explosive materials and their sources.....	98
The making of nuclear weapons.....	99
The International Atomic Energy Agency.....	101
IAEA safeguards.....	101
Fundamental safeguards concepts.....	101

Appendix II.—Continued

	Page
Safeguards for non-NPT states.....	102
Safeguards for NPT states.....	103
Notable differences.....	103
Limitations of IAEA safeguards.....	103
Relation of IAEA safeguards to state systems.....	103
The International Nuclear Fuel Cycle Evaluation (INFCE).....	104
The Non-Proliferation Treaty.....	105
Genesis of the NPT.....	105
Objectives of the NPT.....	106
Analysis of the NPT.....	107
Parties to the NPT.....	108
Table I. Damage radii for various effects of nuclear explosions....	97
Table II. Membership of INFCE working groups.....	105
Appendix III. Notable analyses of nuclear power and proliferation.....	109
Reports of the Committee on Science and Technology.....	109
The European visit of the House Committee on Science and Technology.....	109
Report on oversight of European nuclear energy development (Mr. Wydler).....	111
Report on oversight of Soviet nuclear energy development (Mr. Wydler).....	111
Notable analyses of nuclear power and risks of proliferation.....	114
Secretary Kissinger's views.....	114
Candidate Carter's views.....	115
The Wohlstetter report.....	115
President Ford's policy statement.....	117
The Ford Foundation's report on nuclear power.....	118
Comments to the House Committee on Science and Technology....	119
The Office of Technology Assessment's report.....	120
President Carter's nonproliferation policy statements.....	121
The 1977 report of the U.S. Arms Control and Disarmament Agency.....	122
Nonproliferation principles of the Atomic Industrial Forum....	123
President Carter's press conference in Brazil.....	124
The Rockefeller report for international breeder development....	124
The Atlantic Council's report.....	125

CHAPTER I. SUMMARY ¹

The purpose of this analysis by the Congressional Research Service is to provide the Subcommittee on Fossil and Nuclear Energy Research, Development and Demonstration of the Committee on Science and Technology with a working tool for future consideration of the development of alternative breeder reactors. The analysis considers five alternatives, including two breeders that could produce plutonium or uranium-233—the liquid metal cooled and the gas cooled fast neutron reactors; and three that would produce only uranium-233—the light water 'breeder,' the molten salt breeder, and possibly a heavy water breeder.

The CRS analysis focuses on four of the factors likely to affect decisions by Congress on future development and use of alternative breeders. These four are the stage of technological development, safety, commercial attractiveness, and proliferation risks. Omitted are factors such as radioactive waste management, environmental effects, occupational health and safety risks, public attitudes, and licensability. These commonly affect all alternatives, with little discernible difference seen in our analysis. Note too that each of the breeder alternatives involves some kind of processing of used fuels, whether it be called reprocessing, coprocessing or by some other term.

TECHNOLOGICAL STATUS

The stages of technological development for the several breeder alternatives lie along the path from research and proof of principal experiments to demonstration of commercial prototypes. If final development and demonstration in the least time and with the least additional expense to the ratepayer or the taxpayer is the national goal, then logic would favor the alternative most advanced and so would support the liquid metal fast breeder reactor (LMFBR) which, as now conceived, produces and uses plutonium. A gas cooled version of the plutonium breeder, the gas cooled fast reactor (GCFR) offers some advantages which could make its further development attractive. However, its development trails the LMFBR. Breeders that produce and use uranium-233 are well behind the LMFBR in development, although one version, the light water breeder (LWBR) is in the early stages of experimentation. If this is successful, substantial additional development will still remain before existing light water reactors (LWR) can be adapted to this nuclear fuel cycle.

The continued technological drive in Europe, Japan, and the Soviet Union toward demonstration and use of LMFBR's tends to complicate matters. In principle, if the United States defers demonstration of breeding until after it is successfully demonstrated abroad, the United

¹ Prepared jointly by Carl E. Behrens, Analyst in Environmental Policy; Warren H. Donnelly, Senior Specialist; and Marcia S. Smith, Analyst in Aerospace and Energy Technology.

States might then import foreign technology or even reactors and thus save Government spending. However, to do so probably would weaken the U.S. nuclear industry, reduce U.S. influence in international nuclear affairs, and increase the U.S. trade deficit. If there were a demand for quick expansion of breeders in the United States, the U.S. Nuclear Regulatory Commission (NRC) could be under pressure to license reactors for which it had little information, with attendant risks of mistakes.

How important foreign efforts to develop the breeder will be for the United States depends on their several possible outcomes:

(1) U.S. deferral of breeder demonstration is heeded and foreign countries put off their own demonstration. If this happened, the United States and other countries would keep their relative positions.

(2) Foreign efforts fail to produce a technologically successful breeder. If this happened, the United States would not have wasted time, money and resources, and would be further ahead in planning for national energy supply that does not depend on the breeder.

(3) Foreign efforts succeed technologically but fail economically. Again, the United States would save the effort of chasing a technological will-o-the-wisp.

(4) Foreign efforts succeed both technologically and economically. If this happened, the United States would lag behind other major nuclear countries, with prospects of an expensive catch-up effort or of having to become a buyer rather than a seller of breeder technology and equipment.

SAFETY CONSIDERATIONS

The analysis did not uncover any safety problem likely to prevent use of various breeder cycles. While risks of catastrophic accidents can be postulated for any nuclear power reactor, analysis of these risks for alternative breeders will have to depend more upon hypothetical situations and technological assumptions than is the case for light water reactors because of the limited practical safety experience with alternative breeders. The liquid metal cooled breeders are likely to enjoy some advantage simply because they have had greater research and development support to date, including work on safety. Although the presence of plutonium or uranium-233 in industrial processes needed by various alternative breeders could increase the occupational health and safety risks of workers, government experience to date would indicate these risks can be controlled. Like other nuclear power plants, alternative breeders cannot be designed for absolutely no release of radioactive materials. As with conventional nuclear power reactors, breeder reactors present some risk of a major accidental release of radioactive materials. Zero risk is unattainable. Before breeder reactors can be licensed for commercial use in the United States, the Nuclear Regulatory Commission will have to determine that the probability of this risk is low enough to permit licensing. While the nuclear industry sees this risk from breeder reactors as adequately controllable through design features, different views can be expected from critics of nuclear power and of the breeder.

Whatever alternative breeder may be selected for further development, it is likely that substantially more analysis and research will be needed to comprehend, evaluate, and control the safety risks which have been identified and considered to date. Much of this will be needed to enable the NRC to carry out the safety analyses that are an integral part of its licensing responsibilities.

COMMERCIAL CONSIDERATIONS

At this time, none of the five alternative breeders considered here, including the fast breeders fueled with separated plutonium, are close to commercial use in the United States. The one closest to—but still distant from—commercial feasibility is the liquid metal cooled breeder reactor.

Considering the current pessimism about nuclear power, it seems unlikely that very large breeders will find many buyers. Indeed, because of economic and political factors, few electric utilities at present are ordering even conventional light water reactors. In addition to the well publicized opposition to nuclear power, which can cause difficulties for licensing new facilities, uncertainties in future load growth, in costs, in construction times, and in the role of electricity in the national energy picture, have made it very difficult for utilities to embark upon long term, large construction projects such as nuclear power facilities. This situation is likely to continue unless the financial difficulties and uncertainties facing utilities are somehow relieved.

Given these factors, and consumer resistance to rate increases, it seems likely that utility managements will become increasingly conservative in risking available funds on radically different nuclear power plants and their fuel cycles until these are well demonstrated.

PROLIFERATION CONSIDERATIONS

The driving force behind current attention to alternative breeder cycles is the hope of finding an option, the use of which would not unacceptably increase the risk of further spread, or proliferation, of nuclear weapons and the ability to make them among other nations, and that also would be capable of recovering much more of the energy or uranium and thorium than does the once-through fuel cycle. So one logical criterion for choice among these cycles becomes the proliferation risk. Life would be simple were the risks for various alternatives spread out, neatly and distinctly separated, along the spectrum between the acceptable risks of the once-through fuel cycle with terminal storage of spent fuel and the unacceptable risks of the plutonium breeder featuring separated plutonium.¹ This CRS analysis suggests that proliferation risks of alternative breeders, including variations of the plutonium breeder and the uranium-233 breeder, are likely to cluster close to the risk of the once-through fuel cycle, assuming there is some risk of diversion of spent fuel from terminal storage. How much effect variations in the nuclear fuel materials, such as mixtures of ura-

¹ Note, however, that at a meeting arranged by Chairman Teague of the Committee on Science and Technology between the President and leaders of the nuclear power industry, the President is reported to have said that proliferation was no longer his main reason for opposing construction of the Clinch River Fast Breeder Demonstration. (The Energy Daily, June 16, 1978 : 2).

nium-233 and uranium-238, or of plutonium and depleted uranium, would have on the degree of risk was not clear, but it would seem to be comparatively little. Storage of spent fuel in international facilities, or in national facilities under international control, would be likely to separate further the risks of the once-through cycle from the risks of alternative breeder fuel cycles. However, until such storage is available, there will remain the risk that under some circumstances a nation storing spent fuel might seize it to recover plutonium for weapons. So, for some time to come, comparison of proliferation risks for alternative breeders will have this risk for its yardstick.

The probable clustering of risks close to those of the once-through fuel cycle suggests too that differences in risks for various alternative breeders may not be readily discernible, or may be too small to govern the choice between one and another alternative and the funding of their development and demonstration. This conclusion is likely to be disputed by advocates of various breeder alternatives who can see quantitative differences in proliferation risks to support their positions. However, the analysis of these risks and their subsequent assessment remains a subjective matter because of the many necessary assumptions about nuclear technologies that are still undemonstrated, and about future ways and means of keeping their proliferation risks within acceptable limits. Analyses sponsored by the Department of Energy and the Arms Control and Disarmament Agency are likely to try to define and compare proliferation risks in terms of numbers, suggesting that precise quantification is feasible. In dealing with such analyses, it will be important to know what assumptions are contained, what range of uncertainty is caused by possible errors in assumptions, and, once the uncertainties have been factored in, whether the difference in risk between the candidate fuel cycle and the once-through cycle under national control is enough to be governing.

If the comparative proliferation risks for alternative breeders cluster near those of the once-through cycle and the differences are small, then proliferation considerations will tend to weigh less and other factors weigh more in congressional considerations. In this situation, other factors would become more important in decisions on alternative breeders, such as the state of technological development; the time, money and resources needed to bring alternatives to the point of demonstration; comparative efficiency in use of nuclear fuel; risks to the public health and safety and to the environment; and commercial attractiveness. If comparative risks of proliferation are not noticeably different for various alternatives, then energy policy rather than national security policy consideration could be expected to come to the fore.

MATTERS FOR CONGRESSIONAL ATTENTION

The future of alternative breeder reactors probably will be determined during the next few years, and will be greatly affected by congressional actions. Some of the principal matters that Congress may wish to keep in mind during this time include:

1. The basis for choice among alternative breeders

In choosing among alternative breeders, what comparative weight should be given respectively to factors of status of technological devel-

opment, safety, ability to use uranium-238 or thorium, commercial attractiveness and proliferation risk, particularly if differences in proliferation risk are small? Will proliferation risk remain the dominant consideration?

2. Strategy for research, development and demonstration

What should be the strategy for research, development and demonstration while the International Nuclear Fuel Cycle Evaluation (INFCE) is going on? What can Congress expect from this international effort? To what extent should Congress try to anticipate the outcome of INFCE and take this into account in short-term decisions on alternative breeders?

What contingency planning for changes in research, development and demonstration can be made now for the post-INFCE period, which would probably affect fiscal year 1981 and thereafter?

3. Foreign breeders R.D. & D.

What are the prospects that foreign efforts will produce a plutonium breeder and associated fuel cycle which are technologically and economically attractive?

How important will non-economic factors, such as a desire to reduce energy dependence, influence planning and direction of foreign breeder development?

To what extent can the United States assume it will have access to the results of such foreign work, particularly if it is successful? How adequate are present arrangements for such access?

What are the advantages and disadvantages for the United States of joining international breeder development as an alternative to unilateral U.S. development? What are the prospects for and the most likely mechanisms for effective international development?

4. U.S. nonproliferation R. & D.

Several departments and agencies are working to identify nuclear fuel cycles that have less proliferation risk and also to strengthen non-proliferation measures, especially safeguards and physical security. How are these respective programs of the Department of Energy, the Arms Control and Disarmament Agency, and the Nuclear Regulatory Commission coordinated? What are the related functions and inputs of the Department of State, the Department of Defense and the National Security Council?

What targets have been set for breeder research and development to improve safeguards technology and organization, and to improve physical security technology and organization? How likely is it that these targets can be attained in time to be useful and without unacceptable costs or social effects?

5. Proliferation analysis and assessment

Since much of the reason for current attention to alternative breeders is the risk of proliferation, how these risks are analyzed and assessed and how useful the results are for public and private decisions become important matters. What yardsticks are now in use for the analysis and assessment of the proliferation risk that nations might divert nuclear materials or that subnational (terrorist) groups might steal them? Are these criteria stable enough to provide a basis for long-

range planning? Can the risks be quantified? What assumptions are built into the ACDA's proliferation assessments and into other proliferation analyses? What errors are involved, and what is their significance for risks that have comparatively small differences? How could modification of fuel cycles be compared with other nonproliferation measures in seeking an acceptable balance between breeder performance and nonproliferation risks? What effect is INFCE likely to have upon the perception of proliferation risks in the United States and of their analysis?

The answers to all of these questions can influence decisions affecting future development of breeder alternatives.

CHAPTER II. PURPOSE AND BASIS ¹

In anticipation of continuing congressional attention to the future development and possible commercialization of alternative breeder cycles, the Subcommittee on Fossil and Nuclear Energy Research, Development and Demonstration of the Committee on Science and Technology requested the Congressional Research Service to prepare a summary background analysis of these cycles with attention to their technology, safety, commercial aspects and potential implications for the further spread, or proliferation, of nuclear weapons. The committee also provided funds for supporting contract analyses.

The following CRS analysis reviews the main reasons for attention to alternative breeders, describes their salient characteristics and safety aspects, identifies principal commercial considerations affecting their future use, and explores their implications for spread of nuclear weapons. It describes the legislative basis for U.S. nonproliferation policy, discusses the implications of the analysis for future development of the alternative breeding cycles, and concludes with an identification of major matters for congressional attention. Supplemental appendices include a glossary, information on nonproliferation matters and summaries of recent statements and reports on this subject, and information on the supporting contract analyses.

The CRS analysis draws heavily upon five analyses that were obtained through contracts. These include:

(1) A review of reactor technology in the United States and abroad by Professor John LaMarsh, who is head of the Department of Nuclear Engineering at the Polytechnic Institute of New York;

(2) An analysis of the safety aspects of alternative breeder cycles by the Energy Research Group, Inc., which is an analytical and research company in Waltham, Mass.;

(3) and (4) An analysis of factors of influencing decisions of utilities in buying nuclear power plants by Richard L. Gordon, plus an analysis of utility decision making on choices among alternative breeders by Louis H. Roddis, who are consultants to electrical utilities; and

(5) An analysis of the proliferation aspects of alternative breeder cycles by E. R. Johnson Associates, which offers technical services in nuclear materials management and is located in Fairfax, Virginia.

Of these, the first was funded by the Congressional Research Service and the other four by the Committee on Science and Technology.

¹ Prepared by Warren H. Donnelly, Senior Specialist.

The CRS analysis was made by Dr. Carl E. Behrens, Analyst in Environmental Policy, of the Environment and Natural Resources Policy Division; Ms. Marcia S. Smith, Analyst in Aerospace and Energy Technology, of the Science Policy Research Division; and Dr. Warren H. Donnelly, Senior Specialist, who was also the editor. Their respective contributions are identified in the analysis.

CHAPTER III. REASONS FOR CURRENT ATTENTION TO ALTERNATIVE BREEDER REACTORS*

The main reason for current attention to alternative breeder reactors is the fear that commercial use of plutonium breeder reactors now being developed will spread nuclear weapons and the ability to make them. The perceived risks are twofold: first, that nations with plutonium breeders could quickly make nuclear weapons from the breeder fuels; and second, that in nations using such plutonium breeders, terrorist or other "subnational" groups could have opportunity to steal nuclear materials that could quickly be made into a nuclear explosive. Because the plutonium breeder, and perhaps the thorium breeder, are seen making the difference between a short- and long-term future for nuclear power, many leading nuclear power countries are continuing with their breeder development and demonstration despite U.S. policy which would defer the breeder and the use of nuclear fuels that could be used as nuclear explosive materials. It is this still-changing perception of proliferation risks associated with the present development for the plutonium breeder that has caused interest in alternatives. During coming years, Congress is likely to face questions of whether and how alternative breeders should be developed so that nuclear power systems can recover more of the potential energy from each pound of uranium or thorium mined, while keeping the risks of proliferation within acceptable bounds.

The United States atomic attack on Hiroshima and Nagasaki, Japan, in 1945, dramatically and unforgettably demonstrated the enormously destructive power of even comparatively small and crude nuclear weapons delivered by what now seems a crude system. It comes as no surprise, then, that Congress, in the Atomic Energy Act of 1946, sought to preserve the secrets of nuclear weapons and to tightly circumscribe U.S. cooperation with other nations in nuclear power. The dangers of the further spread, or proliferation, of nuclear weapons and its potential link to nuclear power were well understood and appreciated in the late 1940's. With the passing years, interest in proliferation has ebbed and flowed with changes in international relations and in trends of nuclear power. By way of background, there follows some history of early U.S. thinking on the link between nuclear energy and proliferation, and what to do about it.

PROLIFERATION: DEFINITION AND STATUS

Proliferation refers to the further spread of nuclear weapons among nations of the world. The third world nations see two categories: vertical and horizontal proliferation. Vertical proliferation refers to increases in the number and types of weapons and delivery systems of present nuclear-weapons states. Horizontal proliferation refers to the spread of nuclear weapons to states that previously did not have them.

*Prepared by Warren H. Donnelly, Senior Specialist.

At present, one state, the United States, has both tested and used nuclear weapons; four other states—the Soviet Union, the United Kingdom, France, and the People's Republic of China—have tested but not used nuclear weapons and have nuclear arsenals; a sixth, India, has tested a nuclear explosive device which it described as peaceful. From time to time there is speculation on whether Israel has nuclear weapons and whether other nations are close to having them.

Since the mid-1970's, the definition of horizontal proliferation has begun to change from the possession of nuclear weapons by a state to its possession of nuclear materials and facilities which could be quickly seized to make nuclear weapons or from which nuclear explosive materials might be stolen by terrorist or other so-called subnational groups. This broadening of definition logically would bring into this category states that can produce highly enriched uranium, that possess nuclear fuel reprocessing facilities, that plan to use plutonium as a nuclear fuel, and that have a domestic industrial base for production and use of nuclear power.

The Energy Research and Development Administration in 1977 classified 30 states into three categories of proliferation potential, as shown in table 1.

TABLE 1.—POTENTIAL WEAPONS COUNTRIES, APRIL 1977

[Technical capability only—there is no speculation inferred on the political motivation to develop a nuclear weapons capability]

A. Countries which appear technically capable of detonating a nuclear device in the short term (within less than 1—up to 3 years of a decision to do so) :

Argentina
Canada
Republic of China
West Germany
Israel
Italy
Japan
South Africa
Spain
Sweden

B. Countries which appear technically capable of detonating a nuclear device in the intermediate term (within 4 to 6 years of a decision to do so) :

Belgium
Brazil
Czechoslovakia
East Germany
Republic of Korea
The Netherlands
Norway
Pakistan
Poland
Switzerland

C. Countries which appear technically capable of detonating a nuclear device in the longer term (within 7 to 10 years of a decision to do so) :

Austria
Denmark
Egypt
Finland
Iran
Mexico
Portugal
Romania
Turkey
Yugoslavia

THE DANGERS OF PROLIFERATION

Fundamental to U.S. foreign policy since 1946 has been the concept that the further spread of nuclear weapons is not in the interests of the United States and that it would increase threats to U.S. national security and world peace. Worst case analysis postulates that should more nations acquire nuclear weapons, the probability of their use would increase and their use could trigger catastrophic nuclear war between the United States and the Soviet Union. Less pessimistic thinking sees further proliferation still likely to make international relations less stable, to upset regional balances of military power, and to pose difficult decisions for the United States if a proliferator is one of its allies. A new concern of the mid-1970's is the possibility that terrorist or other violent organizations might succeed in stealing dangerous nuclear materials and make crude but powerful nuclear explosives for mass destruction or political blackmail.

One of the most articulate summaries of the dangers of proliferation was given by Secretary of State Kissinger before the Senate Committee on Government Operations in March 1976. Responding to a question about U.S. nonproliferation policy, Mr. Kissinger said:²

If nuclear weapons spread into an ever-increasing number of lands, if they come into possession of governments in areas where the feelings run high, where the protection against terrorist groups could be weak, where the implications are not fully understood, or where the hatreds are so deep, where the sacrifice of millions does not have the same terror it has to other parts of the world—under all of these conditions—the spread of nuclear technology, leading to nuclear weapons, could produce a catastrophe, first for the area concerned, and eventually for all of mankind.

If nuclear weapons become ordinary weapons, if it is accepted that nuclear wars can be fought like any other war, then a catastrophe sooner or later is inevitable. If the world is united by any common objective, it must be to prevent the outbreak of a general nuclear war. So I agree with this committee completely, and I also share the frustration that compared to the magnitude of the task, that the progress is not more dramatic.

A BIT OF HISTORY

As early as 1944, scientists of the wartime atom bomb project began to speculate about the risks of nuclear energy and measures to prevent its misuse. On November 18, 1944, a "Prospectus on Nucleonics" was completed by a committee headed by Zay Jeffries, a General Electric Co. consultant to the project. Its report outlined applications anticipated for nuclear energy, and speculated on possibilities of nuclear power. The Committee did not limit itself to the technical potential. Pointing out the threat of atomic war, it argued that a worldwide organization was necessary to prevent the atom from becoming the destroyer of nations, that it was vitally important—both before and after establishment of such an organization—for the United States to keep the lead in nuclear research and its industrial applications.³ Shortly before the nuclear attacks upon Japan in 1945, Secretary of War Stimson convened an Interim Committee of scientists, military personnel and Members of Congress. One of its sessions dealt with

² U.S. Congress. Senate. Committee on Government Operations. Export Reorganization Act of 1976. Hearings. 94th Cong., 2d sess., 1976, p. 785.

³ Cf., Richard G. Hewlett and Oscar E. Anderson, Jr. *The new world, 1939/1946*. Vol. 1. A history of the United States Atomic Energy Commission. University Park, Pa.: The Pennsylvania State University Press, 1962, p. 324.

international control. There the committee suggested that each country should promise to make public all work being done on atomic energy. To assure fulfillment of this pledge, it favored constituting an international control committee with complete power to inspect.⁴

Then came Hiroshima and Nagasaki, the end of the war, the establishment of the United Nations and its Atomic Energy Commission, and the legislative effort that produced the Atomic Energy Act of 1946.

Early in 1946, Secretary of State Dean Acheson appointed a Board of Consultants, headed by David E. Lilienthal, to ascertain the facts bearing upon international inspection for international control of nuclear weapons and energy, and to appraise that matter as well as the relative potential of the United States and other nations in atomic energy. The Board included Robert Oppenheimer, who by then had left the wartime Manhattan project to return to the University of California. The Board provided Oppenheimer with the opportunity to push hard for an international atomic control agency. He enthusiastically sketched a vision of an international agency that would have important development functions. Only an organization that was organic and alive could keep abreast of the changing nuclear technology and attract an able and imaginative staff. Dangerous nuclear activities, such as enrichment of uranium, reprocessing of nuclear fuels, or the operation of large power reactors, would be the exclusive prerogative of the international agency. It would have a monopoly of raw materials and also exercise certain controls. But its emphasis would be on positive, not negative, responsibilities.⁵ By March 1946, the Board had completed work and reported to Secretary Acheson.⁶ Central to its recommendations was creation of an International Atomic Development Authority with sweeping operational and regulatory functions. The first proposed purpose of the Agency was to bring under its complete control world supplies of uranium and thorium. "Wherever these materials are found in useful quantities, the international agency must own them or control them under effective leasing arrangements."⁷ The second major function was the construction and operation of useful types of atomic reactors and facilities for production of plutonium and enriched uranium. One of its first problems would be to develop reactors to generate electricity. A third function would be nuclear research. A fourth was to license nuclear reactors and to lease nuclear fuel for their operation. The design of such reactors would be carefully reviewed and their construction perhaps inspected by the Authority to insure that they would not be readily convertible to dangerous use. A fifth, and major, function for the Authority was inspection, as a necessary but insufficient way to prevent proliferation. Of this, the Board said:

Throughout this report we have recorded our conviction that international agreements to foreswear the military use of atomic weapons cannot be enforced solely by a system of inspection—that they cannot be enforced in a system which leaves the development of essentially dangerous activities in the field of atomic energy in national hands and subject to national rivalry, and to insure against

⁴ *Ibid.*, p. 361.

⁵ *Ibid.*, p. 536.

⁶ A report on the international control of atomic energy. Prepared for the Secretary of State's Committee on Atomic Energy by a Board of Consultants. March 16, 1946, 61 p. (Department of State publication 2498).

⁷ *Ibid.*, p. 34.

diversion of these activities to aggressive ends, relies upon supervision by an agency which has no function. But inspection in a wide variety of forms has its proper place in the operations of the Atomic Development Authority—it has a proper and essential place.

Soon after, Bernard M. Baruch, as the U.S. representative, presented a revised United States' atomic energy proposal to the United Nations Atomic Energy Commission which proposed the creation of an International Atomic Development Authority. The authority would be entrusted with all phases of the development and use of atomic energy, starting with the raw material and including:

1. Managerial control or ownership of all atomic energy activities potentially dangerous to world security;
2. Power to control, inspect, and license all other atomic activities;
3. The duty of fostering the beneficial uses of atomic energy; and
4. Research and development intended to put the Authority in the forefront of atomic knowledge and thus to enable it to comprehend and therefore to detect misuse of atomic energy.

Once an adequate system for the control of atomic energy, including the renunciation of the bomb as a weapon, had been agreed upon and put into effective operation and "condign punishments" set up for violation of controls, the United States proposed that:⁸

1. Manufacture of atomic bombs should stop;
2. Existing bombs should be disposed of pursuant to the terms of the treaty to establish the Authority; and
3. The Authority should possess full information as to the know-how for the production of atomic energy.

As for violations, penalties should be fixed for:

1. Illegal possession or use of an atomic bomb;
2. Illegal possession, or separation of atomic material suitable for use in an atomic bomb;
3. Seizure of any plant or other property belonging to or licensed by the Authority;
4. Willful interference with the activities of the Authority; and
5. Creation or operation of a dangerous project in a manner contrary to, or in the absence of, a license granted by the Authority.

With the subsequent failure of the U.S. proposal because of unresolvable differences with the Soviet Union, the prospects for full international management and control of nuclear energy vanished and the world scene was set for national development of nuclear power with attendant differences and rivalries between nuclear nations and competition for the world nuclear market.

The inclusion of a requirement for a veto proof condign punishment of violations was the highwater mark for U.S. thinking about deterring violations of nonproliferation commitments. Though this was not an initial part of the approach of President Truman's administration in 1946, it was added by Bernard Baruch in his consultations prior to his presentation of the U.S. plan for international control of atomic

⁸ The international control of atomic energy. The first report of the United Nations Atomic Energy Commission to the Security Council, December 31, 1946. Washington, D.C. U.S. Govt. Print. Off., pp. 87-91.

energy to the United Nations Atomic Energy Commission. As Ambassador Baruch put it in his address to the UNAEC:⁹

I want to make very plain that I am concerned here with the veto power only as it affects this particular problem. There must be no veto to protect those who violate their solemn agreements not to develop or use atomic energy for destructive purposes.

The bomb does not wait upon debate. To delay may be to die. The time between violation and preventive action or punishment would be all too short for extended discussion as to the course to be followed.

This requirement for punishment failed with the failure of the U.S. proposals. Since then provisions for sanctions, as in the international statute of the International Atomic Energy Agency and in U.S. non-proliferation legislation have been limited to cutting off nuclear exports and assistance.

With the failure of the U.S. proposal, the early years of the atomic age saw attempts to keep the secrets of the atom bomb, with much of the technology for nuclear power kept under secrecy. By the early 1950's the secrecy approach was discredited as the Soviet Union and the United Kingdom tested nuclear weapons. With the advent of the cold war between the Soviet Union and the United States, President Eisenhower in 1953 proposed international cooperation in the use of nuclear energy, which led to creation of the International Atomic Energy Agency, to U.S. removal of secrecy for virtually all of nuclear power technology except for uranium enrichment, to national control and development of nuclear energy, and to the first arrangements for international safeguards. By the mid 1960's the prospects for nuclear power were bright enough for the United States to become concerned over the increased spread of materials and facilities that might be used to make weapons. So it began the drive that led to the Treaty on Non-Proliferation of Nuclear Weapons (NPT), which took effect in 1970. Under the NPT, development and use of nuclear power continued as national enterprises, with nonnuclear weapons states agreeing to forego nuclear weapons and to place all of their nuclear activities under safeguards of the IAEA. The idea that proliferation risks from civil nuclear power could be contained by the NPT commitments and IAEA safeguards was soon to be questioned. By the early 1970's it was evident that many nations, including some likely to make use of nuclear power, would not undertake the NPT commitments. The test of a "peaceful nuclear explosive" by India in 1974, using materials taken from a civil nuclear energy program, followed by commitments of France to supply reprocessing facilities to Pakistan and to South Korea and by West Germany to supply them to Brazil, raised new doubts as to the ability of the international control scheme to contain the risks of nuclear weapons. A new factor appeared also in the mid 1970's, namely fear that a terrorist or some other kind of subnational group might steal nuclear materials and make crude nuclear explosives. The publication of the Willrich-Taylor book on risks of nuclear theft and Senator Ribicoff's publication of the Rosenbaum report, both in 1974, generated substantial interest in this

⁹ Ibid., p. 86.

risk.¹⁰ So the scene was set for the congressional initiatives to seek new controls over U.S. nuclear exports and to seek new international commitments and arrangements to limit the risks of further proliferation. In the span of three decades, the approach had gone through a full cycle from international management and control, to national development and use under international safeguards, and back to revived emphasis upon international control and management, although not to the extent advocated by the United States in 1946.

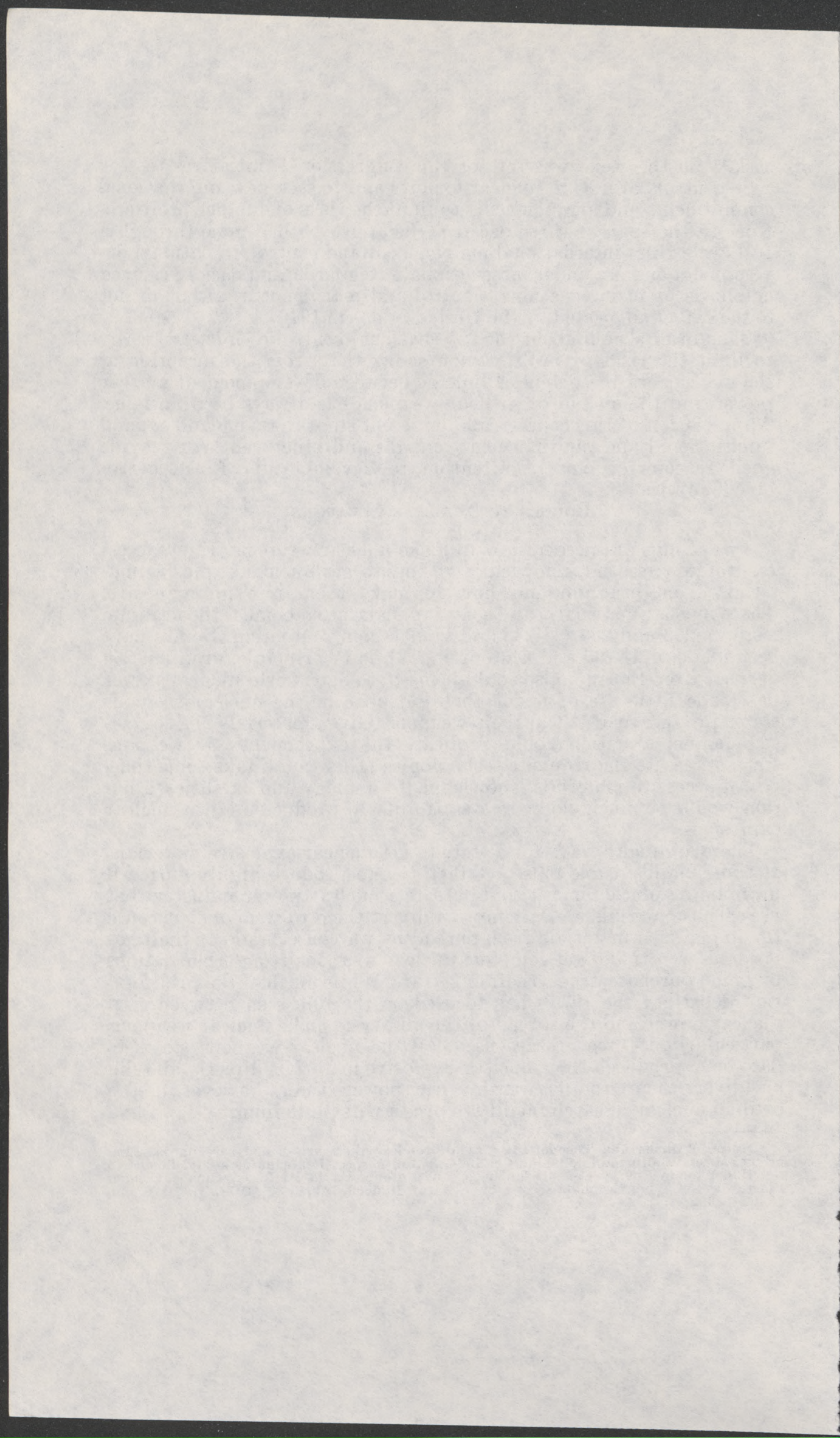
This brief sketch about the international control of nuclear energy to limit the risks of proliferation shows that from the inception of the nuclear era the potential linkage between development of nuclear power and the spread of nuclear weapons has always been an issue. Appreciation of this concern and of recent steps to revive and expand international and multinational controls and other ventures provide good reason for current attention to development of alternative breeder cycles.

ROUTES TO NUCLEAR WEAPONS

Two things are needed now to make nuclear weapons. First, access to uranium; second, knowledge of how to get nuclear explosive materials from uranium and how to make them into an explosive. Three nuclear materials can be used to make atom bombs: the uranium isotopes 233 and 235 (U-233 and U-235) and plutonium. Bombs have been made of U-235 and plutonium. While in principle, uranium-233 derived from thorium also could be used, to date world nuclear power has made little use of it for fuel and none of the nuclear-weapons states produce or use it in their weapons. Given materials and knowledge alone, a nation could replicate the experiments of weapons states to create the requisite technologies. This would take some time. Given access to materials, knowledge, technology and facilities, a nation would be much closer to a capability to produce its own nuclear explosives.

There are many ways for a state to get nuclear explosive materials. It could build visible or secret facilities to produce highly enriched uranium or plutonium; it could create a nuclear power industry that uses such materials and attempt to divert them to weapons; it could try to get such materials from abroad by purchase, trade or theft; or it could even try to get complete nuclear weapons from other nations by guile, purchase, trade, theft or seizure. While much of the proliferation debate of the 1970's has focused on the link seen between civil nuclear power and the spread of the ability to make nuclear weapons, particularly if breeders are used, all the nuclear-weapons states to date have produced their nuclear explosive materials directly and did not divert them from civilian nuclear power. India, however, used a civilian nuclear research facility to produce its plutonium.

¹⁰ Mason Willrich and Theodore B. Taylor. *Nuclear theft: risks and safeguards*. Cambridge, Mass.: Ballinger Publishing Co. 1974, 252 p. A special safeguards study. Report to the U.S. Atomic Energy Commission by a study group. David M. Rosenbaum, chairman. Placed in the Congressional Record by Senator Ribicoff, April 30, 1974, vol. 120, pp. 12352-12362.



CHAPTER IV. TECHNOLOGICAL AND SAFETY ASPECTS OF ALTERNATIVE BREEDERS*

INTRODUCTION AND SUMMARY

The increasing dependence of the United States on imported energy sources has led to debate in Congress concerning what types of indigenous energy sources should be promoted and developed to reduce dependence on these imports. Nuclear power as a source of electricity has received continuing support by the Administration and Congress for more than three decades. Part of the U.S. effort seeks to develop "breeder" reactors which produce more nuclear fuel than they consume during operation, and at the same time produce electricity. Conventional nuclear reactors use uranium less efficiently and concern about limited U.S. supplies of uranium has led some experts to conclude that development of breeders, which would substantially reduce uranium requirements in the future, is critical to ensure future energy independence.

The liquid metal fast breeder reactor (LMFBR) was selected in 1967 by the U.S. Atomic Energy Commission as the best of the several types of breeder concepts available, a decision supported by the Administration and Congress. That choice is now being questioned because the LMFBR, as currently designed, produces and uses the element plutonium in forms which might also be used to make nuclear weapons. In April 1977, President Carter called for cancellation of plans for an LMFBR commercial demonstration plant at Clinch River, Tenn., and redirection of national efforts in the nuclear field toward reinvestigating other breeder reactor concepts, as well as alternative fuel cycles which would not lead to production of plutonium.

The five types of breeder reactors addressed in this analysis include three thermal breeders—the light water breeder (LWBR), the molten salt breeder (MSBR), and the heavy water breeder (HWBR); and two fast breeders—the liquid metal fast breeder cited above and a gas cooled fast breeder (GCFR). The thermal breeders can produce uranium-233 from thorium in the thorium/uranium-233 fuel cycle, while the fast breeders can use either that cycle or one that produces plutonium-239 from uranium-238. The latter fuel cycle is preferable for fast breeders.

The LMFBR has received the most attention and development both in the United States and abroad. For this reason, more is known about the LMFBR than any of the other reactor concepts. Of the other four reactors (LWBR, MSBR, HWBR, and GCFR), only two have proceeded through at least part of the experimental stage (LWBR and MSBR). No experimental facility has been constructed to date

*By Marcia S. Smith, Analyst in Aerospace and Energy Technology, Science Policy Research Division, Congressional Research Service.

for GCFR or HWBR, so less information on these reactors is available, although nonbreeding gas cooled and heavy water reactors have been successfully operated.

A review of the various reactor concepts shows that each has advantages and disadvantages, making choices of a "most preferable" concept difficult. In terms of breeding potential, that is, the ability to create new nuclear fuel material from uranium or thorium, those breeder reactors with the highest breeding ratio are best. These are the two fast reactors, LMFBR and GCFR, operating on a uranium/plutonium fuel cycle. The GCFR is expected to have a significantly higher breeding ratio than the LMFBR, but, as noted above, little development has taken place with this reactor concept. Also, fast breeders could use stockpiled depleted uranium from enrichment facilities to produce plutonium. The LMFBR has the additional advantage of being the most developed of the breeder concepts.

The thermal breeders have very low breeding ratios, but convert thorium into uranium-233, rather than uranium-238 into plutonium. Therefore, if the prime concern is proliferation dangers of plutonium, then these thermal reactors might be preferable if the radioactivity of uranium-233 is seen as discouraging its use for nuclear explosives. Of the three thermal reactors, the MSBR has the highest breeding gain and other attractive features, but comparatively little developmental work has taken place for this concept.

As far as safety of the five alternative breeders is concerned, thermal breeders have lower radioactive inventories, so that if an accident of significant magnitude occurred, less long-term radioactive material would be available for release to the environment. Thermal breeders also do not run the risk of recriticality, so in terms of safety, they may have some advantages. As described below, however, many safety devices are provided in U.S. nuclear reactors to prevent accidents, and fast reactor proponents are convinced that these reactors can be made as safe as thermal breeders. It should also be borne in mind that, for systems that have operated for long periods of time (like the LMFBR), there are both proponents and opponents, while for newer concepts, there are usually only proponents. This is important when considering safety questions, since this is the area in which the most emotional debate can occur.

The following analysis is based primarily, but not exclusively, on information obtained from two studies performed for the Congressional Research Service: the first, on the safety of various breeders, by the Energy Research Group, Waltham, Mass.; and the second by Dr. John Lamarsh, on the technology of alternative breeders and foreign breeder programs.

NUCLEAR FUELS

URANIUM VERSUS THORIUM

There are two types of fuel cycles that can be used in breeder reactors: a combination of uranium-238 and plutonium, or a combination of thorium and uranium-233. In each of these cycles, the fuel, or "fissile material," is plutonium and uranium-233, respectively; these are the elements required for maintaining a chain reaction in the nuclear reactor. The other elements, uranium-238 and thorium, are

called "fertile" materials. By a process called "conversion," if an atom of uranium-238 captures a neutron, it becomes plutonium; if a thorium atom captures a neutron, it becomes uranium-233. This conversion occurs whenever these elements are exposed to neutrons. So, a conventional nuclear reactor, which uses a mixture of uranium-235 and uranium-238 as fuel, also will produce some plutonium. In fact, a conventional reactor may have a net plutonium production rate above that of a comparable LMFBR, since the latter reactor would use much of the plutonium for fuel. For power reactors of 1,000 megawatts electrical output, the core of the conventional reactor would produce 2.2 kilograms of plutonium per day, while that of the LMFBR would produce 0.62 kilograms per day, net.

One goal of a breeder reactor designer is to produce a net gain in fissile material. The surplus fissile material can be recovered from the spent fuel through a chemical procedure called reprocessing and may be used as fuel in other reactors. In principle, breeding can lessen concern about how much uranium will be available for nuclear power: breeders create their own fuel from non-fuel materials, and can multiply the energy recoverable from uranium fifty or sixty fold.

The fissile material for each type could be used to make nuclear weapons. However, there are differences in accessibility. Plutonium can be recovered from spent fuel by chemical reprocessing whereas uranium-233 if mixed with uranium-238, would have to be recovered by isotope separation techniques. The latter usually is considered to be more difficult and to require less readily available equipment than chemical reprocessing. On this basis, uranium-233 could be considered a more proliferation resistant fuel than plutonium. In addition, the naturally intense radioactivity of uranium-233 would make dangerous attempts to steal or divert it. This difference underlies the Carter Administration's decision to reinvestigate breeders other than the LMFBR and to look into the possibility of operating breeders on a thorium/uranium-233 fuel cycle instead of the uranium-238/plutonium fuel cycle.

Because of nuclear characteristics, fast breeder reactors operating on the plutonium cycle have higher breeding ratios than those operating with the use of thorium. This means that the plutonium fueled reactors are better breeders, as shown in table 2 (all fuels are oxides). The three thermal breeders must use thorium as a fuel, which partially explains their low breeding ratios.

TABLE 2.—DIFFERENCE IN BREEDING RATIO AND DOUBLING TIME FOR 5 BREEDER REACTORS DEPENDING ON FUEL CYCLE

Reactor type	Fuel	Breeding ratio ¹	Apparent doubling time (years) ¹
LMFBR	Plutonium	1.28	16.
LMFBR	Thorium	1.04	112.
GCFR	Plutonium	1.5	10.
GCFR	Thorium	1.08	Approximately 60.
LWBR	do	1.02 ²	Infinite. ²
MSBR	do	1.05-1.07	Approximately 20.
HWBR	do	1.00-1.01	Infinite. ³

¹ See glossary. These figures are approximate, and depend on detailed fuel and core designs.

² See LWBR summary chart for explanation.

³ See HWBR summary chart for explanation.

As it occurs in nature, uranium is a mixture of 0.7 percent atoms of uranium-235 and 99.3 percent of atoms of uranium-238. As noted earlier, uranium-235 is fissile and can be used as a reactor fuel or to make weapons. Uranium-238, on the other hand, is a fertile material and can only be used as a material to be made into the fissile material, plutonium. Conventional U.S. nuclear power reactors use enriched uranium for fuel in which the uranium-235 content has been increased to about 3 percent by an isotope separation process called enrichment. The enrichment process produces large amounts of uranium in which the uranium-235 content is depleted to about 0.2 percent and this depleted uranium is useless as a nuclear fuel. However, depleted uranium mixed with plutonium can be used to fuel fast breeder reactors. If this were done, the potential energy of the depleted uranium in principle could become available. At present, the United States has some 265,430 tons of depleted uranium. If used in breeder reactors, this could produce fuels with an energy content equivalent to some 2.3 trillion barrels of oil, which is many times greater than the U.S. proven oil reserves of 30.9 billion barrels in 1977.

In summary, from the standpoint of technology and efficiency, the plutonium breeder is clearly preferable. However, from the standpoint of potential risks for further proliferation, the use of the plutonium cycle in its present form is considered by the Administration and by some Members of Congress to present unacceptable risks.

OXIDE, CARBIDE AND METALLIC FUELS

The fissile material used in a nuclear fuel can be in the form of an oxide, carbide, or metal.

In an oxide fuel, there are two atoms of oxygen per atom of uranium, while in a carbide there is only one atom of carbon per uranium atom, and in the metal fuel, there are no extra atoms at all. These "light" atoms tend to slow down the energy of neutrons in the core, so the fewer of them, the faster the neutrons and the higher the breeding ratio. As shown in Table 3, the difference in breeding ratio and doubling time can be significant depending on the fuel form used. Metal fuels produce the highest breeding ratios, while carbide is second and oxide is last.

TABLE 3.—BREEDING RATIO AND DOUBLING TIME IN LMFBR WITH DIFFERENT FUEL FORMS

	Uranium/Plutonium	Thorium/Uranium
Oxide:		
Breeding ratio	1.277	1.041.
Doubling time	16 yr	112 yr.
Carbide:		
Breeding ratio	1.421	1.044.
Doubling time	9 yr	91 yr.
Metal:		
Breeding ratio	1.629	1.105.
Doubling time	6 yr	43 yr.

Source: Y. I. Chang et al., Alternative fuel Cycle Options. Argonne National Laboratory report ANL 77-70, September 1977.

Metal fuels were used in early LMFBR experiments, and it was learned that they have a tendency to swell when irradiated, as would happen in the core of a nuclear reactor. This meant that either oxide or carbide fuels had to be developed for commercial reactors. Carbide fuels react chemically with water at elevated temperatures, so could not be used since the new reactors would use water as coolant and moderator. Therefore oxide fuels were selected for development.

Once the oxide fuels were developed for commercial reactor use, they became the standard fuel form, and are now used for virtually all reactors. The United States and other countries have ongoing programs to develop carbide fuels, however, since they may have superior characteristics for use in breeders. Such development programs traditionally require a decade or more for completion, so it is not expected that carbide fuels will be available for some time. It is also not known at this time whether the carbide fuels will prove technologically and/or economically superior, since the research and development is only now taking place.

SAFETY ASPECTS OF BREEDER REACTORS

GENERAL

When discussing nuclear reactor safety, it should be remembered that the danger to the public from these reactors is the radioactive material which might be released in the event of an accident. Therefore the question of safety for a reactor revolves around the probability of an accident severe enough to breach those barriers which are provided to prevent such release of hazardous substances. The following sequence of events must occur for radioactive material to be released from the reactor and cause harm to the general population: an event which could initiate an accident occurs; either the equipment designed to protect against such an event fails or the event is of such magnitude that it overcomes the protective equipment; the "engineered safety systems" (described below) fail; and radioactive material that has been released is carried to inhabited areas by air, water or the food chain. Therefore, for each reactor under consideration, the important factors to know are: how much and what type of radioactivity exists in the core; the barriers to its release; the mechanisms for breaching those barriers; and the inherent and engineered safety systems present in the reactor.

Radioactive inventory of the core.—There are two types of radioactive materials of concern in the core of a nuclear reactor: fission products, or the remnants of the fission process, and actinides which are formed when uranium and plutonium capture successive neutrons and do not fission. Fission products are also important because they cause "decay heat" which continues to be released after the fission chain reaction has been stopped, necessitating provision of cooling systems to operate after the reactor has been shut down (see "inherent and engineered safety systems" below). The amount of fission products in a reactor core is essentially the same for all five breeders operating on either the plutonium or thorium cycles. Actinide inventories vary depending on whether the plutonium or thorium cycle is used: the plu-

tonium cycle results in higher actinide inventories than the thorium cycle.

Barriers to the release of radioactivity.—These are passive structures which are an integral part of reactor construction, as opposed to “engineered safety systems” discussed below, and include the *fuel matrix*, a solid material consisting of the reactor fuel which serves to maintain the proper amounts of fuel in the proper position within the fuel cladding; the *fuel cladding*, the solid material surrounding the fuel matrix and containing the fuel, fission products and actinides which serves to maintain the fuel in its proper position within the reactor core, as a medium for the transfer of heat from the fuel to the coolant, and to prevent chemical reactions from occurring between the fuel and the coolant; the *pressure vessel or calandria*, which contains the reactor core, and in some cases, other primary components (a pressure vessel is designed to withstand high pressures in the event of an accident, while a calandria is not in itself able to withstand these pressures, but rather is traversed by pressure tubes which serve that purpose); *piping* or channels for the flow of coolant (some reactors have valves to close off piping in the event of accidents); and *containment*, which is a strong airtight, pressure resistant structure which surrounds the reactor core and all important primary systems such as pumps and steam generators, and serves to protect the core and other systems from external accidents such as airplane crashes.

Mechanism for breaching barriers.—Conditions which could breach these barriers include: high temperatures, which could melt the materials of which the barriers are constructed; high pressures, which could force open the barriers; and high stresses (internal forces) which could break the barriers. These conditions could occur because of several causes.

Nuclear excursions are unplanned increases in reactor power level resulting from a change in reactivity (see glossary) caused by a change in the amount of neutron absorber in the core, the amount of coolant in the core, the amount of fuel in the core, or the location of fuel in the core.

Lack of cooling or “*loss of coolant accidents*” could result from blockage of the pipes carrying coolant into the reactor vessel; a rupture in part of the system causing the coolant to drain out; or failure of the pumps or blowers (for gas-cooled reactors) which circulate the coolant.

There are three types of *stored energy* which might be released in an accident: thermal energy in the form of heat in the fuel, cladding, etc.; mechanical energy such as the pressure of the reactor coolant or the fission product gases in the fuel; and chemical energy from chemical reactions between reactor materials. Possible release of stored energy is important for several reasons. Heat could melt the fuel cladding, reactor vessel or containment floor, or cause high pressures inside the containment resulting in leakage from the containment. Pressure could deform or rupture the fuel cladding or the reactor pressure vessel itself. Damage from the release of stored energy would not be the same for all the five reactor types. The following table summarizes the possible stored energy sources in five reactor types.

TABLE 4.—HYPOTHETICAL ENERGY SOURCES IN REACTOR ACCIDENTS

Energy source	LMFBR	GCFR	LWBR	HWBR	MSBR
1. Nuclear excursions (energy in vaporized fuel).....	Yes	Yes	Yes	Yes	Yes
2. Fuel-coolant interaction.....	Yes	No	Yes	Yes	No
3. Decay heat.....	Yes	Yes	Yes	Yes	Yes
4. Primary coolant blowdown.....	No	No	Yes	Yes	No
5. Clad-coolant chemical reaction.....	Yes	No	Yes	Yes	No
6. Combustion of hydrogen released in 5.....	No	No	Yes	Yes	No
7. Coolant-water chemical reaction.....	Yes	No	No	No	No
8. Combustion of hydrogen released in 7.....	Yes	No	No	No	No
9. Coolant fire.....	Yes	No	No	No	No

Source: Energy Research Group.

External events might also cause damage to the reactor, such as earthquakes, tornadoes, hurricanes, airplane crashes, explosions from materials being transported along nearby roads, railroads or waterways, and floods. Reactors in the United States must be designed to withstand maximum credible accidents, for example, an earthquake of the highest magnitude considered reasonably possible for the site.

Inherent and engineered safety systems.—Inherent safety mechanisms are those present by virtue of the physical nature of the reactor system. For example, the “Doppler effect” produces negative reactivity in the core as the power level in the core increases. This effect can offset the nuclear excursions described above, although its effectiveness is limited by the size of the excursion. The Doppler effect would not offset large excursions, although it might alleviate them.

Engineered safety systems are designed to prevent accidents or to lessen the consequences. These include an *emergency core cooling system* (ECCS) which provides coolant to cool the core and an auxiliary pumping capacity in a loss of coolant accident; *shutdown and postaccident cooling systems* to remove decay heat from fission products; *core splitters* to prevent a molten core from forming into a mass which might again become critical (achieve recriticality); and *core catchers* made of a heat resistant material to prevent a molten core from melting its way through the bottom of the reactor vessel and the containment.

In addition to these safety features, nuclear reactors in the United States also have an exclusion area surrounding the reactor site, usually one quarter to one half mile in radius.

RISK DETERMINATION CRITERIA

There are no standardized criteria for assessing risks from nuclear reactor accidents, so different conclusions may result from using different criteria, such as the probability of having an accident per unit per year; the average accident consequences per unit per year; the worst consequences that could result from any single accident; the probability of various consequences; and the number of years of otherwise expected lifetime lost because of the accident. A commonly used definition is that risk (consequences per unit time) equals frequency (events per unit time) times consequences (per event). There

are also different ways to compare risks. For example, the risks of nuclear energy can be compared with the risks of other energy alternatives like coal, or the risks of breeders versus nonbreeding nuclear reactors. A detailed discussion of these methods of comparing risks can be found in the study by the Energy Research Group.

SUMMARY

In general it can be said that fast reactors are more sensitive than thermal reactors to loss of coolant flow accidents, and risk the possibility of recriticality if the core melts and falls to the bottom of the reactor vessel, although some experts are convinced that recriticality is physically impossible for certain fuel designs. Thermal reactors do not have these problems, although it is conceivable that the core could melt (it would not be subject to recriticality, however). Many experts contend that both the possibility of these types of accidents occurring is extremely small, and that subsequent release of radioactivity is unlikely, considering all the barriers and engineered safety systems which exist to prevent such a release.

Table 5 summarizes safety information for the five breeder reactors.

TABLE 5.—SUMMARY OF BREEDER REACTOR SAFETY INFORMATION

	LMFBR	GCFR	LWBR	HWBR	MSBR
Breeder capability.....	Good.....	Good.....	Marginal.....	Marginal.....	Average.....
NRC safety review.....	Extensive.....	Partial.....	Partial ¹	None.....	None.....
Operational status.....	Commercial version under construction in Europe. Several experimental versions have operated in U.S., but commercial version not constructed.	Design only, no construction plans yet.	Experimental version operating in the U.S.	Nonbreeders operating in Canada.	No plans for design or construction.
Numerical risk analysis complete?	Yes.....	Partial ²	Partial ³	No.....	No.....
Fission product inventory.....	Average.....	Average.....	Average.....	Below average.....	Below average.....
Actinide inventory.....	High ⁴	High ⁴	Low.....	Low.....	Low.....
Energetic core disruptive accident possible?	Maybe.....	Maybe.....	No.....	No.....	No.....
Recriticality possible after meltdown?	Maybe ⁵	Maybe ⁶	No.....	No.....	No.....
Can reinforcing feedback exacerbate accidents?	Yes.....	No.....	No.....	Little.....	Little.....

¹ Largely similar to operating pressurized light water reactors.

² GCFR risk analysis approaching completion.

³ Much of LWR reactor safety study would apply to LWBR.

⁴ High actinide inventory predicated on use of plutonium fuel cycle. Use of U²³³ cycle also possible with attendant lowering of actinide inventory and breeding capability.

⁵ Recriticality in LMFBR may be impossible for certain fuel designs.

⁶ Recriticality is claimed to be unlikely, but not ruled out.

Source: Energy Research Group, Waltham, Mass.

DESCRIPTION OF ALTERNATIVE BREEDER REACTORS

The liquid metal fast breeder reactor (LMFBR) is one of five breeder reactor concepts. The other four are the gas cooled fast breeder (GCFR), the light water breeder (LWBR), the molten salt breeder (MSBR) and a CANDU operating on the thorium cycle, or heavy water breeder. The first two (LMFBR and GCFR) are called

fast breeders, while the remainder are called thermal (or slow) breeders.

FAST VERSUS THERMAL BREEDERS

The terms fast and thermal (or fast and slow) refer to the speed of the neutrons in the core of a reactor. Neutrons are emitted at a very high speed by the fission process, making it difficult for other nuclei to capture them and fission themselves to maintain the chain reaction. For this reason, in some reactors the neutrons are slowed down by a substance called a moderator. When the neutrons are slowed, however, some of them are captured by nonfuel material such as fuel cladding and by the moderator itself. This reduces the number of neutrons available for fissioning, resulting in a lower breeding ratio.

In fast reactors, the neutrons are not intentionally slowed. This allows the greatest possible number of neutrons to be available for fissioning but makes it relatively more difficult for nuclei to capture them. Therefore more fuel (fissile) material is required to maintain the chain reaction in these reactors. For example, in a conventional fission reactor, only approximately 3 percent of the fuel needs to be fissile while in a fast reactor, 10 to 20 percent of the fuel needs to be fissile. Fast reactors do have a higher breeding ratio than thermal breeders, however.

It should be remembered that in breeders, the conversion of fertile material into fissile material occurs not only in the fuel rods, but in a "blanket" surrounding the rods which is provided expressly for that purpose.

Since the LMFBR is the most developed of all the breeder concepts, it will serve here as the reference reactor. This is done to simplify comparisons of the various breeder reactors, and does not imply a preference.

THE LIQUID METAL FAST BREEDER REACTOR (LMFBR)

The technology and safety of the LMFBR is discussed in more detail below. Table 6 summarizes the principal features of the LMFBR, its program status and its advantages and disadvantages:

TABLE 6—LMFBR SUMMARY

Coolant: Sodium.
Primary fuel cycle: Uranium-238/Plutonium-239.
Breeding ratio: 1.28.
Doubling time: 16 years.
Secondary fuel cycle: Thorium/Uranium-233.
Breeding ratio: 1.04.
Doubling time: 112 years.
Overall efficiency: 40 to 42 percent.

Program status.—In the United States, four experimental breeder reactors have been operated. France, Britain and the Soviet Union have operated both experimental and demonstration LMFBR's, and France has begun construction of what will probably be the world's first commercial LMFBR, Super-phenix. Germany and Japan are now operating experimental LMFBR's; Germany has begun construction of a demonstration plant; and Japan has plans for a demonstration plant.

Advantages.—Operating on its primary fuel cycle, the LMFBR has a high breeding ratio and short doubling time. Sodium is an excellent heat transfer agent, resulting in high efficiency and low thermal pollution. This reactor is in the most advanced stage of research and development of any of the five breeders. The reactor vessel does not need to be pressurized, so cracks which might develop in parts of the primary system would not tend to enlarge as could conceivably happen with a pressurized reactor vessel (such as the GCFR). As a fast reactor, the LMFBR can use currently stockpiled depleted uranium for conversion into plutonium.

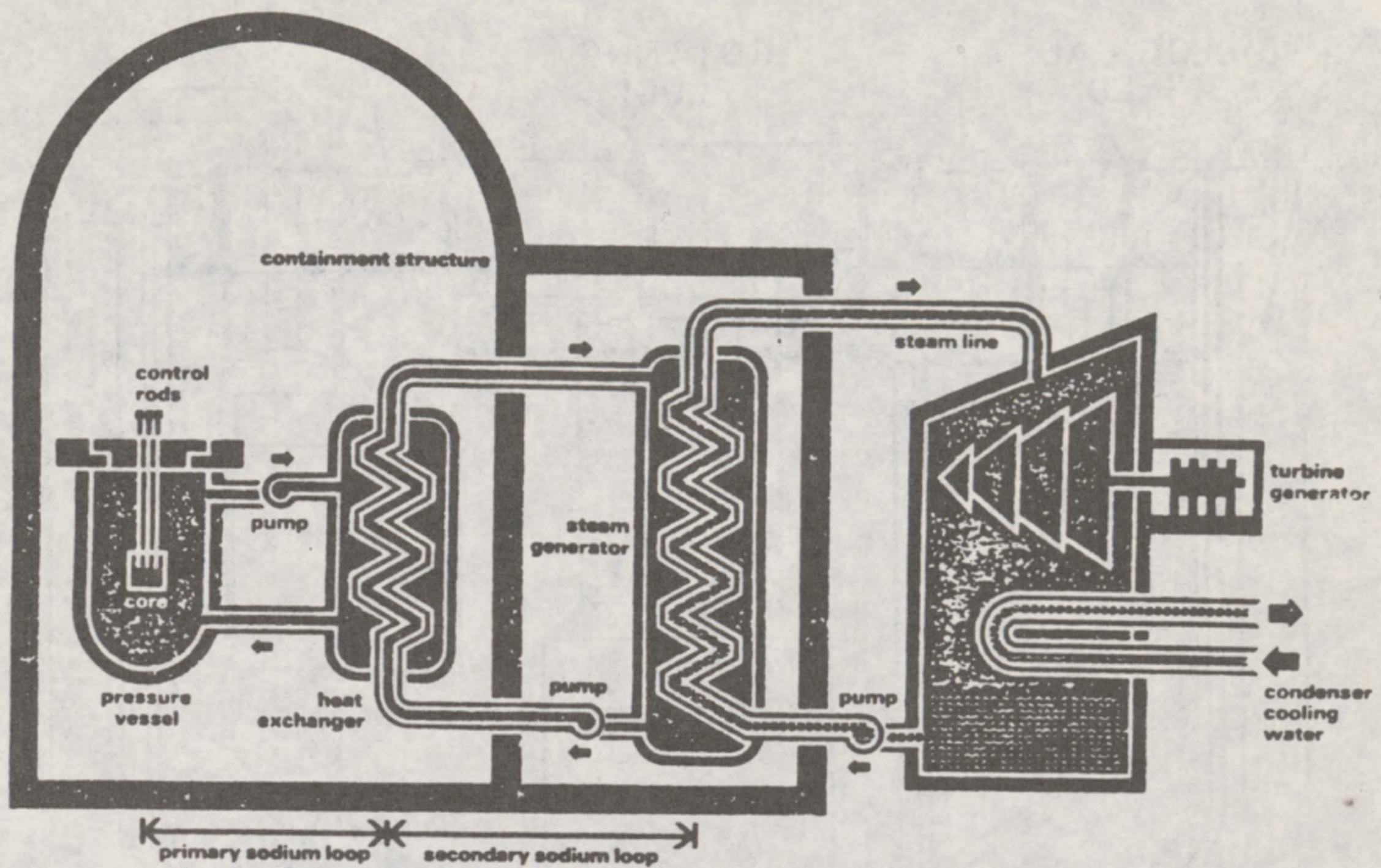
Disadvantages.—Sodium becomes radioactive as it passes through the core region of the reactor, necessitating a secondary loop of sodium to transfer heat to the water/steam loop. Sodium is highly reactive chemically so care must be taken to ensure that it does not come in contact with water in other parts of the system. Sodium has a high melting point so the pipes which carry sodium are heated so the sodium does not solidify (the pipes are surrounded by heating coils called tracing for this purpose). As a fast reactor, the LMFBR core could conceivably achieve recriticality in the event of a core meltdown.

Technology.—The LMFBR is a fast reactor using sodium as its coolant (as a fast reactor, there is no moderator). The sodium flows through the core of the reactor to pick up heat generated there by the fission process. Since the sodium in the core becomes radioactive, it is pumped to an intermediate heat exchanger (IHX) where its heat is transferred to another sodium loop. This second sodium loop carries the heat to another heat exchanger, where it is picked up by water, which is then converted into steam to drive a turbine generator.

Because two sodium loops are required, two different designs have been developed for the LMFBR: the pool (or pot) and the loop. In the pool arrangement, all primary reactor components (core, pumps, IHXs) are located in a single reactor vessel. Only the sodium in this part of the system is radioactive, so shielding is required only for the reactor vessel.

In the loop design, the pumps and IHX's are connected to the core region by piping, rather than being located in the reactor vessel itself. This allows easier access to these components for inspection, maintenance and repair, but requires additional shielding, since these components contain radioactive sodium.

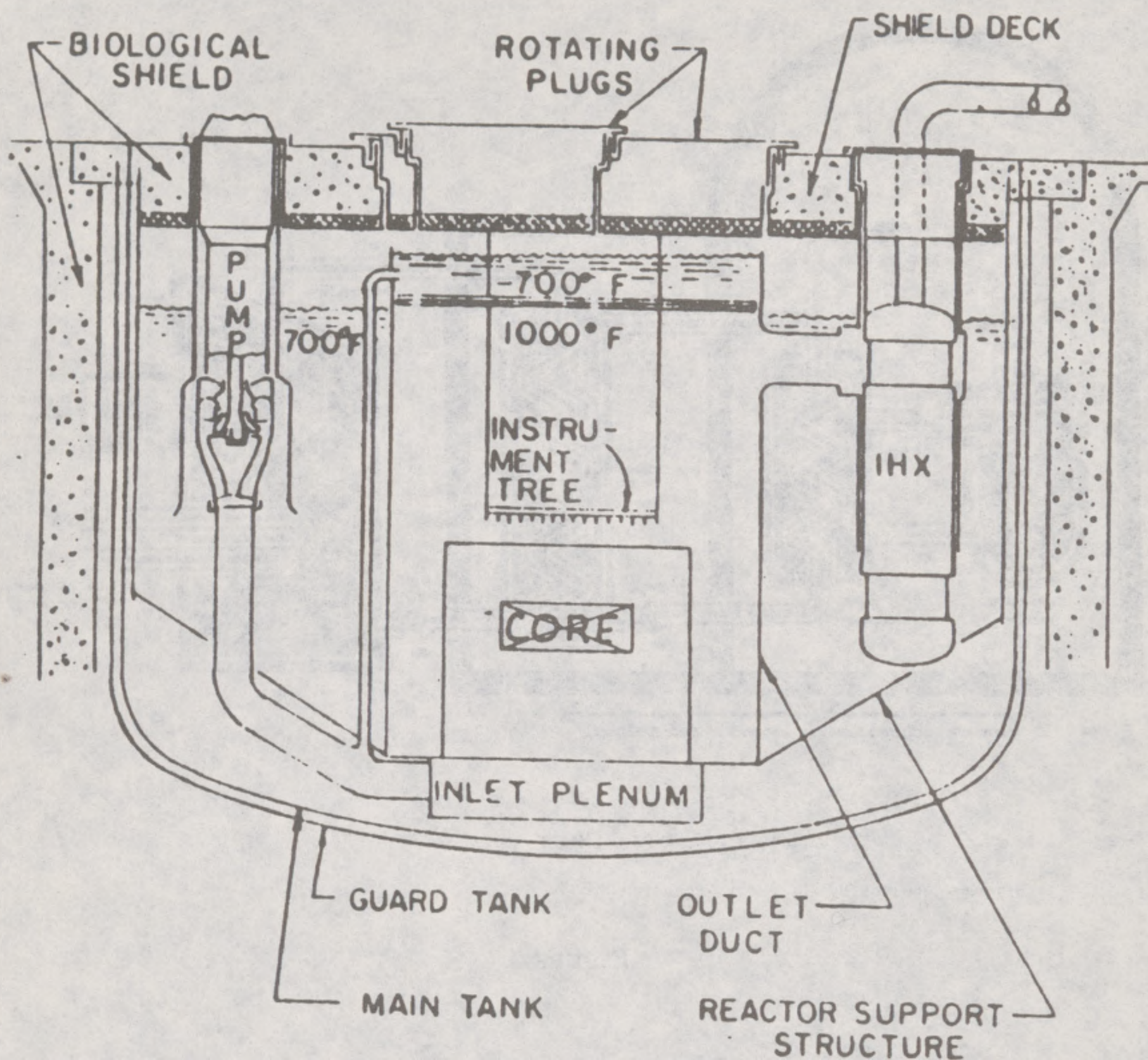
No consensus in the nuclear industry presently exists as to which design is superior. The Clinch River demonstration project is designed as a loop system, as were three of the four experimental LMFBR's operated in this country (the Experimental Breeder Reactor II is a pool design). Of the nine experimental and demonstration LMFBR's abroad, all six experimental and one demonstration facility are loops, while the other two demonstration facilities are pool. The French commercial LMFBR Super-phenix now under construction is a pool type. Some experts have concluded that a loop LMFBR might be preferable for small reactors, while the pool design might be preferable for large reactors. Figures 1 and 2 show schematic diagrams of the pool and loop LMFBR's.



SCHEMATIC DIAGRAM OF LOOP
TYPE LMFBR

Diagram supplied by the Energy Research Group.

FIGURE 1



SCHEMATIC OF POOL-TYPE LMFB
(Primary System Only)

Diagram supplied by the Energy Research Group.

FIGURE 2

Safety.—Since there is considerable experimental experience with small LMFB's, a fair amount of information exists concerning safety for these reactors. In the four experimental LMFB's operated in the United States, there have been two partial meltings of the core.

The first core melt occurred with the Experimental Breeder Reactor I (EBR I) in November 1955. During an experiment to study the reactor's behavior when power level was intentionally rapidly increased under experimental conditions of reduced coolant flow, an operator error resulted in partial melting of the core.

The experiment was conducted under abnormal conditions and the possibility of a meltdown was recognized prior to initiating the ex-

periment. Two of the normal safety mechanisms were purposely disconnected and coolant flow was stopped completely as part of the experiment. It had been planned to shut down the experiment when the temperature of the fuel reached 500° C. However, because of operator error, the temperature overshot, the uranium was heated to about 720° C., and the center of the core melted. The reactor was shut down by emergency operator action in less than two seconds, and the meltdown ceased. No explosive force developed and no injuries resulted. A negligible amount of radioactivity reached the atmosphere.

On October 5, 1966, a second LMFBR core meltdown occurred in an experimental LMFBR, the Fermi reactor. This incident caused more concern than the EBR I event, since it was not a planned experiment and occurred near a large city, Detroit. During a controlled startup of the Fermi reactor, the operator, in response to a decrease in core reactivity, withdrew the control rods to maintain power and subsequently noted an increase in the radioactivity of the argon cover gas. Some of the gas leaked into the reactor building and set off high radiation alarms. The loss of reactivity in the core was attributed to core geometry changes that were occurring from overheating due to blockage of flow at the fuel assembly inlet by pieces of zirconium broken off from conical flow devices. The operator sealed the building ventilation system and began manual reactor shutdown. At about the time of building isolation, the operator also noted that two core outlet thermometers had abnormally high readings, indicating the possibility of fuel melting. The reactor was quickly shut down without injury to operating personnel or dangerous releases of radioactivity. However, some writers argue that the Fermi reactor came very close to catastrophic release of radioactivity.

Concern about the possibility of recriticality in the shut down reactor caused authorities to delay investigation for about a month. When the investigation was performed, it was discovered that two of the fuel assemblies had melted together, apparently because the coolant flow was blocked by two small pieces of zirconium broken off from a conical flow device, an addition made without proof testing or supporting analysis to demonstrate the structural integrity of the component at the operating conditions.

Controversy still continues about the import of the Fermi incident. LMFBR supporters claim that the accident proved that even under crisis circumstances, this type reactor can be safely shut down and no injuries sustained; they also insist that the addition of the untested conical flow devices must be considered as a factor in the accident. Opponents claim that the accident was worse than the design basis "maximum credible accident" which stipulated that all of the fuel in one subassembly would melt (part of the fuel in two subassemblies melted in this case); that the reactor would probably be shut down automatically (it was shut down manually); and that this "maximum credible accident" was assumed to occur at 15 times the power level at which this incident occurred (leading to speculation that if the reactor had been at a higher power level, severe losses could have resulted).

The Fermi reactor was repaired and resumed operation in 1970. It was decommissioned on December 31, 1975, for economic reasons unrelated to this incident.

As noted earlier, fast reactors using the uranium/plutonium cycle have higher actinide inventories than thermal reactors, so more dangerous material is available to be released in an accident. There is also the possibility of a molten core becoming recritical if it falls to the floor of the reactor vessel. As noted earlier, sodium reacts chemically with water (possibly causing explosions) as well as with the oxygen in air (causing sodium fires).

There are differences in the safety aspects of a pool versus a loop LMFBR, which are summarized in the following table prepared by the Energy Research Group:

TABLE 7.—SAFETY CHARACTERISTICS OF LOOP AND POOL LMFBRs

<i>Safety-related feature</i> ¹	<i>Superior concept</i> ²
Less stored energy available for core-related sodium-water reaction.....	Loop.
Lower probability of sodium-water reaction.....	Pool.
Lower probability of loss of coolant.....	Pool.
Greater capability for cooling by natural circulation.....	Pool.
Lower probability of core disruptive accident due to loss of flow.....	Pool.
Greater cooling for core debris in case of core disruptive accident.....	Pool.
Greater resistance to seismic disturbances.....	Pool.

¹ Items are not equally important.

² Choice of superior concept in each case is based on straightforward design. The "inferior" concept is not necessarily unacceptable and might achieve parity by appropriate design.

A 1976 study for the Energy Research and Development Administration (now the Department of Energy) and the Electric Power Research Institute by Atomics International and Burns and Roe found that in 7 of 9 postulated accident scenarios, the pool type showed the least probability of a core disruptive accident. In one other, the loop showed the least probability, while in another the probabilities were the same.¹¹

THE GAS COOLED FAST REACTOR (GCFR)

The technology and safety of the GCFR is discussed below. Table 8 summarizes the principal features of this type breeder, its program status, advantages and disadvantages.

TABLE 8.—GCFR SUMMARY

Coolant: Helium.
 Primary Fuel Cycle: Uranium-238/Plutonium-239.
 Breeding Ratio: 1.5.
 Doubling Time: 7–10 years.
 Secondary Fuel Cycle: Thorium/Uranium-233.
 Breeding Ratio: 1.08.
 Doubling Time: 60–100 years.
 Overall Efficiency: 38 percent.

Program Status.—No GCFR facility has been constructed, although nonbreeding high temperature gas cooled reactors (HTGR) have been built both in the United States and abroad (primarily Britain, where they are referred to as Advanced Gas Reactors—AGR's).

Advantages.—Using its primary fuel cycle, the GCFR has the highest breeding ratio of all breeders. Helium is inert, so it does not react

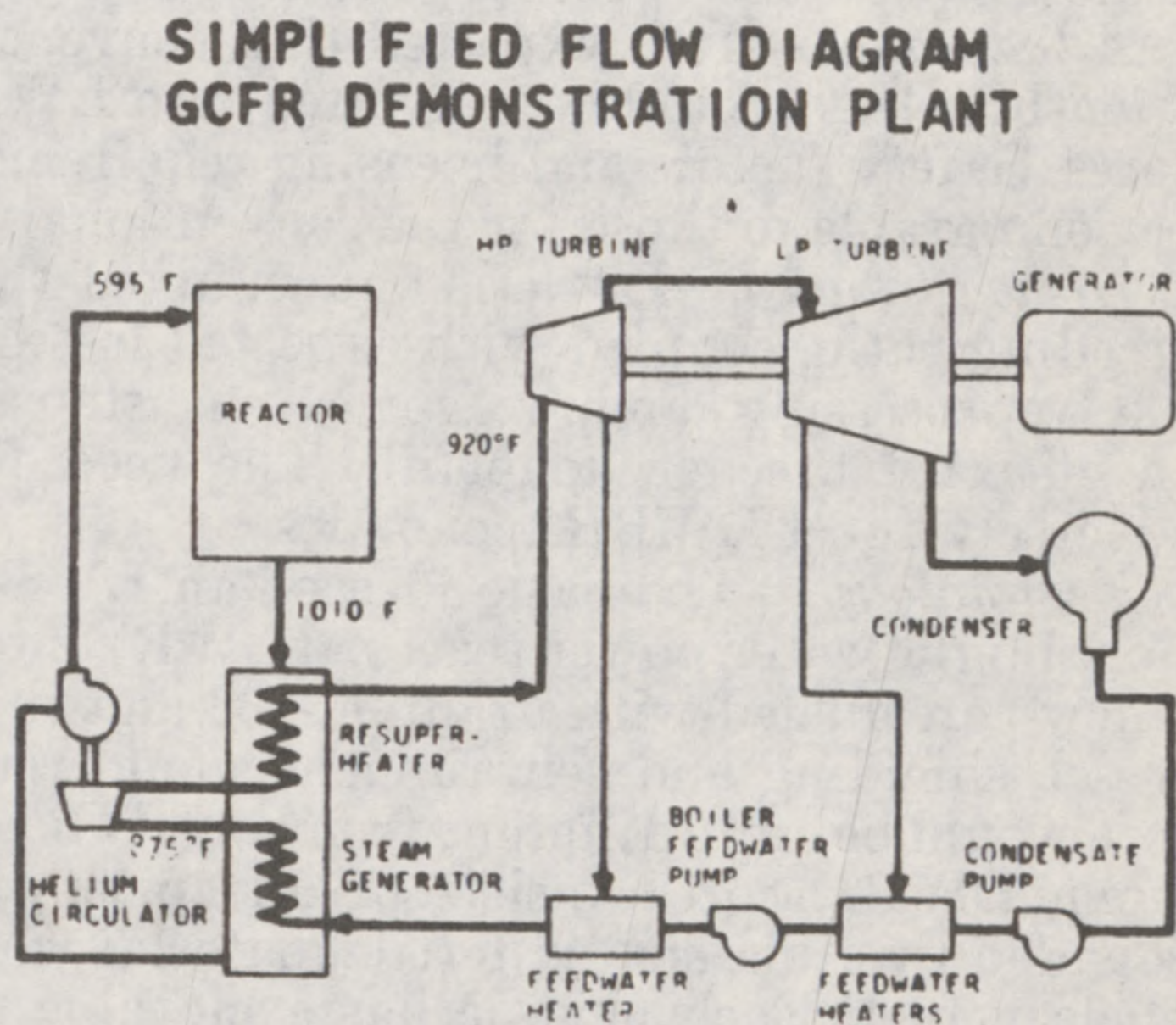
¹¹ Rockwell International, Atomics International Division, and Burns and Roe, Breeder Reactor Division. Pool-Loop-Hybrid: Liquid Metal Fast Breeder Reactor Plant Comparison. Submitted to Energy Research and Development Administration and Electric Power Research Institute. Vol. 1, Executive Summary. FBR-76-1. June 30, 1976.

chemically with water or air. Helium is optically transparent, allowing easy monitoring of reactor components in the core area (unlike sodium which is opaque). As a fast reactor, the GCFR can use currently stockpiled depleted uranium for conversion into plutonium.

Disadvantages.—Helium is not as good a heat transfer agent as sodium, so it is kept under high pressure and pumped at great speed through the reactor core, requiring greater pumping power with reduced overall efficiency for the system. The reactor must also be enclosed inside a heavy pressure vessel, and with the coolant under high pressure, there is always a possibility that it will escape from the reactor vessel, resulting in a need for redundant cooling systems.

Technology.—The primary mechanical difference between the GCFR and LMFBR is that to optimize the heat transfer by helium as a coolant, the reactor vessel is kept under high pressure. The helium is circulated by blowers which move the gas downward through the reactor core, and then up through the steam generators where heat is transferred from the helium to water, which then produces steam to generate electricity.

Figure 3 presents a schematic diagram of a GCFR.



Source: General Atomic Company.

FIGURE 3

Safety.—As with the LMFBR, GCFR's operating on the uranium/plutonium cycle have high actinide inventories. In contrast to the LMFBR, however, a loss of coolant flow accident in a GCFR probably would result in a much smaller reactivity change. Other safety aspects of the GCFR are not as well established since less research and development has taken place for this reactor concept than for the LMFBR.

THE LIGHT WATER BREEDER REACTOR (LWBR)

The technology and safety of the LWBR is discussed below. Table 9 summarizes its principal features, its program status, advantages, and disadvantages.

TABLE 9.—LWBR SUMMARY

Coolant: Water.
 Primary Fuel Cycle: Thorium/Uranium-233.
 Breeding Ratio: 1.02.¹
 Doubling Time: Infinite.¹
 Secondary Fuel Cycle: None.
 Overall Efficiency: 33 percent.

¹The Naval Reactor Branch of the Department of Energy, which is in charge of the LWBR program, does not compute a breeding ratio for the LWBR, but rather uses the fissile inventory ratio (FIR) which is the ratio of the amount of fissile material present at the time of refueling to the amount present at time zero. Since approximately 2 percent of the fissile material is lost during reprocessing and refabrication, and the breeding gain is only expected to be about 2 percent, the amount of fissile material would at best remain constant and never "double." Hence the doubling time is listed here as infinite.

Program status.—Start-up of the world's first experimental LWBR took place in September 1977 at Shippingport, Pa. Experiments with the LWBR are expected to take place over the next four years to determine the potential of this type of breeder reactor.

Advantages.—It is expected that conventional light water reactors (non-breeders) could be converted into LWBR's by redesigning their cores. Safety factors and licensing requirements for the LWBR might be comparable to those for the conventional light water reactor.

Disadvantages.—Little is known about this type of reactor. Its low breeding ratio, coupled with expected losses of fissile material during the reprocessing and refabrication steps, makes its potential as an effective breeder doubtful. The need for pre-breeder cores may adversely affect LWBR economics.

Technology.—The basic idea of an LWBR is to convert a conventional light water power reactor (LWR) into a breeder by substituting a new core fueled with uranium-233 and thorium. While the pressure vessel, shielding and containment would remain the same, an LWBR core would be quite different from an LWR core.

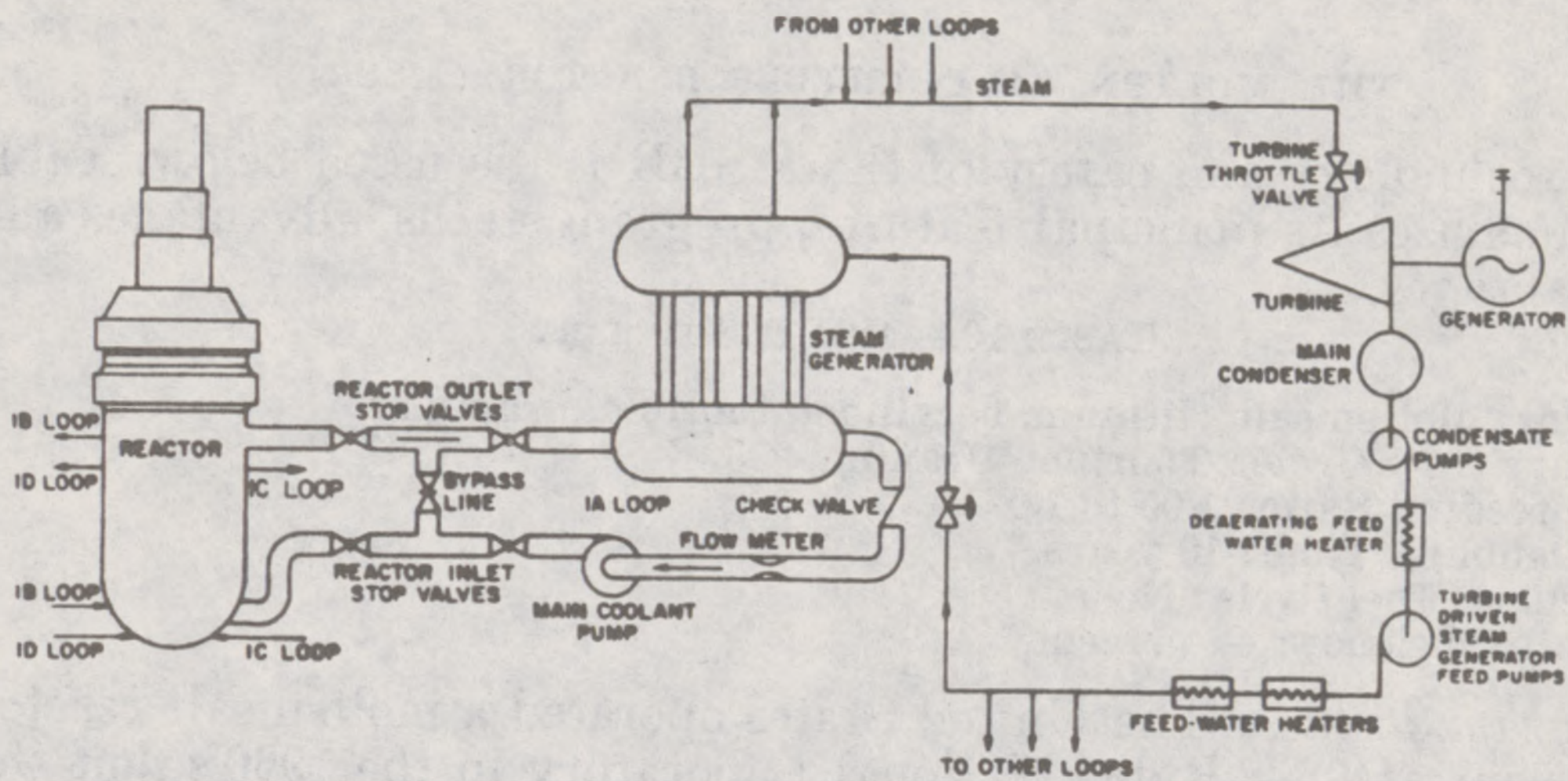
An LWBR core consists of an array of hexagonal modules surrounded by a blanket of fertile material which is to be converted into nuclear fuel. Each module has a movable "seed" which contains the nuclear fuel. Both the movable seed and the blanket are made up of fuel rods. Reactor control is accomplished by moving the seed within each module. This type of control is necessary to conserve neutrons needed if the reactor is to breed. The control rods and guide tubes of a conventional LWR cannot be used because they would absorb too many neutrons.

Safety.—The safety characteristics of an LWBR are similar to the LWR. Since this reactor operates on the thorium cycle, the actinide inventory would be lower than for fast reactors operating with a plutonium cycle.

There is one unique safety problem with the LWBR: possible failure of the bypass inlet flow system which counterbalances the upward hydraulic forces on the movable seed described above. A failure in this system could reduce the downward hydraulic force on an assembly, possibly resulting in a net upward force which might move on the assembly enough to cause a dangerous release of energy or nuclear ex-

cursion. Provisions have been incorporated into the LWBR design to minimize the probability of this occurring.

Figure 4 is a schematic diagram of a light water breeder reactor.



Shippingport Plant Operating Cycle with LWBR Core

Source: Energy Research and Development Administration. Final Environmental Statement: Light Water Breeder Reactor Program. Vol. 2, page III-97.

FIGURE 4

THE MOLTEN SALT BREEDER REACTOR (MSBR)

The technology and safety of the MSBR is discussed below. Table 10 summarizes its principal features, program status, advantages and disadvantages.

TABLE 10.—MSBR SUMMARY

Coolant: Molten salt (lithium, beryllium, thorium, uranium).

Primary Fuel Cycle: Thorium/Uranium-233.

Breeding Ratio: 1.05 to 1.07.

Doubling Time: 19 years.

Secondary Fuel Cycle: None.

Overall Efficiency: 44 percent.

Program status.—The United States operated a molten salt reactor experiment at Oak Ridge National Laboratory in the 1960's, but the program was subsequently cancelled. The Department of Energy has not requested any funding for MSBR for the past two fiscal years.

Advantages.—On-line fuel reprocessing makes diversion of uranium-233 for weapons use highly unlikely. Since reprocessing is done on-line, and no refabrication of new fuel rods is required (since there are no fuel rods), there are no losses of newly created fissile material, resulting in shorter doubling times than other thermal reactors. Also, since fission products are removed during the on-line reprocessing, the reactor does not need to be shut down for refueling. It has the highest efficiency of all the breeders.

Disadvantages.—The MSBR has had comparatively little research and development, and severe technical problems remain. The molten salt fuel is highly corrosive, which complicates piping and pumping systems. The reactor has a relatively low breeding ratio. Since its fuel is liquid rather than solid, double containment is required to assure protection against release of radioactive materials and gases from the molten salts. As the radioactive molten fuel passes through the core and the primary loop, it tends to make all of the equipment radioactive which may result in expensive downtime for maintenance or repairs. Also, automatic, remotely operated equipment is needed. As with the LMFBR, two coolant loops are required to prevent interaction between radioactive coolant and water.

Technology.—The MSBR is unlike any other reactor concept because instead of solid fuel rods containing pellets of uranium/plutonium oxides or thorium/uranium oxides, its fuel is a liquid.

In the fuel, fertile material and coolant are mixed together in a homogeneous, clear fluid with a viscosity similar to that of kerosene. The fuel mixture in the molten salt reactor experiment in the 1960's was as follows: 72 percent lithium fluoride, 16 percent beryllium fluoride, 12 percent thorium fluoride, and 0.3 percent uranium-233 fluoride.

An MSBR core would consist of bare graphite bars with channels for passage of the molten salt mixture. As the fluid moves through the

core, it becomes critical, fissions occur, and the fission energy is absorbed directly by the fluid. The heated fluid then flows through a heat exchanger and back into the reactor. An intermediate loop, also containing molten salt, carries the heat to a steam generator.

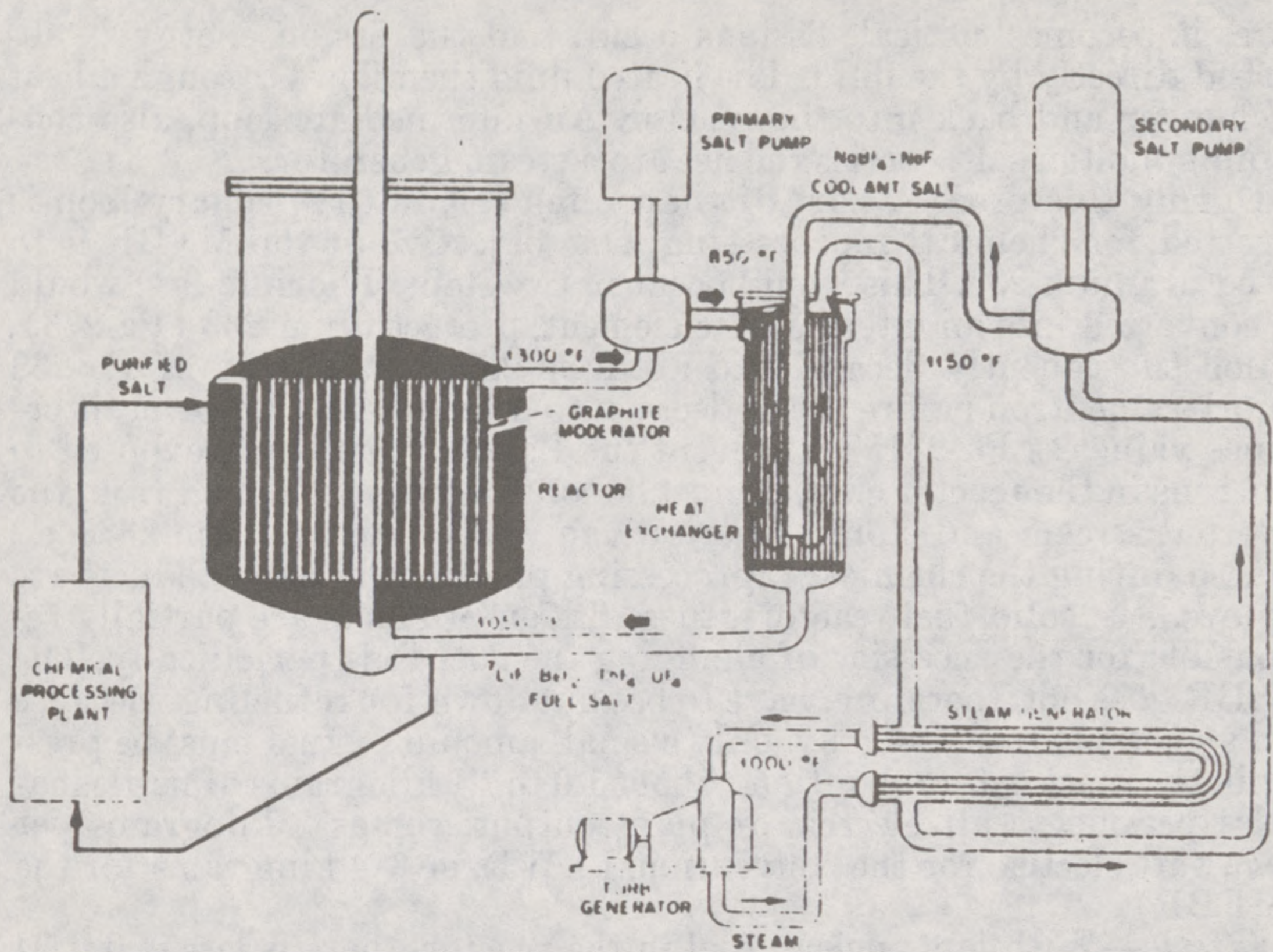
During this process, part of the molten salt in the primary loop is diverted for chemical reprocessing. One objective of the MSBR is to breed uranium-233. This would occur in two steps. Thorium first would be converted into an intermediate element, protactinium-233 (Pa-233), which subsequently decays into uranium-233. If an atom of Pa-233 absorbs a neutron before it can decay into uranium-233, however, it becomes valueless Pa-234. To prevent the Pa-233 from being exposed to neutrons in the reactor core, it must be continuously extracted from the diverted stream and stored where it can decay into uranium-233.

Also during the chemical reprocessing phase the fission products are removed. In solid fuel reactors, these fission products are partially responsible for the necessity of changing the fuel rods periodically. The MSBR does not, therefore, have to be shut down for refueling. Because of its good neutron economy, only a small amount of fuel must be present in the reactor for operation (about 1.0 to 1.2 kilograms of fissile material per megawatt electric of plant output, versus 3 kilograms per megawatt electric for the conventional LWR, or 3–4 kilograms for the LMFBF).

Safety.—With less nuclear fuel in the reactor, there is less material to be released to the environment in the event of an accident. Since fission products are continuously removed from the molten material, the amount present in the reactor itself at any one time would be substantially less than for a conventional reactor. The actinide inventory is low since the fuel cycle is thorium rather than plutonium.

Double containment is required for all equipment containing radioactive liquids and gases (most of the reactor). The inner containment must be sealed while the reactor is operating, and the outer containment must also be sealed, although controlled access through airlocks would be possible at times when the radioactivity level is within permissible standards.

No detailed safety analysis of the MSBR has been performed. Figure 5 provides a schematic diagram of an MSBR.



CONCEPTUAL DESIGN OF A 1000 MWe
MSBR

Diagram supplied by the Energy Research Group.

FIGURE 5

THE HEAVY WATER BREEDER REACTOR (HWBR)

Another potential breeder alternative is the heavy water breeder reactor. The technology and safety of this reactor type is discussed below. Table 11 summarizes its principal features, program status, and advantages and disadvantages.

TABLE 11.—HWBR SUMMARY

Coolant: Heavy Water.
Primary Fuel Cycle: Thorium/Uranium-233.
Breeding Ratio: 1.00 to 1.01.
Doubling Time: Infinite.¹
Secondary Fuel Cycle: None.
Overall Efficiency: 29 percent.

¹ As with the LWBR, some of the new fissile material would be lost in reprocessing and refabricating new fuel rods, so approximately 2 percent of the new fissile material would be lost, resulting in an infinite doubling time.

Program Status.—It has been suggested that the CANDU reactor might be developed as a breeder using the thorium cycle. No CANDU has been operated on the thorium cycle, however, and the U.S. Department of Energy is not developing this concept.

Advantages.—May be able to fit existing heavy water reactors with breeder core. On-line refueling may result in less reactor down-time.

Disadvantages.—Low breeding ratio, with effectively no gain in fissile materials. Licensing requirements for United States unknown. Very little developmental work.

Technology.—If a heavy water breeder could be developed, it probably would be a version of the CANDU reactor currently in commercial use in Canada, which uses natural uranium for fuel and heavy water as a coolant and moderator.

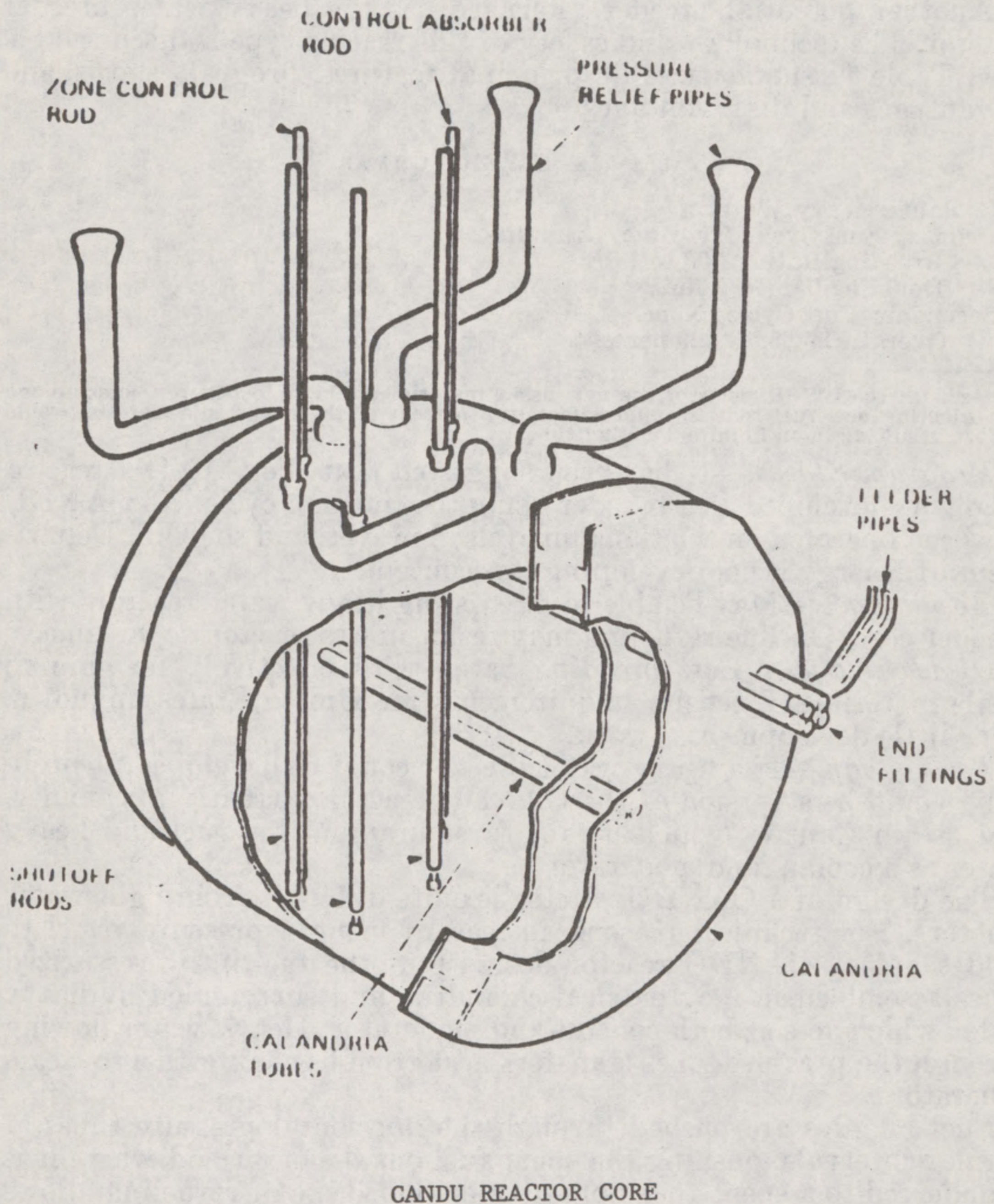
The design of a CANDU reactor is quite different from light water reactors. For technical reasons, instead of using a pressure vessel to hold the fuel, CANDU reactor design puts the fuel into pressurized tubes assembled in a cylindrical calandria, and surrounded by heavy water which acts as both coolant and moderator. Heavy water flowing through the pressure tubes transfers heat from fissioning fuel to steam generators.

Fuel bundles are pushed through the horizontal pressure tubes at regular intervals, pushing the spent fuel out the other end where it is transferred to a spent fuel storage tank. This type of refueling allows the reactor to operate while it is being refueled, resulting in less down-time than for an LWR, which must be taken out of service to refuel.

The fuel costs of a CANDU-type reactor are less than for an LWR because enriched uranium is not needed. On the other hand, the operating costs are higher because of the initial inventory of heavy water and the annual replacement of heavy water losses. Heavy water is expensive to produce.

Designed as a thermal breeder, a CANDU reactor uses thorium as the fertile material and would produce uranium-233. The breeding

ratio from this type of breeder would not be large, perhaps only 1.00. Since approximately two percent of the new fissile material would be lost during reprocessing and refabricating of new fuel rods, there would be no effective gain of fissile material. On the other hand, it would permit conversion of thorium into nuclear fuel. Figure 6 provides a schematic diagram of a CANDU reactor core.



Source: The Energy Research Group.

FIGURE 6

Safety.—The fission product inventory of a CANDU reactor would be somewhat smaller than with other reactors of the same size because the fuel is removed after a relatively short time. Since the breeder version of the CANDU would operate on the thorium cycle, actinide inventories would be low. Because fuel assemblies are contained in individual pressure tubes, this type reactor probably would be more resistant to a loss of coolant accident, since loss of coolant in one pressure tube would not necessarily result in further losses.

The CANDU has proved safe and reliable in Canada for many years, although criteria for possible licensing in the United States have not been well defined.

FOREIGN BREEDER PROGRAMS

In addition to the United States, five other countries have major breeder reactor programs in progress: Britain, France, West Germany, Japan and the Soviet Union.¹² Other countries, especially Italy and India, have also indicated considerable interest in developing national breeder programs, while the Netherlands, Belgium, Switzerland and Luxembourg participate in breeder programs of other countries.

France, West Germany, and Japan are interested in breeder reactors for essentially the same reason: their lack of indigenous energy resources. Since the breeder reactor creates its own fuel, after initial reactor fueling these countries would have independent energy supplies.

While Britain and the Soviet Union have other indigenous energy sources available to them for the near future, they too are developing breeders to provide future options and to diversify their sources of fuels and energy. Britain has oil from the North Sea and substantial quantities of coal, and the Soviet Union is thought to have large quantities of fossil fuels. The leaders in these countries seem to feel that even with such resources, there is no guarantee of future resources for assured energy independence. The Soviet Union has the additional consideration that its fossil fuel resources are in the eastern part of the country, far from the western regions, where fuel is needed. Transportation costs make coal produced electricity expensive in the western part of the Soviet Union.

Following the lead of the U.S. breeder program, other nations too have concentrated on the LMFBR. No consensus has yet developed whether pool or loop types are preferable. It is clear that Britain, France, West Germany, and Japan consider the plutonium breeding LMFBR as the best option. There are reports that the Soviet Union regards LMFBR's as an interim measure until other nuclear power schemes, such as gas cooled breeders with a higher breeding ratio, fusion, and fusion-fission hybrids become commercially available there.

In April 1977, President Carter announced plans for redirecting the U.S. breeder program toward breeder reactors which do not produce plutonium, and called on other nations to reassess their breeder

¹² This review of foreign breeder programs is based upon the independent review made for the Congressional Research Service by Professor John LaMarsh. Since it was completed, the Rockefeller Foundation has published its report on international cooperation on breeder reactors which also provides substantial insight into these programs. Cf. John E. Gray et al. *International cooperation on breeder reactors*. New York: The Rockefeller Foundation, 1978, various pagings.

programs in light of the proliferation potential of plutonium. In general, these five countries have not been amenable to Carter's plan, since for three of them development of breeders is essential to their goal of energy independence. Some consider it arrogant for the United States, which is the world's most energy-consumptive country, with large indigenous energy supplies, to ask them to delay development of what they consider their best hope for energy independence. Although there is opposition to nuclear power abroad, it seems to be based less on proliferation, and more on concerns over reactor safety and how to deal with spent fuel.

In 1977 the United States initiated the International Fuel Cycle Evaluation (INFCE) study, to look into the other breeder concepts discussed in this report, as well as the use of thorium fueled reactors instead of those which operate on the plutonium cycle. Over fifty nations have agreed to participate in this study, including all the countries with breeder programs. But some of these countries have privately stated that regardless of INFCE results, they intend to continue their LMFBR programs. If INFCE should conclude that another breeder concept is more economical and safe, they would consider switching to that type of reactor, but only after some other country has paid for research and development to bring the new concept abreast of the LMFBR.

Table 12 shows what LMFBR's have been operated or are planned for these five countries.

TABLE 12.—FOREIGN LMFBR PROGRAMS

Country and name	Power ¹	Type ²	Type	Operating date
Britain:				
Dounreay.....	60 MWt; 15MWe.....	E	Loop.....	1963.
PFR.....	250 MWe.....	D	Pool.....	1974.
CFR.....	1300 MWe.....	C	Undecided..	Late 1980's.
France:				
Rapsodie.....	40 MWt.....	E	Loop.....	1967.
Phenix.....	250 MWe.....	D	Pool.....	1973.
Super-phenix. ³	1200 MWe.....	C	do.....	1982.
Germany:				
KNK II.....	21.3 MWe; 58 MWt.....	E	Loop.....	1977.
SNR-300. ³	300 MWe.....	D	do.....	1982.
SNR-2. ³	1300 MWe.....	C	do.....	1988.
Japan:				
Joyo.....	100 MWt.....	E	do.....	1977.
Monju.....	300 MWe.....	D	do.....	1984.
U.S.S.R.:				
BR-2/5/10.....	10 MWt.....	E	do.....	1956.
BOR-60.....	60 MWt; 12 MWe.....	E	do.....	1969.
BN-350.....	350 MWe.....	D	do.....	1973.
BN-600.....	600 MWe.....	D	Pool.....	1979.
BN-1600.....	1600 MWe.....	C	Undecided..	Late 1980's.

¹ MWe means megawatts electric, a unit of power. MWt means megawatts thermal, a unit of heat generation rate. Approximately 2.5-3 MWt yields 1 MWe.

² E=experimental; D=demonstration; C=commercial.

³ To be owned and operated by international utility consortiums.

BRITAIN

Following World War II, Britain embarked upon a nuclear program as a result of studies which forecast that shortages of reasonably priced fossil fuels might occur before the end of the century. At first British scientists developed MAGNOX reactors, fueled with natural uranium, moderated by graphite and cooled by carbon dioxide gas. Later, ad-

vanced gas reactors fueled with slightly enriched uranium were developed. By the early 1980's, it is expected that Britain will have about 11,500 MWe nuclear capacity in operation (about 14 percent of total British electrical capacity).

During the 1960's, a large number of electrical power plants were ordered in anticipation of growth in electricity demand. The demand did not materialize as predicted however, so no coal-fired electrical plants have been ordered since 1966, no new nuclear plants since 1970, and only four oil-fired plants since 1970. Nevertheless, the British government has decided to pursue an active LMFBFR development program.

Britain is one of three countries that has reached the demonstration phase in LMFBFR development. Its demonstration prototype fast reactor (PFR) began operation in 1974, and is estimated to have cost \$170 million (in 1974 dollars).

According to its own estimates, Britain has enough oil and coal to provide its energy needs through the end of the century, but energy supplies thereafter are questionable. With these energy sources, though, Britain does have time to reconsider its nuclear options in response to President Carter's request and appears in no special hurry to commercialize breeders.

During 1977 and early 1978, a debate took place in Britain over the expansion of nuclear reprocessing facilities at Windscale, on the northwest coast of Britain. Although the debate primarily concerned the advantages and disadvantages of reprocessing, it provided a forum for general views on Britain's nuclear program, present and future. Vocal opposition to nuclear power was delivered by environmentalists, but on May 15, 1978, Parliament voted 224-80 to approve expansion of the Windscale facility.

The Conservative Party supports breeder development because it believes the LMFBFR will lead to sustained economic growth and assured energy independence in the long-term future. The right wing of the Labor Party supports breeders because it feels a continued abundance of energy is necessary for British goods to remain marketable abroad, thus providing jobs at home. The left wing of the Labor Party, on the other hand, opposes breeders, and nuclear power in general, because of fears that its development will lead to a reduction in the number of coal mining jobs.

By the end of the 1977-78 fiscal year, the British Government will have spent approximately \$1 billion (440 million pounds) on LMFBFR development.

FRANCE

At the present time, France has seven gas cooled reactors and two light water reactors in operation, with a total capacity of approximately 3,000 MWe. France has ordered 24 more 900 MWe light water reactors which are in various stages of construction, as well as two 1,300 MWe light water reactors which are under construction. Supplying enriched uranium for these reactors will provide France with stockpiles of depleted uranium which can be used in LMFBFR's. France estimates that by using this depleted uranium, breeder reactors could supply France's electrical needs for over 100 years.

The French LMFBR program began in 1953, and its first experimental LMFBR began operation in January 1967. A demonstration LMFBR, Phenix, became critical in August 1973 (estimated cost—\$140 million, in 1971 dollars) and a commercial LMFBR, Super-phenix, is scheduled to begin commercial service in 1982. Super-phenix will be owned by an international utility company established in 1973, with participation of France (51 percent), Italy (33 percent), and SBK (a German, Belgian, Dutch, and British group) 16 percent. It is estimated to cost \$1.7 billion in 1982 dollars.

There is opposition to the development of nuclear power in France, as well as in several other European countries, and on July 31, 1977, a protest demonstration was held at the site of the Super-phenix reactor. Although the demonstration had been planned months in advance as a peaceful protest, violence erupted as a small group of the demonstrators attempted to occupy the site and clashed with French police. Over 100 persons were injured during the ensuing melee; one person died.

Despite the incident, the French government reaffirmed its commitment to development of breeder reactors. The President of France, together with a right wing coalition of parties representing more than half the French electorate, support breeder development, as does the French Communist Party which polls about 20 percent of the voters. The Socialist Party, however, has taken the position that nuclear development has progressed too quickly. In the last French election, the Socialist leader, Francois Mitterand, campaigned to delay further nuclear development. He was defeated.

WEST GERMANY

West Germany's only energy resource is coal, which is estimated to be sufficient for 25 more years at the 1973 level of consumption. At the beginning of 1978, Germany had eleven light water reactors in operation and fifteen more under construction or on order. By 1985, it is estimated that about 30,000 MWe of light water reactors will be on-line, or about 26 percent of the anticipated installed electrical capacity at that time.

In 1970, the KNK I reactor began operation, reaching its full power of 20 MWe in 1973. This reactor was designed only to study sodium technology, however, and was not a fast reactor. In 1974, the plant was shut down and the thermal core replaced by a fast core. The facility was then renamed KNK II, and reached criticality in October 1977, becoming Germany's first experimental LMFBR.

A demonstration facility, SNR-300, is under construction in Kalkar, in northwestern Germany, and is planned to begin operation in 1982. It will be owned and operated by SBK, a utility consortium with 70 percent German participation, 15 percent Dutch and 15 percent Belgian, and is expected to cost \$800 million (in 1978 dollars). A commercial facility, SNR-2, is planned for 1988 and will be owned by ESK, a consortium 51 percent SBK, 33 percent Italian, and 16 percent French.

The most vocal opposition to nuclear power in Europe is in Germany, and French officials have suggested it was German antinuclear forces that organized the demonstration at Super-phenix and precipitated

the violence there. Environmental opposition was a prime factor in revision of West German nuclear licensing laws which now require the applicant to prove that arrangements have been made for reprocessing spent fuel.

The West German Government, however, supports development of breeders because of lack of indigenous energy resources. In the summer of 1977, a West German official predicted that a 3- to 5-year moratorium would be placed on nuclear reactor development in response to opposition by environmentalist groups. In November 1977, however, the ruling Social Democrats, together with their coalition partner, the Free Democrats, decided to reject that moratorium request, but gave highest priority to developing coal and stressed that nuclear should only be used when it is clear that energy requirements cannot be met by coal.

JAPAN*

Japan has the highest dependence on imported energy sources of all the major industrial nations—85 percent. Its interest in developing breeder reactors is therefore quite evident. Currently, there are 25 light water reactors operating or under construction in Japan, for a total capacity of 18,000 MWe.

In the mid-1960's, Japan decided that to insure its future energy independence it would build breeder reactors, and selected the LMFBR as the concept to pursue. A decision was made to build an experimental LMFBR facility, Joyo, which achieved criticality in April 1977. A demonstration LMFBR facility, Monju, is scheduled for 1984 and is estimated to cost \$1 billion in dollars escalated to 1984. Japan is estimated to have spent approximately \$700 million on its LMFBR program to date.

SOVIET UNION

Although the Soviet Union is thought to have large reserves of fossil fuels, the Russians have pursued a breeder reactor program as vigorously as any of the other countries. Part of this is attributed to the location of fossil fuel reserves in the eastern part of the country, while needs are great in the western regions. The cost of transporting fossil fuels to the western areas makes such energy quite expensive. Also, the Soviet Government apparently is convinced that world supplies of uranium, oil and gas will be depleted in 50–75 years.

The Soviet Union is thought to have 22,000 MWe of nuclear power capacity either in operation, under construction, or on order, primarily light water reactors.

The first Soviet experimental LMFBR began operating in 1956—the BR-2 which used mercury as a coolant and was rated at 2 MWt. By the mid-1960's the Russians had concluded, like their American counterparts, that sodium was a preferable coolant, so the BR-2 was converted to sodium, uprated to 5 MWt and was redesignated the BR-5. Further modifications in 1965 led to its redesignation as BR-10, with a power of 10 MWt.

*No consideration is given in this report to the Japanese advanced thermal reactor (ATR), a heavy water concept which offers a flexible fuel cycle from plutonium "burner" to plutonium producer for breeder burners. The Japanese initiated full power operation of their FUGEN, a 165 MWe plant, on November 13, 1978.

In 1969, another experimental LMFBR, the BOR-60, began operation with a maximum power of 60 MWt. The Russians' first demonstration LMFBR, BN-350, began operation in 1973 near Shevchenko. The reactor is located near the Caspian Sea, and is used both to generate electricity and to supply heat to desalt water for residual use. The area surrounding Shevchenko is desert, and there is no fresh water other than that produced by the nuclear plant and a companion oil-fired plant.

Another LMFBR demonstration plant is now under construction, the BN-600, with a power rating of 600 MWe. The BN-350 and BN-600 reactors are notably different. The BN-350 features a loop type plant, while the BN-600 uses a pool type. Instead of suspending reactor components from an upper cover plate over the pool, BN-600 components will be supported from the bottom of the reactor. The reactor core also is relatively flat. This flatness, coupled with the unusually high-sodium temperature rise up through the core, will permit use of less sodium than in other LMFBR's, and may result in a higher breeding ratio.

Consideration has been given to constructing an LMFBR commercial facility sometime in the late 1980's, but there are no definite plans. The Soviet Union is also researching gas cooled fast breeders, since they have a higher breeding ratio than LMFBR's.

The Russians appear not as concerned with safety questions as their American counterparts. The maximum-credible-accident concept which is required for designing nuclear reactors in the United States, is not used in the Soviet Union. Safety measures such as containment buildings and exclusion areas are not used in that country. In contrast, however, special attention is paid to possible environmental consequences of nuclear reactors, such as thermal pollution, and care is taken to ensure that, for example, waterways do not become thermally polluted.

CHAPTER V. COMMERCIALIZATION OF ALTERNATE BREEDER TECHNOLOGIES—THE UTILITY ENVIRONMENT*

BACKGROUND

As an alternative to the LMFBR, which it finds unsatisfactory because of proliferation possibilities, the Carter Administration has proposed development of a number of alternative breeders. While the role of developing and demonstrating breeder technology is a function largely of Government investment, the decision on whether, how soon and what kind of breeder cycle may be chosen by the utilities for commercial application will lie with the utility management. Developing a technology will be of little use if it is not commercially viable. Thus, it is important to consider what factors are likely to influence utility decisions about nuclear power and breeders.

Among the variables in utility decision making are the growth in electric power demand, the share contributed by nuclear power, the amount of uranium resources, and capital, operating and fuel costs. Perhaps more important is the economic condition of the utility or utilities that may wish to build a nuclear power plant. Can they obtain the risk capital necessary to build such large and expensive facilities as breeder power plants would appear inevitably to be?

To aid in the analysis of these factors and their relative importance, the Congressional Research Service contracted for studies from two expert consultants, each with a broad but differing background in the utility industry. Louis H. Roddis, the author of the first paper, is a consulting engineer who was president of two large utilities, Pennsylvania Electric Co. and Consolidated Edison of New York, for 15 years. Richard L. Gordon is an economist at the Pennsylvania State University and has written several books and numerous studies of the utility industry.

ECONOMIC DIFFICULTIES

Any analysis of commercial considerations must begin with the industry as it stands today, although the decision on building commercial breeders probably will not be made for some time. Both Roddis and Gordon concluded that if the numerous difficulties facing electric utilities today go unresolved, it is unlikely that new nuclear power technologies, no matter how promising, will be adopted. Roddis, in fact, concluded that not even conventional light water nuclear systems, much less alternative breeders, will be ordered in adequate numbers to operate in the post-1988 period; and he added, "[T]his situation will not improve until major changes have reestablished the stability of the licensing and financial processes."

*Prepared by Carl E. Behrens, Analyst in Environmental Policy.

Instability has been a major characteristic of the electric utility industry since the 1973 oil embargo; as Gordon's study documents, its problems began earlier, with the rise of the environmental movement in the late 1960's. Prior to that time, the electricity industry had been growing at a rate faster than the growth in the gross national product and in energy consumption, and utilities were looked on as "steady, reliable ventures that would rarely face serious disturbances." The cost of producing electricity was declining in real terms, as was the price of oil. New additions to generating capacity were generally more efficient than the existing facilities. As a result, if overoptimistic projections of future growth caused excess capacity, the surplus capacity could usually be sold to other utilities at attractive prices, or savings could be achieved by retiring older, inefficient facilities. The utilities were subject to regulation, but in an era of decreasing costs and rapidly growing markets, regulation was no burden.

The contrast between that earlier period of stability and growth and the present situation of the electric utility industry could hardly be greater.

ENVIRONMENT AND EMBARGO

The developments that have contributed to the current difficulties began with the environmental movement of the late 1960's and the consequent massive involvement of the Federal Government in questions of power plant siting, design, and environmental effects. This Federal involvement in an area that had formerly been largely a matter of State and local control (except for the minor interest of the Federal Power Commission in some rate structures) was augmented by the Federal regulation of commercial nuclear power, since licenses for construction and operation of nuclear plants had to be obtained from the U.S. Atomic Energy Commission.

The environmental regulations affected the climate in which utilities had to operate. The Arab oil embargo and the astronomical rise in oil prices that accompanied it revolutionized the industry.

Electricity consumption grew hardly at all during 1974 and 1975. As a result, utility cash flow was reduced below expectations and caused most utility stocks to fall sharply, making it difficult for them to obtain capital on the equity market. At the same time, construction costs were going up, and a capital shortage made it extremely expensive for utilities to obtain construction money by issuing bonds. Electricity prices increased rapidly as a result of fuel adjustment clauses, which allowed utilities to pass through the higher fuel costs directly to the consumer without requiring regulatory approval of changes in the rates. The result was a reluctance on the part of utility regulators to grant rapid rate increases to compensate for increases in other costs—particularly since the rate increases would go to fund capacity that would not come on line for a substantial number of years.

All these factors produced a financial squeeze on most utilities that could only be relieved by deferring or cancelling planned construction of future generating capacity. Even if the growth rate of electricity consumption had not dropped, the financial status of utilities with large construction plans would probably have required these deferrals.

The economic situation has stabilized slightly since the disastrous

years of 1974 and 1975. Economic recovery in 1976 was accompanied by a growth in electric power consumption of 6.2 percent, and in 1977 a somewhat smaller 4.9 percent. Inflation and interest rates, although still threatening, are less than they were during the "stagflation" years, and utility rate increases have compensated for much of the higher cost of those years. Utility stocks have recovered to a degree from the lows of that period.

Nevertheless, financial problems remain and the situation of the utility industry is not encouraging. The main feature of these problems is a much higher level of uncertainty in estimates for future demand and the ability to supply it, which complicates the planning process and makes it more difficult to obtain capital for future construction.

FOUR KINDS OF UNCERTAINTY

LOAD GROWTH

One form is uncertainty in future demand. The variability of demand since the oil embargo, and the indecisiveness of national energy policy regarding electricity's role in the future, have made it more difficult to project demand more than about five years, a time formerly reasonable for construction planning. At the same time, because of longer construction time for nuclear and coal power plants, the projection must extend 10 years or more. Unfortunately, the facilities that can be constructed rapidly and with lower capital investment are those fueled with oil or natural gas, which are now regarded as unsatisfactory fuels because of increasing price or doubtful availability. The alternatives, coal and nuclear power, appear to require increasingly longer times to bring on line.

Furthermore, the consequences of overestimating, or underestimating, future load growth have increased. Since nuclear plants are large and expensive, they come on line in large units, reducing the utility's flexibility to adjust to short-term variations in load growth. If the new unit pushes the utility's reserve capacity too high, it is burdened with a large capital investment on which it is gaining no return—an effect that is augmented by the fact that in nuclear power the economies of the technology lie in the low cost of fuel, and are only realized if the plant is operated. Nor does it help to delay putting the unit into service, since the utility can generally only recover its capital investment through rates once the unit is operating and part of the rate base.

If delays or misjudgment of load growth leave the utility with too little capacity, it must either operate units that may be expensive to run, such as oil-fired generators, or buy the power from elsewhere, which again may mean buying expensive electricity.

SCHEDULING

Construction times are extremely uncertain, particularly with nuclear units and increasingly with coal-fired plants. There is at present no way of determining how long it takes to build a nuclear unit, because the deferrals in construction schedules of the last several years have been caused mostly by financial difficulties or reductions in the

estimates of future load growth. There is no doubt, however, that in many cases opposition and regulatory difficulties have added to construction times. Planning for future plants in light of experience so far involves serious uncertainties which may or may not be reduced in the coming years.

COSTS

Another uncertainty lies in estimates of the cost of new units and of alternatives to new units. A major factor is the possibility of delays in construction, for the various reasons cited above, which in the presence of rapid inflation and high costs of capital can have a very large effect on the ultimate cost of the unit. This tends to overshadow to an indeterminate extent the cost advantages that a utility may expect to gain from choosing nuclear power over an alternative technology. Uncertainty about the future price of alternative fuels, such as oil or coal, also contributes to the difficulty of estimating relative costs.

NATIONAL POLICY

A fourth area of uncertainty lies in the role of electricity in the evolving national energy policy. Events since the oil embargo indicate that the historical growth of the 1950's and 1960's will not resume. But it is not clear what that growth rate will be, or how it will be influenced by national policy. The attitude of many policy makers toward electricity is equivocal. On the one hand, electricity produced from nonpetroleum fuels would appear to have a strong role to play in achieving a major goal of national energy policy, which is to reduce U.S. dependence on imported oil. However, there are numerous forces in opposition to rapid substitution of electricity for petroleum fuels. Higher costs of electricity are a major factor. Combined with active consumer resistance to increasing rates, financial factors have already caused substantial slowing down of construction of new capacity, and this trend can be expected to continue. There is additional challenge to the concept of centralized power stations and large electric power grids, as opposed to small decentralized units based principally on solar power. Electricity produced by fossil fuels is also questioned because of the large energy losses involved in the conversion, compared to the direct use of these fuels to produce heat or mechanical energy. This questioning is sometimes extended to all sources of electricity, including uranium or hydropower, where the comparison is meaningless because of the nonutility of these sources for any other purpose. All these factors contribute to an uncertainty in the future role of electricity in the national energy economy that is one of the most difficult problems facing the industry.

BREEDERS IN CONTEXT

The complex difficulties summarized above largely overshadows other questions involved in the commercialization of breeder reactors, such as availability of uranium and technical distinctions between various proposed types of breeders.

It also explains the rather equivocal approach to the debate over the LMFBR shown by the industry. Electric utilities must take a relatively short-term view of future investments, since it is difficult indeed

to justify investment in facilities that will begin returning that investment beyond five or ten years in the future. So breeder reactors are unlikely to be a practical part of utility planning. Moreover, the debate over nuclear energy has raised strong doubts about the future of any kind of nuclear power technology, including the present light water reactors. With plants designed to operate for 30 or 40 years, any utility is interested in the long term viability of the nuclear industry—the designers and vendors of reactors and their component parts and associated plant equipment. Without a reasonable prospect of extended return in the nuclear business—which appears to require a firm promise of some form of breeder reactor—that viability is seriously in question.

As Gordon points out, whether or not the current problems of the utility industry are “largely transitional ones that will be resolved by the time the breeder is perfected, remains to be seen.” Roddis suggests several steps that might be taken in that direction. A major one, to strike at the uncertainty about future load growth and the future role of electricity, would be to establish firm national electric capacity goals for 20 years ahead. Other steps would improve the climate for construction of nuclear power plants and give positive national recognition of the need for stable financial climate for utility investment.

BREEDER OPTIONS

Even assuming that such measures are adopted and at least alleviate the industry's problems to the extent that utilities are able to consider choosing between breeder options in the next decade or so, it is clear that the choices will still be influenced significantly on the criteria of predictability and lack of uncertainty. Roddis' review of the various breeder options, summarized in Table 13, indicates that the LMFBR and the light water breeder reactor (LWBR) would have substantial advantages in this regard.

Among the alternate breeders, industry has had the most experimental experience with the LMFBR, which also offers the prospects of a supply of fertile materials in the depleted uranium from enrichment facilities. However, the Administration opposes demonstration of the LMFBR at this time and the prospects of licensing this technology are judged poor.

For the LWBR, estimates of fuel costs are good, licensing predictability is probably better than for the LMFBR, and the Administration's policy is favorable. Industry has limited experience with the technology, however, and there is only limited mining and production of thorium. Moreover, until a working inventory of uranium-233 could be built up, the LWBR's initially would have to be fueled with highly enriched uranium. Producing the uranium-233 also would require use of reprocessing plants, which would be contrary to the Administration's current nonproliferation policy.

The high temperature gas cooled reactor (HTGR) system has advantages and disadvantages from a utility point of view. Utilities have had moderate—although not very encouraging—experience with the technology, and one medium-sized plant has already been licensed. But it too depends on successful use of thorium and uranium-233.

The Canadian CANDU system, both in its present uranium-fueled version and in the proposed advanced thorium-recycle mode, has some advantages, including fairly well known cost estimates, but even the uranium system used in Canada at present would require modifications to be licensable in this country, according to Roddis.

Other systems, including the advanced gas reactor (AGR) being developed in Britain and the water cooled graphite reactor, seem unlikely to be used in this country, while the molten salt reactor and fusion power, with their many unknowns, are at the bottom of alternatives of interest to utilities.

TABLE 13.—COMMERCIAL CHARACTERISTICS OF ALTERNATIVE NUCLEAR CYCLES

System	PWR/BWR uranium- once through	PWR/BWR uranium- plutonium recycle	CANDU uranium- once through	GCR uranium- recycle	AGR uranium- recycle	Water-graphite uranium-once through
U.S. policy, currently (1978)	Favorable	Unfavorable	Favorable	Unfavorable	Unfavorable	Favorable.
Reactor:						
Commercial units operating, under construction, or ordered, United States.	216	0	0	0	0	0. ²
Commercial units operating, under construction, or ordered, other countries.	0	188	34	44	11	10.
U.S. utility knowledge status	Extensive	Extensive	Limited	Limited	Limited	Limited.
U.S. licensing status	Known—Long	Known—Long	Changes required	Obsolete	Changes required	Known.
U.S. equipment suppliers	Available	Available	None	None	None	Available.
Capital cost estimates in United States, accuracy	Good	Good	Fair	Fair	Fair	Good.
Operating cost estimates in United States, accuracy	Good	Good	Fair	Fair	Fair	Good.
Fuel cycle:						
Mining, milling, processing, facilities, world	Extensive	Extensive	Extensive	Extensive	Extensive	Extensive.
Enrichment facilities, world	Extensive	Extensive	Not required	Not required	Not required	Not required.
Licensed reprocessing plants, United States	Not required	Not required	Not required	Not required	Not required	Not required.
Licensed reprocessing plants, other countries	Not required	5	Not required	5 ¹	5	Not required.
Fuel cycle cost estimates in United States, accuracy	Good	Fair	Good	Fair	Fair	Good.
Radioactive waste storage, long term, United States	Not required	0	0	0	0	Few.
Long term spent fuel storage, United States	0	Not required	0	Not required	Not required	Not required.
Year next commercial new power unit could be in service in United States if major changes in stabil- ity of financing and planning process were achieved by 1979.	1990	1990 (1995 fuel cycle)	1995	Obsolete	2000 unlikely choice economically.	1990 unlikely choice economically.

¹ Some foreign reactor fuel probably being reprocessed for military programs.² DOE-owned N-Reactor at Hanford, WA., feeds into commercial grid.

Source: L. H. Roddis.

ABLE 13.—COMMERCIAL CHARACTERISTICS OF ALTERNATIVE NUCLEAR CYCLES—Continued

System	HTGR thorium recycle	LWBR thorium breeder	CANDU thorium recycle	LMFBR uranium breeder	GFR thorium breeder	MSR thorium breeder	Fusion
U.S. policy currently (1978)	Favorable	Favorable	Favorable	Unfavorable	Favorable	Favorable	Future.
Reactor:	1	0 ¹	0	1	0	0	0.
Commercial units operating, under construction, or ordered, United States.							
Commercial units operating, under construction, or ordered, other countries.	0	0	0	6	0	0	0.
U.S. utility knowledge status	Moderate	Limited	Limited	Extensive	Moderate	Limited	Limited
U.S. licensing status	Known	Known-long	Unknown	Deferred	Unknown	Unknown	Unknown.
U.S. equipment suppliers	Available	Available	None	Available	Available	Unknown	Unknown.
Capital cost estimates in United States, accuracy	Good	Good	Fair	Fair	Unknown	Unknown	Unknown.
Operating cost estimates in United States, accuracy.	Good	Good	Fair	Fair			
Fuel cycle:							
Mining, milling, processing, facilities world	Very limited	Very limited	Very limited	Extensive	Very limited	Very limited	Not required.
Enrichment facilities, world	Not required	Not required	Not required	Not required	Not required	Not required	Not required.
Licensed reprocessing plants, United States	0	0	0	0	0	0	Not required.
Licensed reprocessing plants, other countries	0	0	0	5	0	0	Not required.
Fuel cycle cost estimates in United States, accuracy.	Fair	Fair	Fair	Fair	Fair	Unknown	Unknown.
Radioactive waste storage, long term United States.	0	0	0	0	0	0	0.
Long term spent fuel storage, United States	Not required	Not required	Not required	Not required	Not required	Not required	Not required.
Year next commercial new power unit could be in service in United States if major changes in stability of financing and planning process were achieved by 1979.	1995 (2000 fuel cycle)	1995 (2000 fuel cycle)	2000	1995	2010?	2010	?

¹ DOE-owned Shippingport, PA. reactor feeds into commercial grid.

CHAPTER VI. PROLIFERATION CONSIDERATIONS

The central reason to develop alternative breeder technologies is to provide some way of recovering more of the potential energy of uranium and thorium resources without running the proliferation risks seen in plutonium recycle in conventional reactors and commercialization of breeder reactors that involve the presence of separated and easily accessible plutonium at various points of the nuclear fuel cycle.

Alternative breeders and their fuel cycles are being reexamined by Federal agencies and by the International Fuel Cycle Evaluation to see whether or not any of them can offer both improved recovery of the energy contained in uranium and thorium and acceptable proliferation risks. It is an immutable fact of life that any nuclear power system which attempts to tap the potential energy of uranium-238 and of thorium inevitably must create plutonium and uranium-233 which, if separated from other materials, are directly usable to make nuclear weapons or explosives. Nuclear technology can offer no absolute assurance, short of fissioning these materials as soon as possible, that someone, somewhere, under some circumstances not now imaginable, will not be able to get at these materials and to use them. On the other hand, the risks of proliferation can be reduced by technical and institutional measures to make theft or diversion of weapons-usable materials more dangerous, difficult or likely to be detected, and to provide timely warning of such acts. Whether or not the risks of various breeder alternatives can be kept lower than those of the conventional plutonium breeder and comparable to those of light water reactors with terminal storage of spent fuel is a subjective matter given to widely differing opinions. Additionally, it seems probable that some measures designed to keep proliferation risks low will be criticized as oppressive of civil liberties and dangerous to the health and safety of workers in nuclear industries.

To prepare the way for the discussion of proliferation risks of alternative breeders in the next chapter, there follows a discussion of the linkage seen between nuclear power and nuclear weapons, the spectrum of proliferation risks, the sources of nuclear explosive materials, the presumed ease of making such devices, and the idea that alternative breeders can offer a technological fix to keep proliferation risks within acceptable limits.

THE LINKAGE OF NUCLEAR POWER AND NUCLEAR WEAPONS

The perception of a linkage between nuclear power and nuclear weapons has been an enduring feature of the nuclear age. At the outset the United States in its proposals for the control of nuclear energy to the United Nations Atomic Energy Commission in 1946 posited a linkage strong enough to justify a radical proposal for international management and control of nuclear energy. When this proposal failed,

the United States tried to keep the secrets of the atom bomb and extended that secrecy to the early development of nuclear power. Secrecy failed to keep the Soviet Union and Great Britain from developing and testing their own weapons. So in 1953 President Eisenhower in his Atoms for Peace speech to the United Nations proposed international cooperation in national development of nuclear energy subject to some international inspection and verification. By the early 1960's, commercial nuclear power was well enough along to revive the fear that the associated spread of nuclear materials and facilities to produce them had transformed the linkage between nuclear power and weapons from academic to practical reality. Out of this came the U.S. initiatives that culminated in the Treaty on Non-Proliferation (NPT). In this political solution, nonnuclear weapons states that ratified the treaty agreed to forego development of nuclear weapons and explosives and to place their nuclear activities under international inspection in return for access to nuclear power and a commitment of the nuclear weapons states (the United States, the United Kingdom, and the Soviet Union) to work for nuclear disarmament. The NPT deems the linkage between nuclear power and nuclear weapons to be controllable and its risks acceptable. By the mid-seventies, perception of the linkage had changed. Now, as noted above, stronger and more direct linkage is seen. National possession of a nuclear industry, especially one that produces separated plutonium or highly enriched uranium, raise spectres that terrorists or other subnational groups may successfully steal nuclear materials and make them into crude but usable nuclear explosives or that governments whose nuclear industries hold inventories of separated plutonium or highly enriched uranium might seize these materials and in weeks or days have workable nuclear explosives in hand.

THE SPECTRUM OF PROLIFERATION RISKS

Diversion or theft of nuclear materials from commercial nuclear power is one of several ways for a nation to acquire nuclear weapons. Theft is probably the only way for subnational groups to get nuclear explosives. The risks of proliferation lie along a spectrum that includes the following:

- (1) Theft of nuclear weapons by governments or subnational groups;
- (2) Theft of nuclear explosive materials from nuclear weapons factories;
- (3) Loss of control over nuclear weapons in a coup or political disorder;
- (4) Clandestine production of nuclear weapons materials;
- (5) Theft or diversion from commercial nuclear power facilities of nuclear materials not directly useful for nuclear weapons but useful as a source of such materials;
- (6) Theft or diversion from commercial nuclear power facilities of nuclear materials directly usable to make nuclear weapons;
- (7) Production of nuclear explosives for "peaceful purposes" by nuclear-weapons states, or by non-nuclear-weapons states that have not made the NPT commitment to abstain from producing such devices; and

(8) Overt development and manufacture of nuclear weapons by states that now do not have them.

Considering this range of risks, one relevant question for deciding the future of advanced nuclear power technologies and their fuel cycles is not whether there is any risk, but rather how that risk compares with other risks. At the moment, the U.S. policy accepts risks (1) through (5). The President accepts the "once-through" nuclear fuel cycle with its use of natural or slightly enriched uranium, coupled with terminal storage of spent fuel—without reprocessing—in safeguarded facilities, and has indicated approval of uranium-233 mixed with uranium as a fuel. He draws the line, however, at the commercial production of separated plutonium for nuclear fuel. Here, then, is the implicit basic criteria of the administration: how do various advanced nuclear fuel cycles compare in proliferation risks with those that are now acceptable?

THE PRESUMED EASE OF MAKING NUCLEAR EXPLOSIVES

Notable for the debate over nuclear power and the spread, or proliferation, of nuclear weapons in the mid-1970's is the presumption that it is credible that a few terrorists, criminals, or extremists with some scientific and technical training but no prior experience in designing or making nuclear warheads or explosives, can successfully design and build such devices in secret without discovery. A powerful example of this presumption is to be found in Senator Glenn's remarks in opening recent hearings on nuclear terrorism at which he said in part:¹³

It is mind-boggling to even consider the prospects of nuclear weapons being possessed by . . . terrorist groups, but what may be unthinkable to some must be faced in order that we may protect humanity from this potential threat.

* * * * *

For if a terrorist or terrorist group can achieve a nuclear capability, then that capability is within the grasp of every country on earth. And who will doubt the serious national security implications of that situation.

For many years, there has been an ongoing debate within the nuclear community in the United States concerning the question of how easy it is to design and construct nuclear explosive devices. It is obvious that . . . the resolution of this debate presents ramifications for safeguards which are of utmost importance to everyone.

In other words, if the mechanical equipment of a bomb is available, the only lacking ingredient for a truly workable bomb is uranium enriched to weapons grade or plutonium.

* * * * *

If such material becomes available to unauthorized groups, we can no longer take any comfort from the fact that their nuclear weapon may never get built or may turn out to be a dud; we must assume it will work;

* * * * *

The relative ease with which nuclear weapons could be illegally made from these . . . materials means, however, that our only true bulwark against their malevolent use are the safeguards measures which have been implemented to prevent their falling into the wrong hands.

Additional information about the making of nuclear weapons or explosives appears in appendix II.

¹³ Senator Glenn chaired hearings on nuclear terrorism for the Committee on Governmental Affairs, March 22 and 23, 1978.

MATERIALS FOR NUCLEAR WEAPONS AND EXPLOSIVES

The highest proliferation risk associated with civil nuclear power is the presence of nuclear materials which if diverted or stolen could readily be used to make a nuclear weapon or explosive. Other risks include the creation of a trained body of nuclear scientists and engineers whose skills could be tapped to make nuclear weapons and to create an industrial base capable of supplying materials and equipment needed to launch a nuclear weapons program. The latter risks are common to all nuclear power systems. The first is the basis for concern about commercial reprocessing and demonstration of the plutonium breeder.

Nuclear materials directly usable to make nuclear weapons and explosives do not exist in nature. They have to be made. Those of greatest risk include uranium highly enriched with uranium-235, uranium-233 and plutonium. None of these are used as fuel for light water reactors. All might be used to fuel one or another kind of breeder reactor. Table 14 lists various forms of nuclear materials and indicates their usability to make nuclear weapons or explosives. The risks are greatest for nuclear materials in metallic form, and are somewhat less for those in chemical form such as oxides or nitrates which are to make nuclear fuel elements. The risks are much less for materials contained in spent fuel. Among materials that are indirectly usable, those presenting the most risk contain nuclear materials which can be extracted by simple chemistry. The risk is less for materials that would require reprocessing or enrichment. Table 15 lists nuclear materials likely to be found in alternative breeder fuel cycles.¹⁴

TABLE 14.—USABILITY OF NUCLEAR MATERIALS FOR NUCLEAR WEAPONS OR EXPLOSIVES

Material and form	Usability		Processing required
	Direct	Indirect	
Plutonium:			
Metal.....	Yes.....		
Oxide.....	Possibly.....	Yes.....	Chemical separation.
Oxide with uranium in nuclear fuels.....	No.....	Yes.....	Do.
Oxide or other forms in spent nuclear fuels.....	No.....	Yes.....	Reprocessing.
Thorium: Ore, metal, chemical forms.....	No.....	No.....	
Uranium-235:			
Normal ore, metal, chemical forms.....	No.....	No.....	
Slightly enriched (3-6 percent) metal.....	No.....	Yes.....	Chemical processing to produce uranium hexafluoride for enrichment to weapons grade.
Oxide in nuclear fuels.....	No.....	Yes.....	Do.
Oxide or other forms in spent nuclear fuels.....	No.....	Yes.....	Reprocessing, chemical processing and enrichment.
Moderately enriched (20 percent) metal.....	Unlikely.....	Yes.....	Chemical processing and enrichment.
Oxide.....	do.....	Yes.....	Do.
Oxide in nuclear fuels.....	No.....	Yes.....	Do.
Oxide or other forms in spent nuclear fuels.....	No.....	Yes.....	Reprocessing, chemical processing and enrichment.
Highly enriched (90 percent):			
Metal.....	Yes.....		
Oxide.....	Yes.....		
Oxide in nuclear fuel.....	No.....	Yes.....	Chemical separation.
Oxide or other forms in spent nuclear fuels.....	No.....	Yes.....	Reprocessing.
Uranium-233:			
Metal.....	Yes.....		
Oxide.....	Yes.....		
Oxide in nuclear fuels.....	No.....	Yes.....	Chemical processing and enrichment.
Oxide or other forms in spent nuclear fuels.....	No.....	Yes.....	Reprocessing, chemical processing and enrichment.

¹⁴ Additional information on nuclear explosive materials appears in appendix II.

TABLE 15.—NUCLEAR MATERIALS IN ALTERNATIVE BREEDER FUEL CYCLES

Material	LWR with no recycle	LMFBR	GCFR	LWBR	MSBR	HWBR
Thorium		Possibly	Possibly	X	X	X
Uranium-238	X	X	X			
Uranium-235:						
Slightly enriched (3-6 percent)	X					Possibly
Moderately enriched (20 percent)		Possibly	Possibly			
Highly enriched (90 percent)		X	X			
Plutonium	(1)	X	X			
Uranium-233		Possibly	Possibly	X	X	X

¹ In spent fuel only.

Note: LWR=light water reactor. LMFBR=liquid metal fast breeder reactor. GCFR=gas cooled fast breeder reactor. MSBR=molten salt breeder reactor. HWBR=heavy water breeder reactor. LWBR=light water breeder reactor.

ALTERNATIVE BREEDER CYCLES AS A TECHNOLOGICAL FIX

There are two fundamentally different approaches to preventing the further spread of nuclear explosives and the ability to make them. One is to turn to political measures to reduce the motivation for States or organizations to acquire such devices, and to new kinds of organizations or institutions, to prevent, detect and react to threats of proliferation. The other is to change the technology of nuclear power generation to avoid or to minimize the use of nuclear materials which if stolen or diverted can quickly be made into nuclear explosives or weapons. The following analysis deals essentially with the second approach, in particular with the development of alternative breeder cycles.

As noted earlier, alternative breeder cycles are not new ideas. The former Atomic Energy Commission funded research and development for many years on many ways of using uranium-238 and thorium as sources of nuclear fuels. By the 1960's, the plutonium breeder led the technological race in the United States and support for other approaches began to dry up. The underlying assumption at that time, particularly when the Nuclear Non-Proliferation Treaty was being negotiated in the late 1960's, was that plutonium breeder reactors would be used and that plutonium, uranium-233 and even highly enriched uranium-235 would be used commercially for nuclear fuel without unacceptable risks of proliferation. By the closing days of President Ford's administration, this salient feature of U.S. non-proliferation thinking was challenged, although President Ford did not defer demonstration of the plutonium breeder. The solution advanced by President Carter and his new administration was to put off reprocessing of spent fuels and demonstration of the breeder, so as to minimize further the use of separated plutonium.

The risks of proliferation, however, are not tied to possession of separated plutonium alone. Some see a growing risk in an increasing world inventory of plutonium contained in spent fuel. A leading spokesman for this viewpoint, Dr. Walter Marshall, Deputy Chairman of the United Kingdom Atomic Energy Authority, holds that using thermal reactors in a once-through fuel cycle is not a satisfactory nonproliferation policy because, in essence, every nuclear fuel storage facility, wherever it may be, becomes a "plutonium mine."¹⁵ In effect,

¹⁵ Walter Marshall. Nuclear power and the proliferation issue. *Atom.* April 1978, p. 84.

a storage policy can set off a "proliferation time clock" as the protective radioactivity of spent fuel decays:¹⁶

* * * With this policy every nation with a nuclear power plant and a spent fuel element storage facility has set up a target for plutonium diversion and has established an option to construct weapons in ways that are easier and easier to operate as the stored plutonium becomes associated with less and less radioactivity.

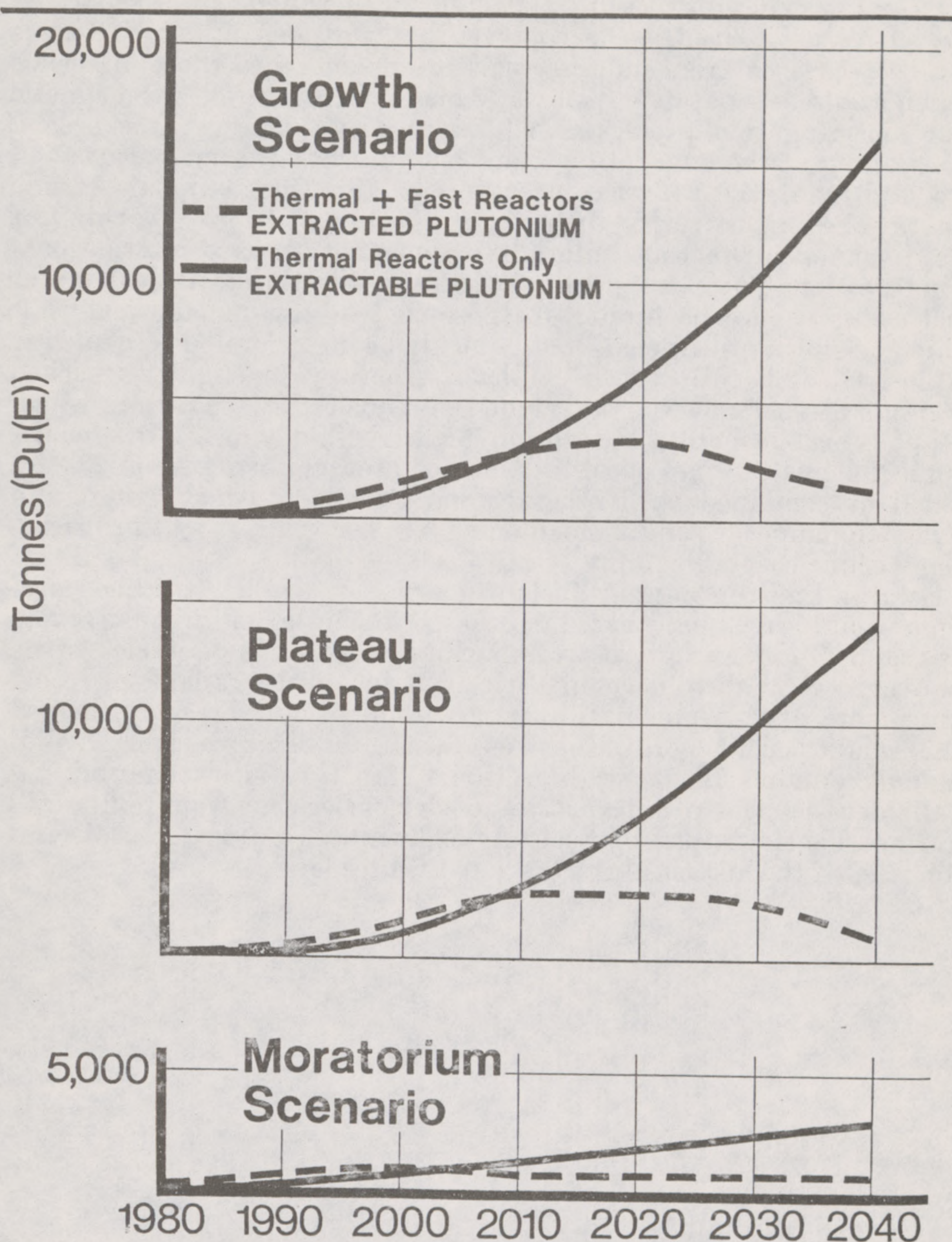
The real proliferation problem, for him, is to retrieve spent fuel from scattered storage facilities. Whether the fuel is then reprocessed or not is not a proliferation issue but one for environmental and economic consideration. The crucial matter is to know exactly where the plutonium is and, if it is not associated with high radioactivity—that is, if it is "extractable"—to have it in as few locations as possible.

The once-through fuel cycle with terminal storage could dramatically restrict the availability of plutonium if two conditions hold. First, the plutonium in the spent fuel must be inaccessible for an indefinite length of time; second, the spent fuel be kept in a few storage centers under international control. Otherwise, Dr. Marshall would opt for use of fast breeders operated to burn up plutonium as fast as it is produced. To make this point, he postulated three scenarios for nuclear energy into the middle of the next century. One was a growth scenario in which world use of energy and nuclear power would continue to grow. The second was a plateau scenario in which energy use continues to grow, but nuclear generating capacity levels off at a total world capacity of 2,500,000 megawatts. The third was a moratorium scenario in which total world nuclear capacity is held to 350,000 megawatts.¹⁷ For each scenario he estimated the world total for extracted plutonium in use in thermal and fast reactors and the total amount of extractable plutonium in spent fuel from nuclear power limited to thermal reactors. The resulting curves, shown in Figure 7, illustrate his proposition that if thermal reactors alone are used, the world inventory of "extractable" plutonium would continue to grow, with more and more of it becoming extractable as the radioactivity of spent fuel decays. On the other hand, the introduction of fast reactors could control the total world plutonium inventory and greatly limit the inventory of "extracted" plutonium. From a nonproliferation view, both are highly desirable.

¹⁶ Ibid.

¹⁷ According to Dr. Marshall, the growth scenario is reasonable, the plateau scenario is an unreasonable assumption and the moratorium scenario is an irresponsible assumption.

EXTRACTABLE WORLD PLUTONIUM



Notes:

- (1) For illustrative purposes only it is assumed that spent fuel falls into the "extractable" category after 5 years cooling.
- (2) In the case of the thermal and fast reactor there is no "extractable" plutonium. All fuel, both thermal and fast, is reprocessed at less than 5 years cooling.
- (3) It will be observed that up to about 2008 the amount of "extracted" plutonium in the fast reactor and thermal reactor case somewhat exceeds the amount of "extractable" plutonium for the "thermal reactor only" case. The reason for this is that for the particular case studied prompt reprocessing after 9 month delay is assumed. Thus, the plutonium is separated from its radioactivity early and placed into store. In practice, thermal reactor fuel is not being processed at such an early date and the thermal + fast reactor case will not cross the "thermal reactor alone" curve. It should also be noted that by carefully optimizing the introduction of the fast reactor, the amount of "extracted" plutonium can be considerably reduced compared with the case studied.

Source: Walter Marshall. Nuclear power and the proliferation issue. Atom., April 1978, p. 92.

FIGURE 7

Other nuclear fuel materials, notably uranium-233 and highly enriched uranium, also can be used to make a nuclear explosive, and some nuclear fuels contain these materials in forms which can be separated by chemistry. Recently the concern that weapons usable materials can be recovered from nuclear fuels has extended to those materials which would be separated by physical methods, notably electromagnetic and centrifugation processes. Adding to these concerns has been a questioning of the nonproliferation commitments of some nations and the ability of the safeguards system of the International Atomic Energy Agency to verify such commitments and to give warning of the diversion of nuclear materials in time for effective international counteraction. These fears lead to the proposition that nuclear power fuel cycles should be limited to those that do not include materials which, if stolen or diverted, could quickly be incorporated into nuclear explosives. This proposition emphasizes natural or slightly enriched uranium as fuel and would exclude those nuclear fuel cycles in which weapons-usable materials occur in readily usable forms. It becomes vague for nuclear fuel cycles in which plutonium or uranium-233 are mixed or combined with other things intended to make theft and diversion dangerous and difficult enough to keep the risks of proliferation within acceptable limits.

Because limiting nuclear fuels to natural or slightly enriched uranium would leave unrecovered most of the potential energy in uranium ores, and might exclude use of thorium as a source of nuclear fuel, there are proposals to develop alternative fuel cycles capable of recovering more of this potential energy without use of breeder reactors. This would permit more efficient use of natural resources while avoiding unacceptable risks of proliferation. Competing with such proposals is the development of alternative breeder cycles that would offer still greater efficiency in use of nuclear fuels while avoiding the proliferation risks of the historical approach to the breeder.

CHAPTER VII. PROLIFERATION RISKS OF ALTERNATIVE BREEDER CYCLES*

The dominant reason for current interest in alternative breeder fuel cycles is not efficiency in use of nuclear fuel resources, or economics, or safety, or environmental effects, but rather the risk seen that commercial use of the plutonium breeding fuel cycle featuring separated plutonium at various places will unacceptably increase the risks of the further spread of nuclear weapons or explosives and the ability to make them. Alternatives to the unmodified plutonium breeder are being examined in the United States and in the International Nuclear Fuel Cycle Evaluation to see which fuel cycles can get more energy out of uranium and thorium than the once-through cycle while still keeping proliferation risks within acceptable limits.

The purpose of this chapter is to summarize and compare the proliferation risks of the once-through nuclear fuel cycle with leading alternative breeder fuel cycles. The comparison draws heavily upon two sources: first, the landmark report on nuclear proliferation prepared for Congress in 1976 by the Office of Technology Assessment (which is summarized in appendix III) ; and, second, upon an analysis of the comparative proliferation risks of different types of breeder reactors prepared for the Congressional Research Service by E. R. Johnson Associates, Inc., and funded by the Committee on Science and Technology.¹⁸

FUEL CYCLES FOR ALTERNATIVE BREEDERS

A convenient way of seeing how the different kinds of nuclear materials would attend commercial use of alternative breeder fuel cycles is to examine their respective fuel cycles. Figure 8 shows the basic elements for nuclear power fuel cycles from the mining of uranium to the terminal storage of radioactive wastes and indicates the kinds of materials to be found at different points. The industrial establishments implicitly present in a fuel cycle would vary from country to country and by type of reactor. In the United States many of the fuel cycle steps are performed in privately owned establishments scattered throughout the country, with a consequent flow of different nuclear materials in interstate commerce. Table 16 shows the kinds of nuclear materials likely to be found at different parts of the fuel cycles for five alternate breeder cycles, in comparison with the light water reactor fuel cycle without recycling. The more directly usable a nuclear

*Prepared by Warren H. Donnelly, Senior Specialist.

¹⁸ E. R. Johnson Associates, Inc. Comparative proliferation risks of breeder reactor types. A report prepared for the Congressional Research Service of the Library of Congress, 1978, various pagings. The purpose of the Johnson study was to analyze the different aspects of alternative breeder reactor concepts and associated fuel cycles to compare the proliferation risks associated with each. It also analyzed the current status of safeguards activity of the U.S. Government and of the International Atomic Energy Agency.

material is for nuclear weapons or explosives at any point of a fuel cycle and the greater its quantities, the more vulnerable that point is deemed to be to diversion or theft.

BASIC ELEMENTS OF NUCLEAR POWER FUEL CYCLES

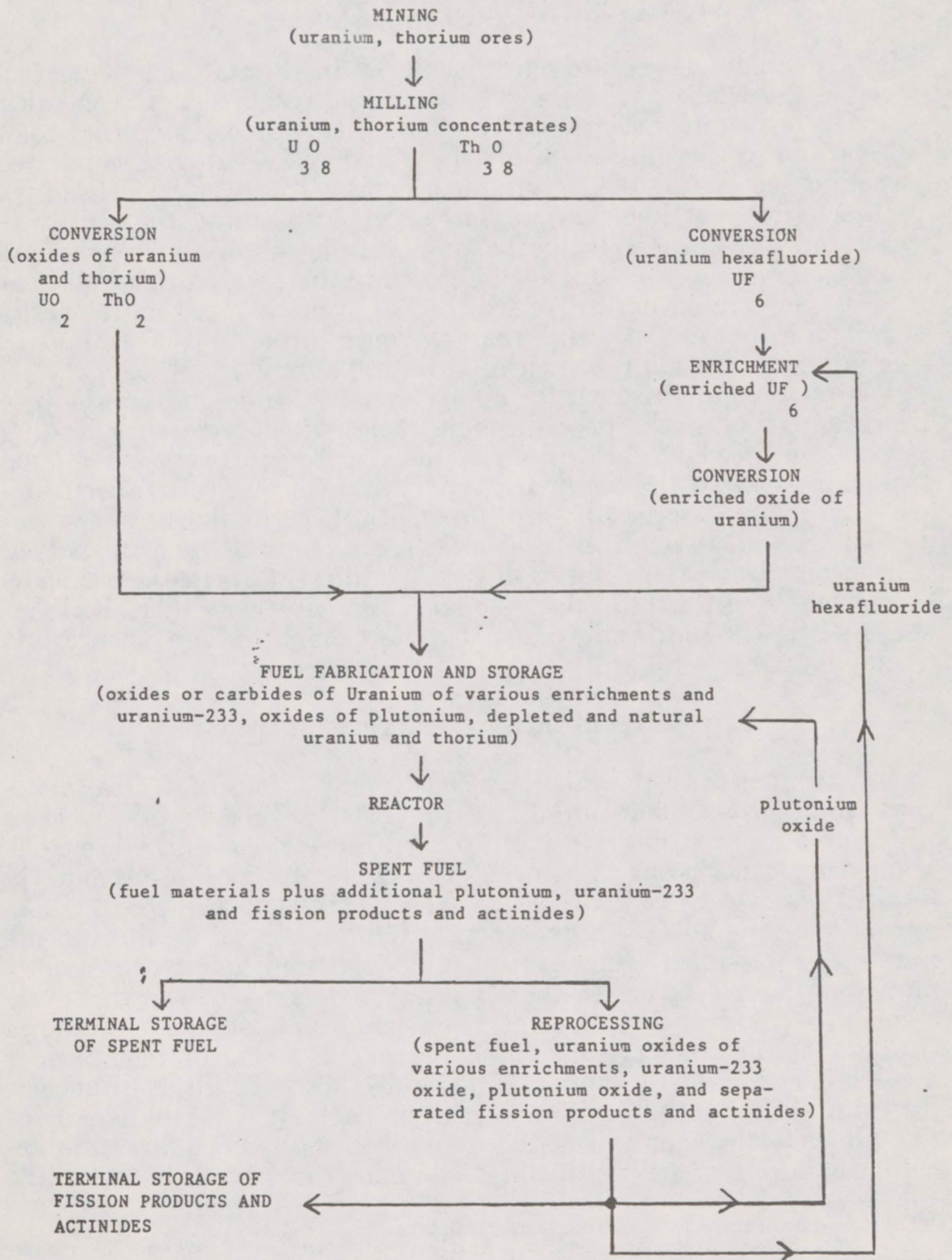


FIGURE 8

VULNERABILITY OF ALTERNATIVE BREEDER CYCLES

The following summary of the vulnerabilities of alternative breeder fuel cycles draws heavily upon the Johnson Associates analysis, which takes the standard LMFBR fuel cycle as the base case and then ex-

amines the vulnerabilities for the gas cooled fast reactor, the light water breeder and its prebreeder stage, and the molten salt breeder. With these is a summary of the vulnerability of the light water fuel cycle with terminal storage of unprocessed spent fuel. An analysis of the once-through cycle has been added to fill out the comparison.

TABLE 16.—NUCLEAR MATERIALS IN PARTS OF FUEL CYCLES FOR ALTERNATIVE BREEDER REACTORS

Place	LWR with no recycle	LMFBR	GCFR	LWBR	MSBR	HWBR
Mining.....	Uranium ore..	Uranium and thorium ores.	Uranium and thorium ores.	Thorium ore..	Thorium ore..	Thorium ore.
Enrichment.....	LEU, DU.....	HEU, MEU, DU	HEU, MEU, DU			
Fuel fabrication and stor- age.	LEU.....	HEU, MEU, PU, U-233, DU, NU.	HEU, MEU, PU, U-233, DU, NU.	U-233, thori- um.	U-233, thori- um.	U-233, thorium
Spent fuel ¹	LEU, PU.....	LEU, MEU, PU, U-233, DU, NU.	LEU, MEU, PU, U-233, DU.	U-233, thori- um.	U-233, thori- um.	U-233, thori- um.
Reprocessing.....		LEU, MEU, PU, U-233, DU.	LEU, MEU, PU, U-233, DU.	U-233, thori- um.	U-233, thori- um.	U-233, thori- um.

¹ All spent fuel from whatever type reactor contains fission products and actinides.

Note: DU=depleted uranium. HEU=highly enriched uranium (i.e., 90 percent). LEU=low-enriched uranium (i.e., 3-6 percent). MEU=moderately enriched uranium (i.e., 20 percent). NU=natural uranium.

The once through cycle.—Because the President and his administration and the Congress in the Nuclear Non-proliferation Act of 1978 accept the proliferation risks of light water reactors with terminal storage of spent fuel and no reprocessing, it is pertinent to briefly examine this cycle for vulnerability.

Slightly enriched uranium, which is potentially convertible to explosive-grade materials, could be diverted at many points of the once-through cycle. However, the difficulty of obtaining a nuclear explosive from it keeps its risk acceptable. The Office of Technology Assessment examined diversion potential by estimating the amount of material which would have to be diverted at various stages of the LWR fuel cycle to produce enough materials for one nuclear explosive.

Diversion from uranium mills.—The first potential diversion point would be at a uranium mill where uranium oxide (yellow cake) could be diverted. After some chemical processes, this material could be enriched to explosive-grade uranium or transformed into plutonium in a dedicated (clandestine) reactor. According to OTA, about 6.5 metric tons of yellow cake would supply enough feed material to yield about 30 kilograms of 90 percent material by enrichment, enough for one or two explosives. About 75 metric tons of yellow cake would be needed to fuel a dedicated production reactor capable of producing 10 kilograms of plutonium-239 annually. The capital cost of such a reactor and associated small reprocessing plant capable of producing enough plutonium for one or two weapons a year would be in tens of millions of dollars and the technical effort within the capabilities of many nations but entirely impractical for a nonstate adversary.

*Diversion from enrichment.*¹⁹—The next potential diversion point would be an enrichment plant, which would be a more attractive target for a diverter. Although slightly enriched uranium cannot be used

¹⁹ U.S. Congress Office of Technology Assessment. Nuclear Proliferation and safeguards. New York: Praeger Publishers, 1977, p. 154.

directly to make a nuclear explosive, it is a much more convenient material for clandestine enrichment than normal uranium. To obtain 30 kilograms of 90-percent uranium-235, nearly 8,000 kilograms of natural uranium hexafluoride would be needed for feed, and 6,900 separative work units for enrichment. However, if three percent materials could be diverted for feed, only about 1,500 kilograms of uranium hexafluoride and about 2,500 SWU would be required to produce these 30 kilograms of weapons-grade material.²⁰

A nation which would divert enriched uranium from a commercial enrichment plant has several options. It could try to modify an existing enrichment plant to produce highly enriched uranium. This would be least difficult for an enrichment plant using centrifuges, but would be complicated and time consuming for a gaseous diffusion plant. OTA noted that the Chinese appear to have followed this route in converting a gaseous diffusion plant supplied by the Soviet Union. Another option would be to convert only part of an unsafeguarded enrichment plant to produce highly enriched uranium. Still another would be to divert some low-enriched uranium to a small, secret enrichment plant. Only about 400 centrifuges of European design would be needed to produce 30 kilograms of uranium-235 enriched to 90 percent from 3 percent feed materials. For comparison, a centrifuge enrichment plant capable of supplying 10 light water reactors of 1,000 megawatts generating capacity with low-enriched uranium would require about 200,000 centrifuges.²¹

Enrichment is not usually thought of as an option for subnational groups. However, low-enriched uranium could be an attractive target for embezzlers, if a black market were to develop.

From the output of an enrichment plant to the loading of fabricated nuclear fuel into the reactor, the only target in the LWR fuel cycle with spent fuel storage would be the low-enriched uranium itself. This, as noted above, is not directly usable for nuclear weapons or explosives.

Technological surprise in enrichment.—The consensus that the LWR fuel cycle without reprocessing presents acceptable risks of proliferation—for the risks are not zero—could be changed quickly by unexpected developments in enrichment technologies. An unexpected increase in the ease of manufacture for centrifuge equipment or in use of lasers for isotope separation could make slightly enriched uranium, or normal or even depleted uranium, a much more credible source of uranium-235 with which to make nuclear explosives. If it became credible that a comparatively small installation could extract kilograms of uranium-235 per year from these nuclear materials, then the whole array of problems for safeguarding and protection of nuclear materials would be greatly expanded. At the moment slightly enriched uranium, normal uranium and depleted uranium are not viewed as dangerous materials. Unexpected progress in isotope separation could upset this situation.

Diversion from spent fuel.—At the heart of U.S. nonproliferation policies is the supposition that plutonium contained in spent fuel which is stored under international auspices does not present an unacceptable proliferation risk.

²⁰ A separative work unit (SWU) measures the work required to enrich uranium. It takes about 100,000 SWUs per year to supply fuel for a light water reactor of 1,000 megawatts electrical generating capacity.

²¹ OTA, *op. cit.*, p. 155.

Spent light water reactor fuel upon discharge typically contains about 0.8 percent plutonium, of which about 25 percent is plutonium-240 and plutonium-242. With plutonium recycle, LWR spent fuel typically would contain about 1 to 2 percent plutonium of which 35 percent would be in isotopes plutonium-240 and plutonium-242. The OTA notes in its analysis that a high content of plutonium-240 and plutonium-242 is widely, but incorrectly, believed to make the plutonium unsuitable for militarily effective weapons. Rather, a high content of these isotopes is a complication. Given a free choice, a weapons designer would prefer plutonium with a lower plutonium-242 content. But, reported OTA, effective nuclear explosives can be made with plutonium of plutonium-240 content noted above.²²

With a plutonium content of 0.8 percent, about 1.4 metric tons of spent fuel would have to be reprocessed, assuming no recovery losses, to obtain 10 kilograms of plutonium. Three typical pressurized water reactor fuel elements would contain this much plutonium. Viewed another way, one year's spent fuel from a large PWR typically would consist of about 31 metric tons of uranium dioxide containing about 240 kilograms of plutonium.²³

It is assumed that many developing countries could construct reprocessing plants to extract plutonium from spent fuel. On the other hand, it seems unlikely that diversion of spent fuel could occur undetected in a nuclear power fuel cycle under IAEA safeguards. As seen by the OTA, theft and reprocessing of spent fuel by subnational groups is just barely credible.²⁴ As seen by Dr. Walter Marshall, Deputy Chairman of the United Kingdom Atomic Energy Authority, it is not credible to think of any but the most mature and experienced organizations obtaining plutonium from recently discharged fuel elements, and equally it is not credible to think that all lesser organizations throughout the world would find it impossible to obtain plutonium from spent fuel 30 years old. "In this very general sense we must regard some plutonium in some old fuel elements stored somewhere in the world as 'accessible.'"²⁵

The protection afforded by the radioactivity of spent fuel diminishes with time. Initially spent fuel is intensely radioactive, so much so that a person standing close to an unshielded spent fuel element would quickly receive a lethal exposure to the radiation and even enough to cause incapacitation. This radioactivity falls by a factor of 300 over the first year and a factor of 2,000 over the first 10 years. However, even after several decades of cooling, the spent fuel would remain radioactive enough to require special precautions and equipment in handling and reprocessing to prevent exposure to dangerous amounts of radiation. To illustrate the diminishing protection from radioactivity, when fresh spent fuel has to be transported, a typical shipping cask weighs about 100 tons. After a decade of cooling, the same spent fuel can be moved in a cask weighing a few tons.

The protection afforded to spent fuel through its radioactivity depends upon the amount of radioactive material it contains, the knowledge of the people handling it, the adequacy of their equipment and

²² Ibid., p. 156.

²³ Ibid., p. 155.

²⁴ Ibid., p. 156.

²⁵ Walter Marshall, *op. cit.*, p. 81.

the time available. So there is no simple rule to establish whether or not plutonium in spent fuel is inaccessible. Rather there are many gradations of inaccessibility which Walter Marshall has arranged in the four levels shown in table 17.

TABLE 17—LEVELS OF PROTECTION FOR PLUTONIUM FROM ASSOCIATED RADIOACTIVITY OF SPENT FUEL OR CHEMICAL FORM

Level 4: Inaccessible plutonium. Material contained in fully irradiated spent fuel recently removed from a nuclear reactor.

The radioactivity of the spent fuel is so great that the plutonium can only be recovered in a well designed and operating reprocessing plant.

Level 3: Extractable plutonium. Material contained in a fuel element which has cooled for several years.

The associated radioactivity is sufficient to still present a formidable problem to any group which tries to recover the plutonium. "It is not credible to think of a subnational group actually obtaining separated plutonium from such fuel elements stored in most parts of the world. But it is not beyond the limits of imagination that such a group might succeed somewhere in the world, provided they were dealing with a fuel element old enough for the radioactivity to have substantially decayed."

Level 2: Extracted plutonium. Material which is produced by a reprocessing plant in the form of a diluted mixture of plutonium and uranium oxide.

It is not immediately usable in weapons but needs further processing to separate the plutonium and to convert it into metal form.

Level 1: Material which has been separated from spent fuel and is stored in purified form which is immediately usable in a crude weapon, or plutonium metal.

Source: Walter Marshall. Nuclear power and the proliferation issue. Atom, April 1978. p. 81.

Some analysts, however, say that the residual radioactivity of older, spent nuclear fuel presents more of a barrier to clandestine reprocessing than as seen by Marshall.

The light water reactor with reprocessing and recycle

From the standpoint of the President and the Administration, the light water reactor with reprocessing and recycle of plutonium presents an unacceptable proliferation risk and should be deferred. The proliferation risk would be greatest at commercial fuel reprocessing plants which produce separated plutonium, at storage places for this recovered plutonium, at fuel fabrication plants and associated storage, and, of course, in transit.

From the standpoint of both governments and subnational groups that might wish to divert or steal plutonium, a large commercial reprocessing plant would be an attractive target. The output of the standard process is a liquid form of plutonium, plutonium nitrate, which requires simple chemistry to convert into nuclear explosive materials. A reprocessing plant probably would also contain plutonium dioxide, and mixtures of this material with uranium oxides. Ten kilograms of plutonium, could be obtained from about 300 kilograms of mixed oxide containing about 3.5 percent plutonium dioxide. OTA sees the logistical problem of removing this much material as a significant deterrent. An obstacle to a subnational group would be the chemical separation of plutonium from uranium. Although conceptually simple, the operation would require practical experience in chemical engineering and perhaps several weeks' to several months to carry out. For a government, the chemical separation problem would be minor and could probably be accomplished in a few days.²⁶

²⁶ OTA, op. cit., p. 156.

The standard LMFBR

The standard LMFBR fuel cycle features separated plutonium in metal or oxide form. Its principal vulnerability is accessibility at places in its nuclear fuel cycle where there are amounts of these materials. The fuel materials probably would be a mixture of plutonium oxide (10 to 20 percent) and oxide of normal or depleted uranium.

The most probable points for accumulation include reprocessing plants, and associated storage; shops for the fabrication of plutonium oxide into nuclear fuel elements and associated storage; and transport between these places. In addition, spent fuel will contain comparatively large amounts of plutonium at spent fuel storage facilities.

As noted earlier, the material posing the greatest risk would be plutonium metal, followed by plutonium oxide. Partially fabricated and complete fuel elements also would be a source of plutonium. Although in a form somewhat more difficult to recover than from bulk oxide, freshly fabricated fuel elements should pose no major recovery problems to a government. The plutonium contained in spent fuel would be the least accessible. However, as noted above, it too could be recovered in a clandestine reprocessing plant.

A single standard LMFBR with an electrical generating capacity of 1,000 megawatts is estimated by Johnson Associates to produce annually some 1,980 kilograms of plutonium of which 1,700 kilograms would be recycled back to the reactor, 260 kilograms would be available to fuel other reactors, and 20 kilograms would remain unrecovered in the reprocessing wastes. Figure 9 shows this annual flow of materials.

In comparison with the once-through fuel cycle, the standard LMFBR cycle presents somewhat fewer diversion points, but, unfortunately, these contain materials more directly usable in nuclear devices. Mining and milling could be reduced for the LMFBR for a long time because the depleted uranium from past and present enrichment operations could be used as fertile material. Enrichment would be superfluous for the LMFBR, except possibly for initial cores to start up. As in the case of the light water fuel cycle with reprocessing and recycle of plutonium, the most vulnerable points for the LMFBR would include the reprocessing plant, the fuel fabrication plant and the fresh-fuel storage places, and the transportation links between them.

ANNUAL QUANTITIES FOR LMFBR
FUELED WITH PLUTONIUM AND DEPLETED URANIUM
(FULL RECYCLE)

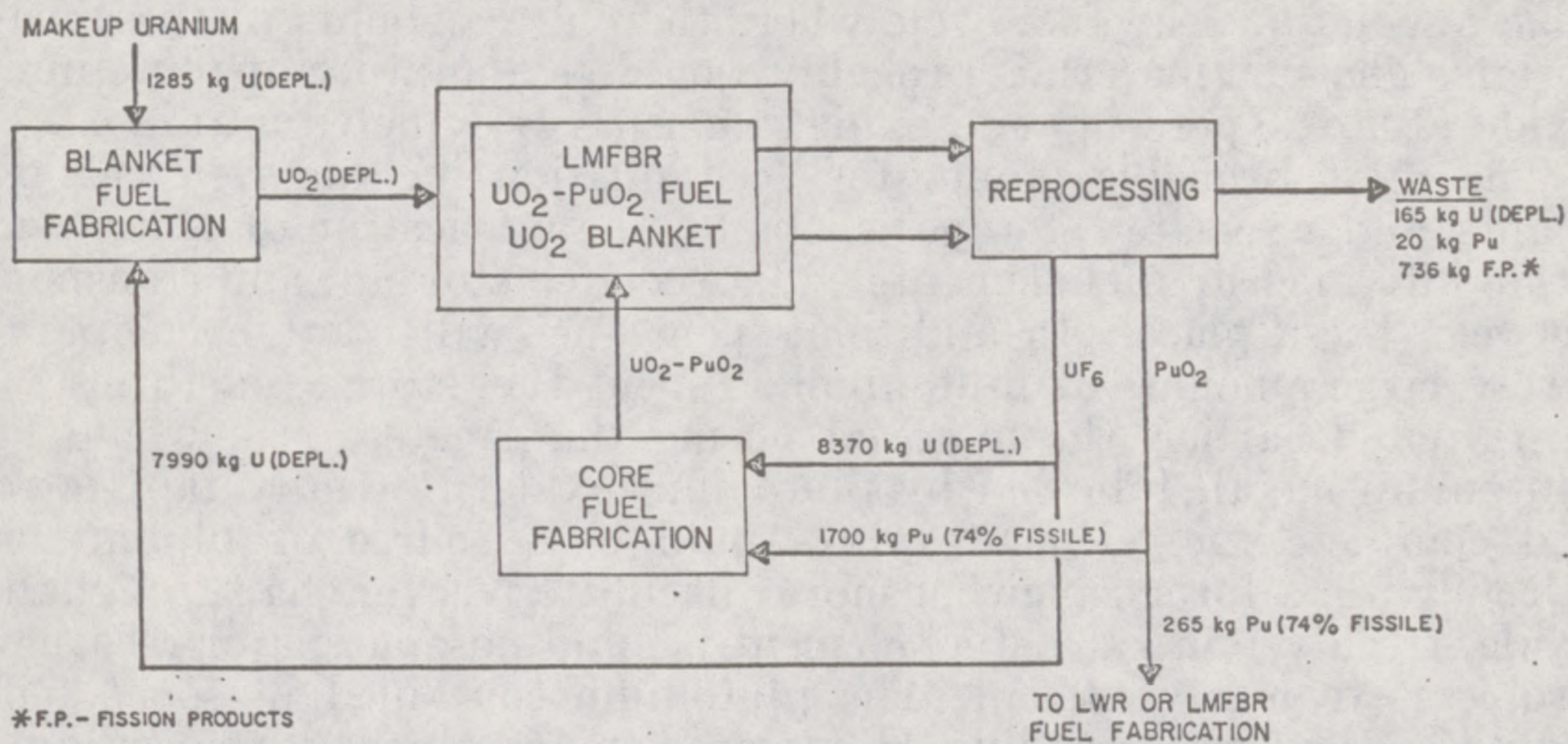


FIGURE 9

Diversion from the reactor itself is not credible, according to OTA. Spent fuel in storage, in transit to reprocessing, and in the input stages of reprocessing, would be highly unattractive to a would-be diverter because of its radioactivity. However, it must be expected that reprocessing of diverted spent fuel in a clandestine reprocessing plant is within the capabilities of many nations.

An LMFBR fuel fabrication plant would probably contain depleted or natural uranium dioxide and pure plutonium dioxide. These materials would be mixed at the fabrication plant and compressed into fuel pellets. The percentage of plutonium and uranium in fresh fuel would vary with design, but would probably lie between 10 and 20 percent. Fuel material with a 10 percent concentration of plutonium would not be useful for a nuclear explosive, although a 20-percent material might have marginal usefulness. However, in either case, only 110 or 55 kilograms, respectively, of fuel material would have to be stolen to recover 10 kilograms of plutonium. Fabricated fresh fuel for an LMFBR would have a plutonium concentration two to six times greater than for fuel for a light water reactor, depending upon details of both schemes.

As for vulnerability, in general diversion opportunities at an LMFBR reprocessing plant would be similar to those at an LWR reprocessing plant, with risks increased by the fact that the amount of plutonium per metric ton of breeder fuel would be about 10 times that for LWR fuel. According to the OTA, about five times as much plutonium would flow through the fast breeder cycle than through an LWR cycle to generate the same electricity. Another notable difference is that some plutonium produced in a breeder would contain less than 5 percent plutonium-240, which would make it a much more desirable nuclear explosive material than plutonium from a light water reactor.²⁷

²⁷ Ibid., p. 160.

The gas cooled fast reactor

The gas cooled fast reactor employs a nuclear fuel cycle similar to the LMFBR. So the kinds and quantities of nuclear materials to be found in its fuel cycle approximate those for the LMFBR. Because of these similarities, the vulnerabilities of these two cycles would be about the same.

The light water breeder reactor

Initially, the nuclear fuel for a light water breeder fuel cycle would consist of a mixture of oxides of uranium-235 and thorium for the core, and thorium oxide for the blanket. Uranium-233 is an excellent nuclear explosive material. The principal vulnerability for this cycle would be the presence in many places of uranium-233 in various chemical forms, beginning at the reprocessing plant and including other places similar to those for the LMFBR fuel cycle. A distinguishing feature which would somewhat reduce vulnerability is the radioactivity of uranium-233, which would require use of heavy-shielded facilities with remote operation. While this radioactivity is not enough to immediately incapacitate a person handling uranium-233, it would be dangerous and, in addition, it would increase the probability of detection of attempts to remove small quantities from a properly safeguarded facility. The annual flow of materials for a light water breeder of 1,000 MWe capacity would include some 1,636 kilograms of uranium-233 of which 1,610 kilograms would be returned to the reactor, 10 kilograms would be available for other use, and 16 kilograms would remain unrecovered in reprocessing wastes. Figure 9 shows this material flow.

Although the radioactivity of uranium-233 is a deterrent to subnational theft, a government wishing to recover this material from spent fuel could easily provide the shielding and equipment necessary to handle the material. Also, the radiation of uranium-233 would create uncertainties in measuring and accounting for the material because of its effect on the accuracy of the equipment.

A notable feature of the thorium fuel cycle which could discourage theft is the possibility of mixing uranium-233 with normal uranium to provide a fuel material that cannot be directly used in a nuclear explosive. Usually uranium-233 concentrations of about 12 percent or less are postulated. The uranium-233 could not be separated by chemical means. However, it could be separated by physical means, notably by gas centrifugation. According to the OTA, the number of gas centrifuges needed to produce concentrated uranium-233 from such a mixture is significantly less than that required to produce equivalent concentrations of uranium-235. As a practical matter, enrichment of denatured uranium-233 would be more difficult because of the radiation which would complicate both the chemical processing necessary to convert diverted material into gaseous uranium hexafluoride and the subsequent centrifugation.²⁸

The light water breeder differs from the LMFBR in an important way. The latter produces a distinct surplus of plutonium over what is required to refuel the reactor. The light water breeder, on the other hand, with a smaller breeding ratio, produces only enough to refuel itself. So any substantial diversion of materials from a light water

²⁸ Ibid., p. 161.

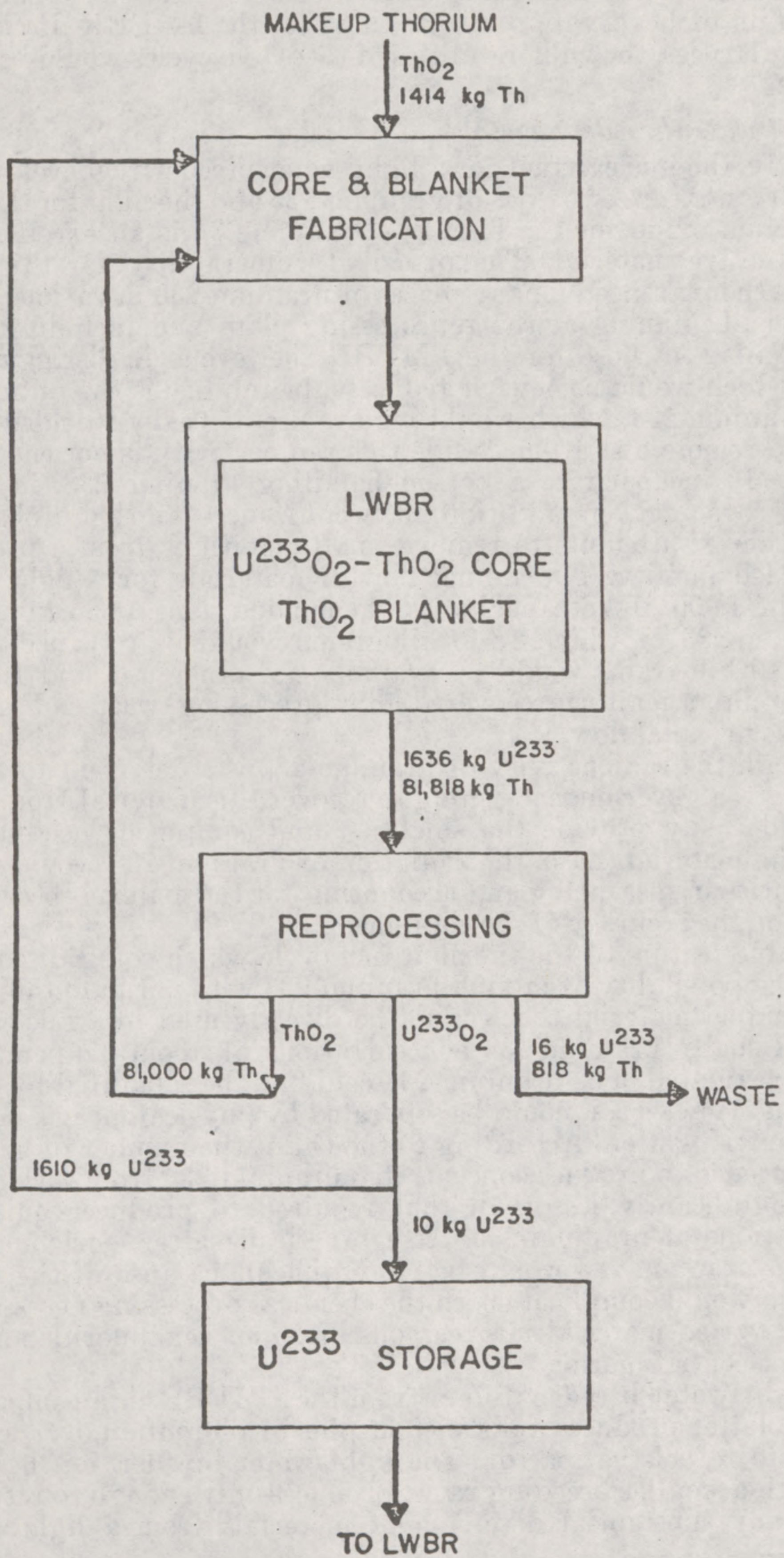
ANNUAL QUANTITIES FOR LWBR FUEL CYCLE

FIGURE 10

breeder cycle would have to be replaced or the generation of electricity curtailed, either of which would signal diversion.

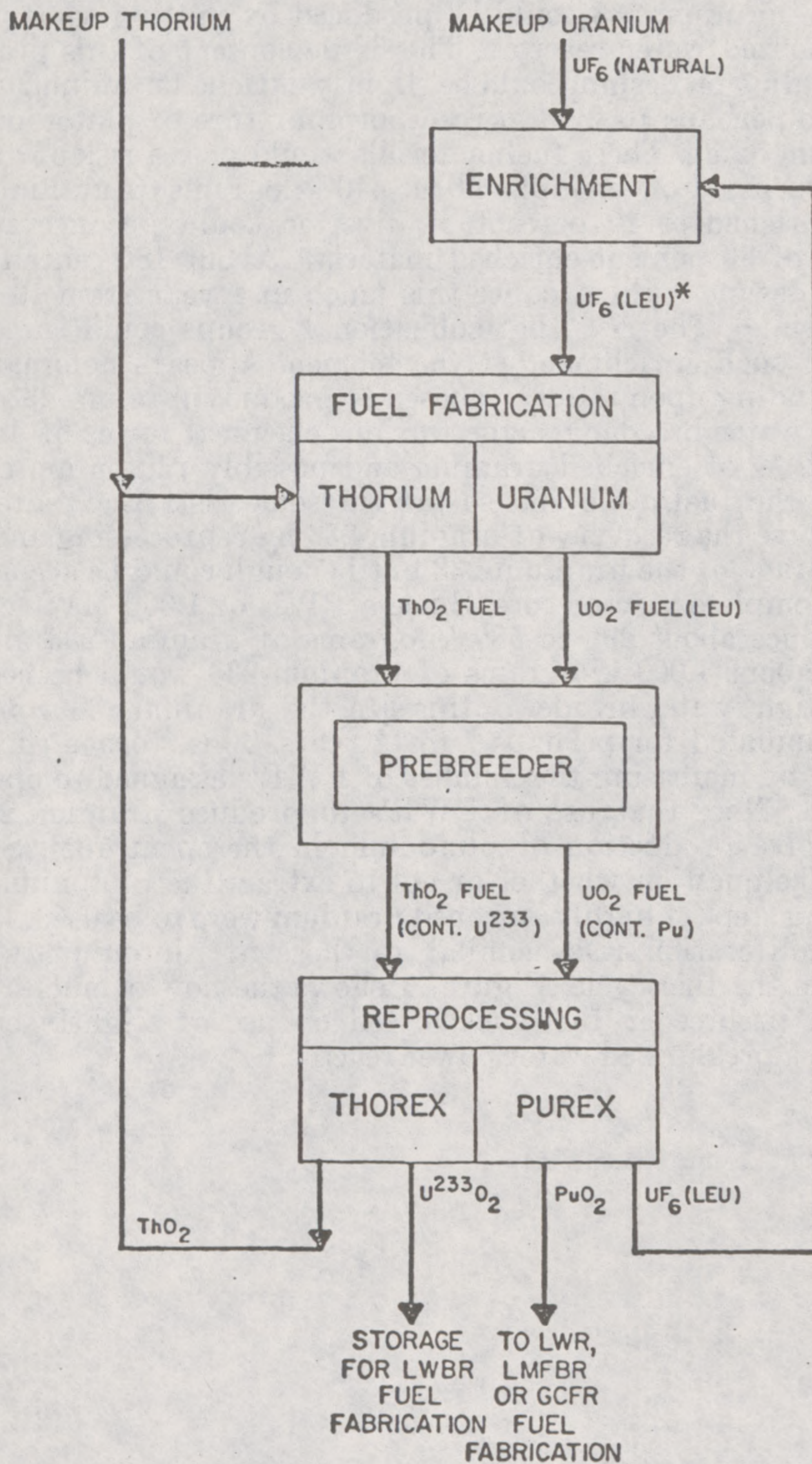
The light water breeder, prebreeding cycle

Because the uranium-233 to fuel a light water breeder does not occur in nature, a startup inventory would have to be accumulated in advance. The uranium-233 could be produced by putting some thorium into pressurized water reactors. The fissile content of this prebreeder fuel, depending on design, could be slightly enriched uranium, uranium enriched to perhaps 10 to 15 percent, or a mixture of plutonium oxide and thorium oxide. These fuel materials would pose a risk of diversion by governments. For example, about 440 kilograms of uranium hexafluoride enriched to 10 percent, if diverted could produce about 30 kilograms of 90 percent-enriched material. About 180 centrifuges of European design could produce this much in a year from 10 percent feed material.²⁹ The risk that subnational groups could successfully accomplish such enrichment at the moment appears nominal.

So, depending upon the way chosen to produce uranium-233 to start up a light water breeder reactor, various chemical forms of uranium-233 as well as of enriched uranium and possibly plutonium could be present in the fuel cycle and so present some risk. Each alternative would involve the recovery of uranium-233 by reprocessing and would require storage of the uranium-233 until enough could be accumulated to fuel a complete reactor core. Since a PWR of 1,000 MWe capacity could produce about 290 to 580 kilograms of uranium-233 annually, and since about 4,000 kilograms of uranium-233 would be needed to start up a light water breeder of this size, the uranium-233 would have to be accumulated for perhaps 7 to 14 years. This storage time could be reduced by increasing the number of PWR's assigned to operate as prebreeders. Note that use of PWR's to produce uranium-233 also would involve production of plutonium in the spent fuel. So there would be the question whether or not to extract the plutonium in the reprocessing step. If highly enriched uranium were to be used, it would present proliferation risks similar to those of plutonium where it appeared in the fuel cycle. Figure 11 shows the flow of nuclear materials for a prebreeder fuel cycle based on use of slightly enriched uranium in a pressurized water power reactor.

²⁹ Ibid., p. 162.

NUCLEAR MATERIALS IN PREBREEDER FUEL CYCLE

ALTERNATIVE I

* LEU - LOW ENRICHMENT
URANIUM (< 5% U-235)

FIGURE 11

The molten salt breeder reactor

The molten salt breeder reactor would differ radically as to the location and accessibility in its fuel cycle of nuclear materials usable in an explosive device. Unlike all the preceding alternatives, the molten salt breeder would not use fabricated nuclear fuel. Instead, it would be fueled with a molten salt of fluorides of lithium, beryllium, thorium and uranium-233. During operation of the MSBR, part of the fuel salt would be continuously diverted to a reprocessing facility located at the reactor site. About 10 percent of the total fuel inventory would be contained in the reprocessing stage. At equilibrium operation, Johnson Associates estimates that a molten salt breeder reactor of 1,000 MWe generating capacity and its reprocessing plant would contain an inventory of about 1,500 kilograms of uranium-233.

The most vulnerable point of the MSBR fuel cycle would be at the reactor site where comparatively large amounts of separated uranium-233 would exist in forms readily convertible to weapons materials. However, there would be no fuel fabrication operations and none of the proliferation risks normally associated with this step and attendant transportation. Excess uranium-233, perhaps about 30 kilograms a year, would be at some risk, bearing in mind that its radioactivity probably would reduce the risks of successful diversion or theft and subsequent use. Figure 12 shows the daily flow of materials in a MSBR of 1,000 MWe capacity.

DAILY QUANTITIES FOR MSBR FUEL CYCLE

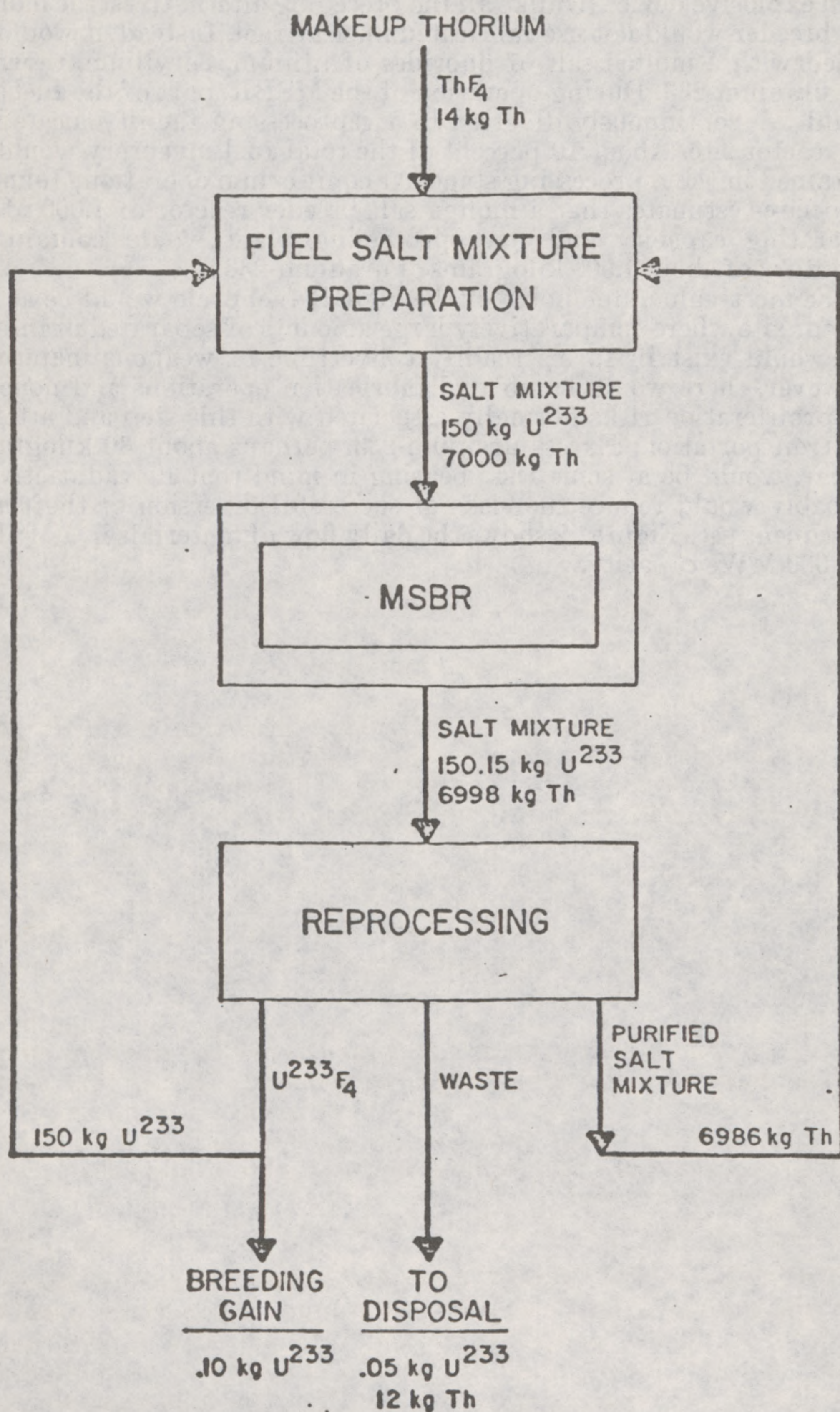


FIGURE 12

As with the light water breeder, the startup of a MSBR in the absence of an inventory of uranium-233 could add to proliferation risks. If insufficient uranium-233 were available, the reactor could be started up using highly enriched uranium or plutonium which would continue to circulate within the system until consumed and replaced by bred uranium-233. If plutonium were used as a startup fuel, its first point of accessibility in routine operation would be in the purified fuel salt emerging from reprocessing where it would be about one percent.

The heavy water breeder reactor

The fuel cycle for the heavy water breeder, assuming it can be developed, would closely resemble that for the light water breeder, with one important difference. If a CANDU-type reactor is used, then the fabricated fuel would be simpler in design than the fuel elements used in U.S.-type reactors and would be changed more frequently, almost on a continuous basis. The implied steady flow of comparatively small quantities of spent fuel probably would complicate the safeguarding of this fuel cycle and perhaps reduce its effectiveness and reliability.

DECREASING PROLIFERATION RISKS OF ALTERNATIVE BREEDERS

The risk of diversion or theft of nuclear materials from alternative breeder cycles can be decreased in several ways. None of them, however, singly or in combination can offer absolute assurance against any theft or diversion. What they may be able to do is reduce the prospects for successful theft or diversion enough to make them a fuel cycle acceptable to the public.

Measures to decrease the risk of theft or diversion can be divided into technological and organizational or institutional categories. This analysis does not extend to the category of international political action. Technological measures could change the characteristics of alternative breeder fuel cycles, while organizational measures could interpose safeguards and physical security. Both offer some promise, but whether or not it is enough to overcome fears that nuclear breeding will unacceptably increase the risks of proliferation probably will remain in question. Another consideration is whether the measures are intended to deter governments or subnational groups from nuclear weapons or explosives. This distinction can notably affect such measures. If the dominant fear is further spread of nuclear weapons among nations, one set of measures would be indicated; if it is that subnational groups may get nuclear explosives, then other measures are appropriate. If the fear is undifferentiated, then both sets of measures would be needed, with possibilities for confusion or costs that are not worth the decrease in risks.

Technological measures

Were proliferation risks not a constraint, breeder fuel cycles probably would involve the separation of plutonium and perhaps uranium-233 from spent fuel and their storage, transport and fabrication in simple chemical forms. However, given the utility of plutonium and uranium-233 for nuclear explosives, the President and some Members of Congress consider the risks of an unmodified breeder fuel cycle to be unacceptable. The hope of the Administration is that its examina-

tion of other nuclear fuel cycles in connection with the International Nuclear Fuel Cycle Evaluation will produce alternatives that can use nuclear fuel resources more efficiently than does the light water reactor, but not pose unacceptable risks for spread of nuclear explosives. Many technological measures have been proposed to reduce these proliferation risks by making the nuclear fuel materials more difficult and dangerous to divert or steal, and by making nuclear fuel materials unusable for nuclear explosives without additional processing. Table 18 summarizes four general approaches to such technological measures. Two recent proposals that combine some of these measures are coprocessing of nuclear fuel and the proposed Civex process.

TABLE 18.—SUMMARY OF TECHNOLOGICAL MEASURES TO REDUCE PROLIFERATION RISKS OF ALTERNATIVE BREEDER FUEL CYCLES

1. Adopt fuel cycles which do not require separation of nuclear materials directly usable in nuclear explosives.
2. Make nuclear fuel materials difficult to divert or to steal by :
 - (a) Using low-enriched uranium or low concentrations of plutonium or uranium-233 in nuclear fuels to increase the amount of material that would have to be diverted or stolen.
 - (b) Using uranium-233 diluted with normal or depleted uranium for the same reason.
3. Make nuclear fuel materials dangerous to divert, steal or handle by :
 - (a) Leaving some fission products in fuel materials produced by reprocessing.
 - (b) Putting radioactive isotopes into nuclear fuel materials (spiking).
 - (c) Irradiating fresh fuel before shipment to make it radioactive.
 - (d) Using uranium-233 for fuel.
4. Use nuclear fuel materials that are difficult to convert into nuclear explosive materials (slightly or moderately enriched uranium, or uranium-233 mixed with normal or depleted uranium).

Coprocessing.—If plutonium or uranium-233 is not separated from other materials in a reprocessing plant, it will not be on hand to divert or to steal. Furthermore, the plutonium concentration in the fuel material produced by coprocessing can be low enough to make the material useless for direct incorporation into a nuclear explosive, to greatly increase the amount that would have to be diverted or stolen to get a desired amount of nuclear explosive material, and to require additional processing to separate the nuclear explosive material. Coprocessing could reduce the risks of diversion in that concentrated nuclear materials would not exist. On the other hand, recovery of plutonium and uranium-233 from coprocessed fuel material would be well within the capabilities of most governments. Coprocessing also could reduce the risk of theft by subnational groups by increasing the amount of fuel material they would have to steal and by requiring chemical processing which would expose the group to danger of detection during the time required to separate out enough materials to make an explosive.

Civex.—Civex is a concept proposed to decouple civilian nuclear power from nuclear weapons by making it technically impracticable as well as economically undesirable to divert plutonium from nuclear facilities. It is an international idea proposed jointly by Dr. Chauncey Starr, president of the Electric Power Research Institute, and Dr. Walter Marshall, Deputy Chairman of the United Kingdom Atomic Energy Authority. Two days after Civex was announced, a

subcommittee of the Committee on Science and Technology voted to add \$15 million to the Department of Energy's authorization for fiscal year 1979 to work on the Civex fuel cycle.

Like coprocessing, Civex would reduce prospects for plutonium diversion by not separating plutonium. Civex backers claim that diversion by altering a Civex plant's mode of operation or by quick modification of its equipment would also be impossible and that there would never be a capability for producing pure plutonium or weapons-usable materials anywhere in the system. Civex would go beyond coprocessing by leaving some fission products in the fuel materials produced, with enough radioactivity to be immediately debilitating and lethal in 4 to 48 hours for persons handling the material without protection. Civex is also an organizational concept that departs from present practice in the nuclear industry by combining in a single facility the industrial operations of spent fuel reprocessing and refabrication of recovered material into new fuel, thereby eliminating the external transportation of material containing plutonium. Civex would combine the frequently proposed individual concepts of coprocessing, coprecipitation, spiking, and colocation into one physical facility.

However, as with coprocessing, the plutonium in Civex fuel materials could be recovered by governments.

On the whole, Civex presents somewhat more proliferation risk than the once-through fuel cycle, assuming that stored spent fuel in this cycle is at zero risk. If some risks of seizure is assumed for spent fuel, then the proliferation risk of Civex-type nuclear fuel materials would appear not to differ greatly.

Alternative fuels for breeder cycles.—The possibility of altering the fuel cycles for breeders to reduce their proliferation risks depends upon their breeding capability. The greater the breeding ratio, the more the fuel cycle can tolerate changes. From this standpoint, the fuel cycles for fast breeders probably can best tolerate technical change to decrease nonproliferation risks, whereas the fuel cycle for the light water breeder and the molten salt breeder would tolerate the least.

The Johnson Associates report identifies eight variations of the fast reactor fuel cycle in addition to the conventional base case (see table 19). Of these, four feature the use of fuel materials produced by coprocessing or Civex methods, and include radioactive contaminants. Two propose a denatured mixture of uranium-233 and depleted uranium. These variations, if successfully developed and commercially attractive, could reduce proliferation risks below those of the unmodified LMFBR fuel cycle, but probably not to the risks of the light water reactor without reprocessing, if it is assumed that spent LWR fuel is at zero risk of seizure or theft for reprocessing. If the seizure risk for spent LWR fuel is taken into account, then there does not appear to be a sharp distinction between the respective proliferation risks from modified fast breeder fuel cycles and the LWR cycle. Note that the self-protecting feature of fuels containing radioactive materials decreases as the radioactivity decays, and that risks from use of denatured fuels would increase if isotope separation techniques are improved. These factors would tend to put the risk of a modified fast breeder fuel cycle closer to the risks of the unmodified fast breeder and further from the risks of the LWR fuel cycle.

TABLE 19.—POSSIBLE ALTERNATIVE FUEL CYCLES FOR USE WITH LMFBR

Alternative designation	Core fuel	Axial blanket	Radial blanket	Special safeguards treatment of fissionable materials
Base	PuO ₂ -UO ₂ (depl.)	UO ₂ (depl.)	UO ₂ (depl.)	None.
1	PuO ₂ -UO ₂ (depl.)	UO ₂ (depl.)	UO ₂ (depl.)	Coprocessed/contaminated.
2	PuO ₂ -UO ₂ (depl.)	ThO ₂ -UO ₂ (depl.)	ThO ₂	None.
3	PuO ₂ -UO ₂ (depl.)	ThO ₂ -UO ₂ (depl.)	ThO ₂	Coprocessed/contaminated denatured.
4	U ²³³ O ₂ -UO ₂ (depl.)	ThO ₂	ThO ₂	None.
5	U ²³³ O ₂ -UO ₂ (depl.)	ThO ₂	ThO ₂	Coprocessed/contaminated/denatured.
6	U ²³³ O ₂ -ThO ₂	ThO ₂	ThO ₂	None.
7	20 percent enriched UO ₂ .	UO ₂ (depl.)	UO ₂ (depl.)	None.
8	20 percent enriched UO ₂ .	UO ₂ (depl.)	UO ₂ (depl.)	Coprocessed/contaminated.

Organizational measures

Organizational ways to reduce the risks of proliferation from theft or diversion of nuclear fuel materials include national controls backed by international verification; physical protection and security for dangerous nuclear materials; and arrangement of nuclear industries to minimize or eliminate the risks of transportation. Control and verification measures, commonly referred to as safeguards, already exist. There is, however, some question whether or not they are effective enough to permit commercial use of breeder cycles. Physical security measures are being developed for the existing nuclear installations and presumably could be extended to breeder reactors and the sensitive facilities of their fuel cycles. Colocation of nuclear facilities to reduce transportation remains in the proposed stage.

There follows a summary description of these several measures, their current status, and their applicability to alternative breeder cycles.

International management and control.—The first major organizational proposal for control of proliferation risks from nuclear power came in 1947 in the report of a U.S. Advisory Board of the Secretary of State, and the subsequent modification and presentation of its ideas to the United Nations Atomic Energy Commission by Bernard Baruch. Central to its recommendations was creation of an International Atomic Development Authority with sweeping operational and control functions. The Baruch proposal called for the creation of such an authority to which should be entrusted all phases of the development and use of atomic energy, starting with the raw material and including:³⁰

1. Managerial control or ownership of all atomic energy activities potentially dangerous to world security;
2. Power to control, inspect, and license all other atomic activities;
3. The duty of fostering the beneficial uses of atomic energy; and
4. Research and development intended to put the Authority in the forefront of atomic knowledge and thus to enable it to comprehend and therefore to detect misuse of atomic energy.

³⁰ The international control of atomic energy. The first report of the United Nations Atomic Energy Commission to the Security Council. Dec. 31, 1946. Washington, D.C. U.S. Government Printing Office, 1947, pp. 81-91.

Once an adequate system for the control of atomic energy, including the renunciation of the bomb as a weapon, had been agreed upon and put into effective operation and "condign punishments" set up for violation of the rules of control, the United States proposed that:³¹

1. Manufacture of atomic bombs should stop;
2. Existing bombs should be disposed of pursuant to the terms of the treaty to establish the Authority; and
3. The Authority should possess full information as to the know-how for the production of atomic energy.

Safeguards.—The idea of international management and control for nuclear power did not succeed. By the mid-1950's, it was replaced with the idea of national development and use of nuclear energy under international safeguards.

Nuclear safeguards now mean many things to many people. There are national and international safeguards systems. Whether or not these should provide physical security for nuclear materials and installations remains a matter of some controversy. Because breeder reactors and their fuel cycles should be safeguardable, it is pertinent to look briefly at the U.S. domestic safeguards system as an example of what can be expected in various nations and at the safeguards system of the International Atomic Energy Agency.

National safeguards systems.—The United States has two nuclear safeguards systems. One is operated by the Department of Energy for nuclear materials primarily used in its manufacture of nuclear weapons in Government facilities. The other is operated by the Nuclear Regulatory Commission and applies to licensees who hold nuclear materials under NRC licenses. Since reactors and other parts of alternative breeder cycles probably would have to be licensed by the NRC, the following description focuses on NRC safeguards. Note, however, that DOE funds substantial research and development to improve safeguards technologies the results of which are likely to find early application in the NRC safeguards system.

The objective of NRC's safeguards is to deter, prevent, or respond to (1) unauthorized possession or use of significant quantities of nuclear materials through theft or diversion; and (2) sabotage of nuclear facilities.³² The NRC safeguards program has as its objective achieving a level of protection against such acts to insure against significant increase in the overall risk of death, injury, or property damage to the public from causes beyond the control of the individual. According to the NRC, the implementation of this objective is through protection in depth. Protection includes measures such as use of threat, intelligence, armed guards, alarmed fences and vaults, stringent material accountability, electronic detection devices, and organized rapid response resources. For fiscal year 1977, the NRC requested \$3.4 million for safeguards and a staff of 106 in comparison with \$1.1 million for fiscal year 1976 and a staff of 61.³³

Additional insight into the functions and mechanisms of the NRC's safeguards function can be found in the recent report of its Material

³¹ Ibid.

³² U.S. Nuclear Regulatory Commission. Budget estimates fiscal year 1977, p. 24. In U.S. Congress. Joint Committee on Atomic Energy. Hearings. Nuclear Regulatory Commission authorizing legislation, fiscal year 1977. 94th Cong., 2d sess., 1976, p. 257.

³³ Ibid.

Control and Material Accounting Task Force.³⁴ The Johnson Associates report also examines NRC safeguards regulations and technology in some depth.

NRC safeguards have four functions:

(1) Deterrence, which is intended to discourage a potential adversary from attempting a malevolent act;

(2) Prevention, which is intended to impede or stop an adversary from successfully completing a malevolent act or successfully perpetuating a hoax;

(3) Response, which is intended to detect and assess a loss of nuclear materials and to provide a predetermined response to an actual or alleged theft;

(4) Assurance, which is intended to satisfy the NRC and the public that the safeguards program is in place, that it can respond effectively to a threat or an attempted malevolent act, and that nuclear materials are present in assigned locations and accounted for.³⁵

The NRC safeguards program can be divided into materials control, materials accounting, and physical protection. These were defined by the task force as follows:³⁶

Material control is that part of the safeguards program encompassing management and process controls to: (1) assign and exercise responsibility for nuclear material, (2) maintain vigilance over the material, (3) govern its internal movement, location, and utilization, and (4) monitor the inventory and process status of all nuclear material.

Material accounting is that part of the safeguards program encompassing the procedures and systems to: (1) perform nuclear material measurements, (2) maintain records, (3) provide reports, and (4) perform data analysis to account for nuclear material.

Physical protection is that part of the safeguards program encompassing the equipment, procedures, and physical controls to: (1) protect nuclear materials from theft or diversion through the use of access and egress controls and physical barriers, (2) detect attempts at theft or diversion through the use of surveillance measures and alarm systems, and (3) respond to attempts at theft or diversion through the use of onsite security personnel and offsite law enforcement assistance.

IAEA safeguards systems.—The International Atomic Energy Agency has several safeguards systems. In terms of the future of alternative breeder cycles, the system most likely to be significant is the one used in nonnuclear weapons states that have ratified the Nuclear Non-Proliferation Treaty and so applies to all nuclear materials. The aim of IAEA safeguards is to prevent the diversion of nuclear material to military uses or explosives. This is done by checking facility records kept for national safeguards systems and by inspection, so that any diversion would be promptly detected. Non-nuclear-weapons states party to the NPT are committed to maintain a national system of accounting and control for their nuclear materials. The interaction of these national systems and the international system of the IAEA is focused upon design review, records, reports, and inspection as follows:

(1) Design review: The nation must supply the IAEA with in-

³⁴ U.S. Nuclear Regulatory Commission. Report of the Material Control and Material Accounting Task Force. Summary. Report NUREG-0450, vol. 1. April 1978.

³⁵ Ibid., pp. S-5, S-6.

³⁶ Ibid., p. S-2.

formation on relevant design characteristics of its existing nuclear plants and of new plants in the planning stage.

(2) Records: The nuclear plant operator must keep a precise account of all nuclear material he has, receives, sends out, etc., based on exact measurements of the material.

(3) Reports: On the basis of information given by the plant operator, the national authority sends to the IAEA regular reports on the amount of nuclear material in each plant and of all changes in these amounts so that the IAEA can keep its own state of accounts for verification and comparison purposes.

(4) Inspections: IAEA inspectors make independent measurements and observations to verify the information submitted by the country concerned. All inspectors have to be approved by the IAEA's Board of Governors (34 member states) and designated with the consent of the country concerned. The inspected state may reject individual inspectors.

As seen by a leading U.S. official, the IAEA system is neither designed nor intended to prevent diversion of nuclear materials from stated peaceful purposes. Rather, its objective is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and the deterrence of such diversion by the risk of early detection. Prevention of diversion, identification of the diverter, or determination of the use to which diverted materials have been put all lie beyond the authority vested in the Agency by its member states. Similarly, while the Agency cannot simply assume that clandestine facilities do not exist, it is not charged with the responsibility of detecting them. So U.S. judgment of how well safeguards are being applied and what improvements are needed must be made in the light of these and related factors.³⁷

At the end of 1977, the Agency had a total of 119 safeguards agreements in force with 74 states, and had concluded safeguards agreements with an additional 15 states that were not yet in force.³⁸ According to information available to the Agency, there were significant nuclear facilities in 13 non-nuclear-weapons states not party to the NPT. These included: Argentina, Brazil, Chile, Colombia, the Democratic People's Republic of Korea, Egypt, India, Indonesia, Israel, Pakistan, South Africa, Spain, and Turkey. The Agency was applying safeguards in 12 of these states, excluding Egypt. In the case of eight states, all nuclear activities involving significant quantities of special nuclear material were covered by those safeguards. The five exceptions were Egypt, India, Israel, South Africa, and Spain.³⁹

During 1977, the Agency carried out 706 inspections in 45 states, compared with 565 inspections in 40 states during 1976. Of the inspections of 1977, 283 were of powerplants, 117 of bulk fuel plants, and 306 of other facilities including research reactors. In addition, two reprocessing plants were under continuous inspections. In terms of nuclear

³⁷ Cf., Lawrence Schienman. "International Safeguards: Objectives, Status and Unresolved Issues, a United States View." Remarks. American Nuclear Society Executive Conference on Safeguards, Oct. 17, 1977. Dr. Scheinman is Senior Advisor to the Under Secretary for Security Assistance, Science and Technology, of the Department of State.

³⁸ International Atomic Energy Agency. Annual report for 1977. IAEA Doc. GC(XXII)/597, p. 40.

³⁹ Ibid., p. 41.

materials, in 1977 12,197 of plutonium in spent fuel, 5,715 kilograms of plutonium in other forms, 5,346 kilograms of slightly enriched uranium in other forms were under Agency safeguards.⁴⁰

IAEA safeguards are generally accepted as providing adequate warning of theft or diversion from nuclear fuel cycles involving natural uranium or low enriched uranium with no reprocessing. There are doubts as to their effectiveness for nuclear fuel cycles using plutonium or uranium-233, particularly for safeguarding of reprocessing plants and facilities handling these nuclear fuel materials in bulk quantities. The emphasis in the non-proliferation act upon assurance of timely warning of diversion as a condition for U.S. approval of foreign reprocessing of spent nuclear fuel of U.S. origin reflects this concern. So the future of alternative breeder cycles may depend almost as much upon improvements in safeguards systems as upon development of alternative breeders to reduce risks of theft or diversion.

Since the United States is a nuclear weapons state, the NPT does not require it to place all its nuclear materials and activities under IAEA safeguards. However, to get non-nuclear-weapons states to ratify the NPT, the United States, France and the United Kingdom have voluntarily negotiated agreements with the Agency to apply its safeguards to some nuclear installations in each country. President Carter submitted the U.S. agreement to the Senate for its advice and consent on February 9, 1978. If approved, this agreement will commit the United States to list its nuclear facilities not associated with defense purposes and to permit the Agency to decide which among them are to be inspected. Other facilities would supply materials-accounting information to the Agency.

Physical security.—Much of the concern about proliferation in the 1970s has focused on possible theft of dangerous nuclear materials by criminals or terrorists. An increased interest in requirement for physical security to protect against theft of nuclear materials or sabotage of nuclear facilities has been the result. This concern is reflected in regulations of the Nuclear Regulatory Commission and in the provisions of the Nuclear Non-Proliferation Act of 1978.

The purpose and design of physical security for a nuclear installation depends on the quantity and form of the nuclear materials present. For a light water power reactor, the principal objective is to protect it against sabotage and secondly to protect its nuclear materials against theft which, in the absence of plutonium recycle, is in relatively unusable form. On the other hand, the physical security objective for a reprocessing plant, or for a fuel fabrication plant where dangerous nuclear materials are likely to be present primarily would be to protect the materials from theft or diversion and only secondly to protect the facility against sabotage. The most sensitive part of nuclear fuel cycles for physical security is the transportation of nuclear materials. The NRC already has specified elaborate security requirements for the transport of dangerous nuclear materials by road, rail, air, and sea.

Physical security becomes increasingly important as a part of safeguards for situations where nuclear materials-accounting techniques alone cannot provide the level of protection sought. The Nuclear Regu-

⁴⁰ Ibid., p. 43.

latory Commission doubts that material-accounting alone could detect illicit actions in a reliable and timely manner, and have sufficient accuracy to give a high confidence that materials have not been stolen. So the NRC seeks to insure that adequate physical protection of nuclear material and accountability, coupled with investigations of inventory differences and other safeguards-related events will provide acceptable assurance that no undetected theft of significant amounts of nuclear materials has occurred. Recent improvements ordered by the NRC lead to its judgment that there is reasonable protection against hypothetical threats of determined, violent assaults by highly motivated and skilled assailants willing to receive and inflict casualties and actively aided by a facility employee in any position, including that of guard.⁴¹

Physical security has its costs, and some think they may be too high for the benefits received. For example, one recent estimate of costs for physical security was \$32 million during 40 years of operation for a nuclear power plant. This was described as a stiff price to pay for an NRC requirement not based upon any identified threat but rather as a "prudent action."⁴²

Physical security requirements raise controversial questions of effects upon civil liberties of employees and of nearby citizens. Such questions are not confined to the use of nuclear energy. Many industrial, commercial or governmental activities require high physical security, but have not caused problems or effects postulated by some analysts for physical security for nuclear energy.

In terms of alternative breeder cycles, the cost and intensity of physical security would be greatest for facilities containing materials readily usable for nuclear explosives, notably fresh fuel in storage for breeder reactors, and separated plutonium at reprocessing plants, fuel fabrication plants, and in transportation. The security requirements would be less for breeder fuel cycles based on highly radioactive fuel materials. The more unusable and radioactive the materials at risk, the less the need for intense security. On this basis, fast breeders fueled with Civex materials, or breeders operating on the uranium-233 fuel cycle would require less physical security than the unmodified fast plutonium breeder. The once-through fuel cycle probably would require still less physical security except for the storage of spent fuel.

COMPARISON OF PROLIFERATION RISKS FOR ALTERNATIVE BREEDER CYCLES

Future national policy decisions for alternative breeder cycles and for U.S. nonproliferation goals and actions logically should depend upon comparative proliferation risks. Unfortunately, the estimation of these risks is imprecise and subjective, with a consequent fuzziness. If alternatives differ little in estimated proliferation risks, or if uncertainties cause an overlapping of risk estimates, then comparative risk will not be as important in choice between one cycle and another. Of

⁴¹ Ralph G. Page. Development and status of U.S. Nuclear Regulatory Commission safeguards. Paper at the American Nuclear Society Executive Conference on Safeguards, October 1977. Mr. Page is Deputy Director of the Division of Safeguards, Office of Nuclear Material Safety and Safeguards, NRC.

⁴² Donald F. Knuth. "Protection of Nuclear Powerplants From Acts of Sabotage." Paper at the American Nuclear Society's Executive Conference on Safeguards, October 1977.

course, if a clear-cut difference emerges, then comparative risk would be important for decisions. The international nuclear fuel cycle evaluation now in progress and the U.S. technical support for that evaluation are likely to produce many comparisons of proliferation risks which will appear in arguments for one or another fuel cycle. In considering such analyses, Congress will need to know what are the assumptions and uncertainties in such estimates and whether the risk estimates overlap, are close together or are clearly separate.

As for this CRS analysis, proliferation risks are divided into two categories: first, the risks from theft of nuclear materials by subnational groups; second, the risks of diversion of nuclear materials by governments. For each category, the risks fall within a spectrum bounded on the lower side by the once-through fuel cycle and on the higher by the conventional plutonium breeding cycle with the production and use of separated plutonium.

Risks of subnational theft

Concern that subnational groups might successfully steal and misuse nuclear materials remains a dominant feature in the debate over proliferation and what to do about it. This debate raises a fundamental issue: Should U.S. nonproliferation policy assume that such groups have more motivation, reason, and capacity to steal and misuse nuclear materials than they do to employ other ways to cause mass casualties, panic, and disruption? Should one level of motivation be assumed for nuclear materials and another, lesser motivation for other ways to cause many deaths and destruction? If it is credible that subnational organizations can overcome present security for nuclear materials, what are the implications for protection of nonnuclear facilities and places where there may be large public gatherings. If a double standard of motivation is used, then the basis for it should be explicitly stated.

As for risk of subnational theft of nuclear materials from alternative breeder fuel cycles, it would be greatest for those where separated plutonium or highly enriched uranium is present; less for fuel cycles for which nuclear fuel materials are difficult and dangerous to steal; and least for fuel cycles which do not use highly enriched uranium, plutonium or uranium-233. In each instance, the amount of risk would depend upon the accessibility of the material, the amounts present, and the subsequent time needed to process stolen material to transform it into an explosive. Table 20 provides a summary comparison of these risks.

Looking at the comparative risks, it appears that the once-through fuel cycle presents the least risk for subnational theft and the plutonium breeder with separated plutonium the most. Alternative breeders fueled with nuclear fuel materials produced by coprocessing and spiking, or Civex, or made radioactive by preirradiation, or containing uranium-233 would represent an intermediate risk, probably little distinguishable from that of a subnational theft of spent fuel from the once-through fuel cycle.

TABLE 20.—PROLIFERATION RISK ASPECTS OF SUBNATIONAL THEFTS FROM ALTERNATIVE BREEDER CYCLES

Item	LWR					MSBR	HWBR
	No recycle	Recycle	LMFBR	GCFBR	LWBR		
Materials at risk.....	LEU	LEU, Pu	Pu	MEU, HEU, Pu	U-233	U-233	U-233.
Proliferation risks at fuel cycle stage:							
Feed materials.....	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal.
Enrichment:							
LEU.....	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal.
MEU.....			Nominal	Nominal			
HEU.....			Potential, prompt	Potential, prompt			
Fuel fabrication, storage, and transport.....	Nominal	Potential, prompt	Potential, prompt	Potential, prompt	Potential, delayed	Potential, delayed	Potential, delayed.
Spent fuel:							
Terminal storage.....	Nominal	Nominal	Nominal	Nominal	Nominal	NA	Nominal.
Temporary storage pending reprocessing.....							
Capabilities needed to recover explosive-grade materials:							
Further enrichment of.....	LEU	LEU		MEU			
Shielded enrichment for U-233.....					X	X	X.
Chemical separation of Pu.....	X	X	X	X			
Radiochemical separation of Pu (from spent fuel).....	X	X	X	X			
Radiochemical separation of U-233 (from spent fuel).....					X	X	X.
Radiation hazards:							
From enriched uranium, Pu ²	Nominal	Nominal	Nominal				
From coprocessed and spiked, preirradiated or Civex fuel materials.....	High	High	High	High			
From U-233.....							
From spent fuel.....	NA	High	High	High	High	High	High.
Adequacy of safeguards.....	Adequate	Improvements needed.	Improvements needed.	Improvements needed.	Improvements needed.	Improvements needed.	Improvements needed.
Physical security required.....	NA	NA	NA	NA	NA	NA	NA.

¹ The MSBR does not remove spent fuel from the on-site system.² Assuming no criticality accident which can produce an intense burst of radiation.

Note: LEU=low enriched uranium, 3-6 percent. MEU=moderately enriched uranium, 20 percent. HEU=highly enriched uranium, 90 percent. NA=not applicable. X=required capability.

Risks of national diversion

Concern that a non-nuclear-weapons state might take nuclear materials from its nuclear fuel cycle as a quick route to nuclear weapons differs from concern about risks of subnational theft. Governments of most non-nuclear-weapons states, excepting only the poorest and least industrial, probably can mount clandestine undertakings which are well beyond the credible capacity of criminals and terrorists. This means that there are more risks of secret diversion or outright seizure of spent fuel, or radioactive or denatured fuel materials, by governments if it is assumed that their nonproliferation commitments may be broken or ignored. A state advanced enough to use nuclear power probably could have clandestine facilities ready to process such materials and recover nuclear weapons materials. Whether or not such facilities could long be kept secret is another matter. If it is credible that a non-nuclear-weapons state can design a reliable nuclear weapon without prior experience and assemble all its parts in advance, except for the nuclear charge, then it seems equally credible to assume such a state can secretly build whatever clandestine facilities it might need to extract plutonium or uranium-233 from spent fuel or other nuclear fuel materials. Table 21 compares proliferation aspects of national diversion for alternative breeder cycles.

TABLE 21.—PROLIFERATION RISK ASPECTS OF GOVERNMENT DIVERSIONS FROM ALTERNATIVE BREEDER CYCLES

Item	LWR					MSBR	HWBR
	No recycle	Recycle	LMFBR	GCFBR	LWBR		
Materials at risk	LEU	LEU, Pu	Pu	MEU, HEU, Pu	U-233	U-233	U-233
Proliferation risks at fuel cycle stage:							
Feed materials	Some, long delay	Some, long delay	Some, long delay	Some, long delay	Some, long delay	Some, long delay	Some, long delay
Enrichment:							
LEU	Some, delayed	Some, delayed					
MEU				Some, delayed			
HEU				Most, prompt			
Fuel fabrication, storage and transport	Some, long delay	Most, prompt	Most, prompt	Some, delayed	Less, delayed	Less, delayed	Less, delayed
Spent fuel:							
Terminal storage	Some delayed						
Temporary storage pending reprocessing		Some delayed	Some delayed	Some delayed	Less delayed (*)	Less delayed (*)	Less delayed
Capabilities needed to recover explosive-grade materials:							
Enrichment of	LEU	LEU		MEU			
Shielded enrichment for U-233				X	X	X	X
Chemical separation of Pu	X	X	X	X			
Radiochemical separation of Pu (from spent fuel)	X	X	X	X			
Radiochemical separation of U-233 (from spent fuel)				X	X	X	X
Radiation hazards:							
From enriched uranium, Pu	Nominal	Nominal	Nominal	Nominal			
From coprocessed and spiked, preirradiated or Civex fuel materials	High	High	High	High	High	High	High
From U-233	NA	High	High	High	High	High	High
From spent fuel	Adequate	Improvements needed.	Improvements needed.	Improvements needed.	Improvements needed.	Improvements needed.	Improvements needed.
Safeguards	Low	High	Low/high	Low/high	Low	Low	Low
Physical security requirements							

Note: LEU = low enriched uranium, 3-6 percent. MEU = moderately enriched uranium, 20 percent. HEU = highly enriched uranium, 90 percent. X = a requirement for the indicated capability.

Given the above assumptions, there appears to be little substantial difference in risk between the once-through fuel cycle and alternative breeder cycles that employ radioactive and denatured fuels. This pessimistic conclusion assumes that a nation intent upon getting nuclear explosive materials from its civil nuclear power industry probably would be more likely to seize spent fuel rather than to take other nuclear materials the diversion of which would more quickly affect the generation of nuclear power and might be more readily detected. Some analysts may argue that the thorium cycle is less susceptible to national diversion because separation of uranium-233 from denatured fuel is more difficult than separation of plutonium from spent fuel. However, considering the availability of centrifuge equipment, it appears credible that a government could assemble a workable clandestine separation plant. Note, the comparative risks would change if international arrangements are made for spent fuel storage in an international facility or in national repositories under international protection and control. In this case, the risks of diversion of plutonium from spent fuel would go down, but the risks of separation of uranium-233 from thorium cycle fuel would remain. Noted that with a once-through fuel cycle, the world inventory of plutonium in spent fuel would increase each year. At the moment there is little progress toward establishing international storage or control for spent fuel and the provisions of the Nuclear Non-proliferation Act would make it difficult for the President to routinely require the return of spent fuel to the United States after use abroad.

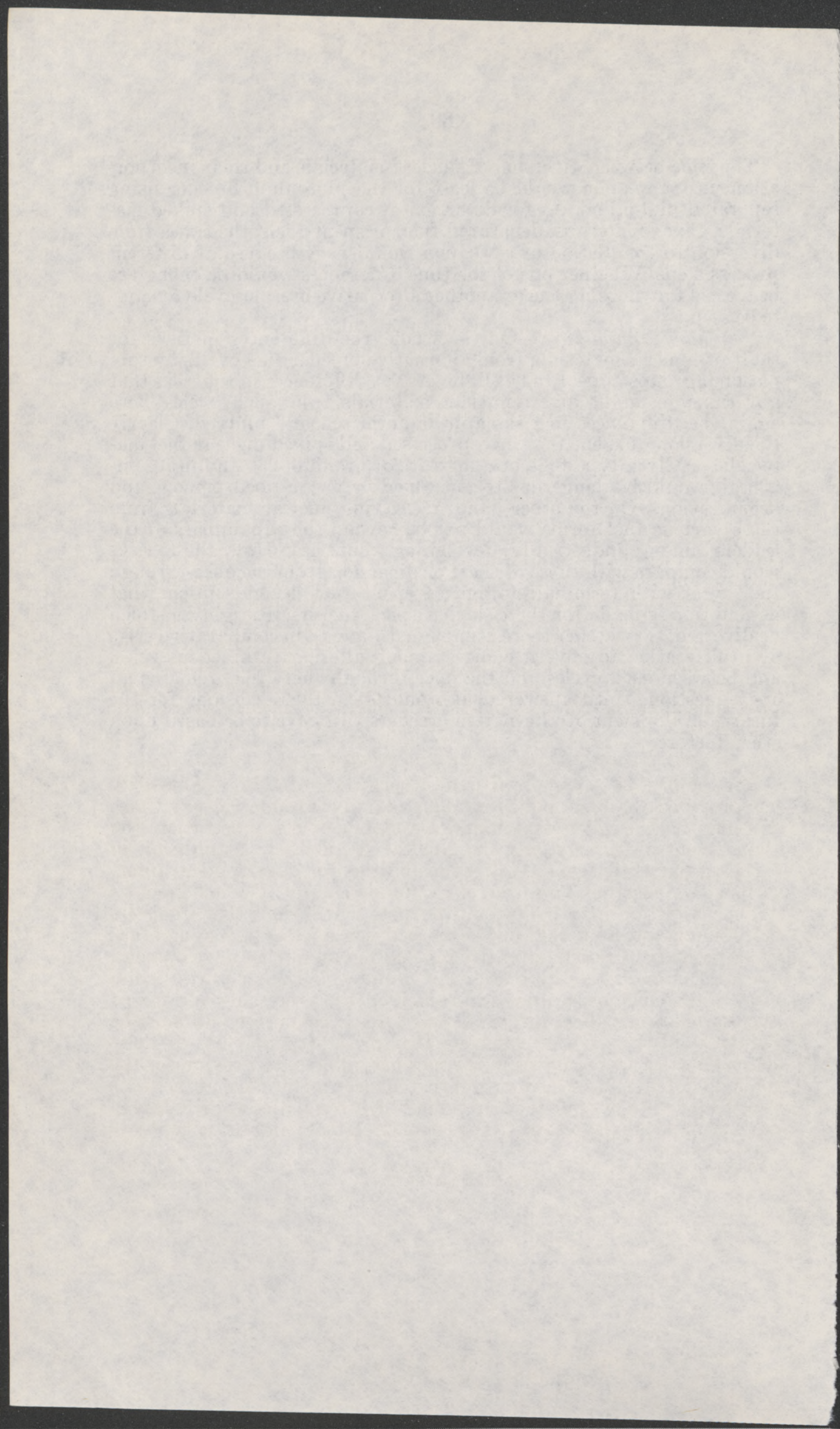
The ability of international safeguards to provide timely warning of diversion is an important factor in assessing the risks of national proliferation from alternative breeder cycles. Since present sampling and analytical techniques cannot offer absolute assurance of timely detection of any diversion, these measures, as indicated earlier, must be supplemented to limit access to and to observe places where dangerous nuclear materials are found. National fuel reprocessing plants probably provide the greatest problem for safeguards. Continuous international inspection would be a prerequisite, plus substantial improvements in techniques and equipment for measuring nuclear materials, particularly in diluted or radioactive forms. Safeguards probably are the most reliable for the once-through fuel cycle and the least reliable for the plutonium breeder with separated plutonium. While safeguards technologies to deal with coprocessed or Civex-type materials need improvement, what this improvement should be has yet to be specified and agreed upon.

A cautionary note: Safeguards are intended to provide warning of theft or diversion and so deter the temptation to steal or divert. The overall effectiveness of safeguards thus is inextricably linked to the kinds of responses the community of nations is likely to make should theft or diversion occur. Whether sanctions would be applied and how effective they would be is, however, beyond the scope of this analysis.

Physical security cannot be considered a barrier to national diversion because it would be under control of the very government that might wish to divert nuclear materials. International physical security, were it available, probably would be unable to withstand assault by a government intent upon seizure, but would provide an immediate signal of any such attempt.

The time between diversion of nuclear materials and their incorporation into a weapon would be least for the plutonium breeder using separated plutonium. As for diversion of coprocessed and spiked materials, Civex materials, denatured fuel, or spent fuels, the times from diversion to completion of a weapon would vary because of different process steps. Whether or not the time differences would be enough to be a basis for choosing one or another alternative breeder cycle remains to be seen.

Summary comparison.—On the whole, the differences in risks for theft of nuclear materials from alternative breeder fuel cycles by subnational groups appear to be slight. As for differences in the risks that governments might divert nuclear materials from such cycles, here again the differences in risks appear uncertain and blurred. Clearly the diversion of spent fuel, or coprocessed and spiked nuclear fuel materials, or Civex type fuel, or a mixture of uranium-233 and uranium-238 all would be dangerous to untrained or unequipped persons and organizations. On the other hand, recovering nuclear materials from these various fuel forms would not be beyond the capabilities of the leaders among industrially developing countries. How these risks would compare with those of theft or diversion from the once-through fuel cycle with terminal storage of spent fuel depends upon what assumption is made for the risk that spent fuel itself might be stolen or diverted. So whether there is enough difference in comparative risks of proliferation to govern choices among alternative breeder cycles, and between such cycles and the once-through fuel cycle, remains an open question. Until answered, it would seem that decisions for the future development of alternative breeders will have to be based upon other factors.



CHAPTER VIII. THE LEGISLATIVE BASIS FOR U.S. NONPROLIFERATION POLICIES*

One reason why development of alternative nuclear breeders is under consideration is President Carter's nonproliferation policy. Another lies in policies and other measures appearing in legislation. The main statutory statements of U.S. nonproliferation policy are to be found in the Atomic Energy Act of 1954 as amended, and in the recently enacted Nuclear Non-Proliferation Act of 1978. With this in mind, there follows a brief summary of the legislative basis for U.S. nonproliferation policies.

MAJOR LEGISLATION

Policies for the development of nuclear power in the United States, the evolution of U.S. technical assistance and exports for nuclear power abroad, and control of the link between civil nuclear power and the spread of nuclear weapons, all are affected by the statutory provisions of the Atomic Energy Act of 1954 as amended, the Atomic Energy Reorganization Act of 1974, and the Nuclear Non-proliferation Act of 1978, as shown in table 22. These provisions are summarized below as background for the subsequent description of Federal agencies and programs affecting the possible further spread of nuclear weapons or explosives.

The Atomic Energy Act of 1954 As Amended

For the past 24 years, the Atomic Energy Act of 1954, as amended, has provided the basic policy guidance for the Atomic Energy Commission, the Energy Research and Development Administration, the Department of Energy, and the Nuclear Regulatory Commission in carrying out their respective responsibilities for development, international cooperation, and control of atomic energy. The act includes statements of findings, policy, and purpose which show that Congress in 1954 was aware of the connection between nuclear energy and national security. The act's statement of findings holds that development, use, and control of atomic energy for military and other purposes are vital to the common defense and security; that processing and use of nuclear materials affect interstate and foreign commerce and must be regulated in the national interest; that processing and use of these materials must be regulated in the national interest to provide for the common defense and security; and that nuclear materials and facilities are affected with the public interest, and their regulation is necessary in the national interest to assure the common defense and security.⁴³

*Prepared by Warren H. Donnelly, Senior Specialist.

⁴³ The Atomic Energy Act of 1954 as amended, sec. 2.

TABLE 22.—STATUTES CONTAINING PROVISIONS RELATING TO NUCLEAR ENERGY AND NONPROLIFERATION

	Atomic Energy Act of 1954 as amended	Energy Re- organization Act of 1974	Nuclear Non- proliferation Act of 1978
Findings.....	X	X	X
Policy.....	X	-----	X
Purpose.....	X	-----	X

The fundamental policy statement of the act addresses foreign and domestic aspects separately. Noting that atomic energy is capable of peaceful as well as military uses, Congress declared it to be U.S. policy that:

The development, use, and control of atomic energy shall be directed so as to make the maximum contribution to the general welfare, subject at all times to the paramount objective of making the maximum contribution to the common defense and security; and

The development, use, and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise.⁴⁴

To carry out these policies, the act provides for six programs, five of which bear more or less directly upon domestic development and international cooperation for nuclear power. These five statutory programs are:⁴⁵

For conducting, assisting, and fostering research and development in order to encourage maximum scientific and industrial progress;

For the dissemination of unclassified scientific and technical information and for the control, dissemination, and de-classification of Restricted Data, subject to appropriate safeguards, so as to encourage scientific and industrial progress.

For Government control of possession, use, and production of atomic energy and special nuclear material, whether owned by the Government or others, so directed as to make the maximum contribution to the common defense and security and the national welfare, and to provide continued assurance of the Government's ability to enter into and enforce agreements with nations or groups of nations for the control of special nuclear materials and atomic weapons.

To encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defense and security and with the health and safety of the public;

For international cooperation to promote the common defense and security and to make available to cooperating nations the benefits of peaceful applications of atomic energy as widely as expanding technology and considerations of the common defense and security will permit.

The Energy Reorganization Act of 1974

Although the Energy Reorganization Act of 1974, Public Law 93-438, addressed reorganization rather than policy or programs, in the declaration of purpose, Congress declared, in part, that the general welfare and the common defense and security required effective action to develop and increase the efficiency and reliability of use of all energy sources to strengthen the U.S. position in international trade and assistance in nuclear energy in relation to proliferation.

The Nuclear Non-proliferation Act of 1978

The recently approved Nuclear Non-proliferation Act of 1978, which President Carter signed on March 10, 1978, contains detailed state-

⁴⁴ Ibid., sec. 1.

⁴⁵ Ibid., sec. 3.

ments of findings, policy, and purpose that will substantially affect U.S. international trade assistance, and relations in nuclear energy.

In a statement of findings, Congress implicitly expanded the definition of proliferation to include the ability to produce nuclear explosive materials and to note the link of civil nuclear energy to proliferation Congress found and declared that:⁴⁶

The proliferation of nuclear explosive devices or of the direct capability to manufacture or otherwise acquire such devices poses a grave threat to the security interests of the United States and to continued international progress toward world peace and development.

Based upon this finding, Congress declared it to be the policy of the United States to:

(a) actively pursue through international initiatives mechanisms for fuel supply assurances and the establishment of more effective international controls over the transfer and use of nuclear materials and equipment and nuclear technology for peaceful purposes in order to prevent proliferation, including the establishment of common international sanctions;

(b) take such actions as are required to confirm the reliability of the United States in meeting its commitments to supply nuclear reactors and fuel to nations which adhere to effective non-proliferation policies by establishing procedures to facilitate the timely processing of requests for subsequent arrangements and export licenses;

(c) strongly encourage nations which have not ratified the Treaty on the Non-Proliferation of Nuclear Weapons to do so at the earliest possible date; and

(d) cooperate with foreign nations in identifying and adapting suitable technologies for energy production and, in particular, to identify alternative options to nuclear power in aiding such nations to meet their energy needs, consistent with the economic and material resources of those nations, and environmental protection.

To promote this fourfold policy, the act included a statement of purpose calling for a more effective framework for international energy cooperation to meet energy needs and to insure that civil nuclear power does not contribute to proliferation; for the United States to reliably meet its commitments to effective nonproliferation policies; for incentives to other nations to join the United States in such international cooperation and to ratify the NPT; and for effective U.S. control over its nuclear exports.⁴⁷

THE IMPLICATIONS FOR ALTERNATIVE BREEDER REACTORS

The statutes affecting nuclear energy and nonproliferation suggest a legislative preference for world use of nuclear power that avoids reprocessing of spent fuel to recover plutonium and the use of plutonium as a nuclear fuel. The legislation draws no distinction between separated plutonium and plutonium combined with other materials or

⁴⁶ The Nuclear Non-proliferation Act of 1978, Public Law 95-242, sec. 2.

⁴⁷ Ibid., "SEC. 3. It is the purpose of this Act to promote the policies set forth above by—

"(a) establishing a more effective framework for international cooperation to meet the energy needs of all nations and to ensure that the worldwide development of peaceful nuclear activities and the export by any nation of nuclear materials and equipment and nuclear technology intended for use in peaceful nuclear activities do not contribute to proliferation;

"(b) authorizing the United States to take such actions as are required to ensure that it will act reliably in meeting its commitment to supply nuclear reactors and fuel to nations which adhere to effective non-proliferation policies;

"(c) providing incentives to the other nations of the world to join in such international cooperative efforts and to ratify treaty; and

"(d) ensuring effective controls by the United States over its exports of nuclear materials and equipment and of nuclear technology."

treated to make it more difficult or dangerous to steal or divert. This legislative opposition to reprocessing logically would extend to reprocessing fuels in the thorium cycle. It would also discourage spread of national enrichment capacity and would have such installations under national auspices and control, although it is silent on whether or not U.S. enrichment facilities would be transferred to an international regime. The legislation is optimistic in its directions to the President to negotiate and to seek international support for measures that would limit the risks of proliferation. If these ventures succeed, their success probably would diminish some of the linkage between nuclear power and nuclear weapons, and so reduce opposition to final development and commercial use of some kind of modified breeder fuel cycle. If these ventures do not succeed, then the failure is likely to be cited as added reason to attempt to proscribe nuclear power fuel cycles involving plutonium, uranium-233, or highly enriched uranium.

APPENDIX I. ACRONYMS AND GLOSSARY¹

AGR	Advanced gas reactor (nonbreeding).
GCFR	Gas cooled fast [breeder] reactor.
HWBR	Heavy Water Breeder Reactor (for Candu/PHW).
LMFBR	Liquid metal fast breeder reactor.
LWBR	Light water breeder reactor.
LWR	Light water reactor (nonbreeding).
MSBR	Molten salt breeder reactor.
MWe	Megawatts electric (a unit of power).
MWt	Megawatts thermal (a unit of heat generation rate).
	Approximately 2.5-3 MWt yields 1 MWe.

GLOSSARY

Actinide—Radioactive isotope formed when uranium or plutonium captures successive neutrons without fissioning.

Blanket—A region surrounding the core of a breeder reactor containing fertile material for conversion to fissile material.

Breeding ratio—Number of new fissile atoms produced per atom of fissile material consumed. If the ratio for a given reactor is greater than one, it is a breeder; if less than one, it is a converter. A high breeding ratio results in a short doubling time.

Coolant—The medium in a nuclear reactor which absorbs heat from the reactor core where fission occurs and heat is produced, and transfers it to systems which convert the heat into steam.

Doubling time—The amount of time required for the fissile material in a breeder reactor to double. There are three types of doubling time. *Apparent linear doubling time*, which assumes that the reactor is never refueled and none of the new fissile material is ever removed. *Apparent compound doubling time* assumes that new fissile material is removed as soon as it is produced and placed in other breeders to produce more fissile material—the time to double the total amount of fissile material is apparent compound doubling time. *Compound doubling time* includes "out of reactor" procedures such as the time required for refueling the reactor, reprocessing spent fuel rods, and refabricating new fuel rods. Therefore it is the total time required for the amount of fuel material at any point in the reactor-reprocessing refabrication chain to double.

Driver—That part of the reactor's core which produces heat for power generation.

Fertile—Refers to an atom which cannot be fissioned with slow neutrons but can be made fissile by the addition of a neutron to its nucleus. For example, the isotope uranium-238 is fertile in that it cannot fission without first capturing one neutron—which converts the element into plutonium which is fissile.

Fissile atom—An atom which can be fissioned by neutrons of any speed.

Fission—The physical process whereby the nucleus of an atom is split into two or more nuclei of lower atomic weight whose total mass is less than that of the original nucleus. The lost mass becomes energy according to Einstein's equation. Fission is initiated by the capture of a neutron by the nucleus of a fissionable atom, and is accompanied by the emission of between one and three other neutrons. These neutrons in turn can fission adjacent nuclei, producing a self-perpetuating reaction, or *chain reaction*.

Fission products—The elements remaining after fission, either solid or gas. These are radioactive, and can produce "decay heat" after a reactor has been shut down, necessitating provision of core cooling systems to operate even when the fission reaction is shut off. Decay heat can produce about 8 percent of the

¹ Prepared by Marcia S. Smith, Analyst in Aerospace and Energy Technology.

reactor's full power output, although it drops off steadily after the reactor has been shut down.

Moderator—A substance used to slow down neutrons so fissile nuclei can more easily and efficiently capture them. The neutrons lose energy by colliding with the nuclei of the moderator, and are termed "slow" or "thermal" neutrons. Some common moderators include graphite, water, and heavy water (deuterium).

Nuclear excursion—An unplanned increase in reactor power level caused by the presence of undesired positive reactivity (see below). Most excursions are terminated automatically by the reactor protection system (RPS). Very large excursions could result in release of radioactive material.

Reactivity—The fractional excess of neutron production from fission over neutron absorption within the reactor. Positive reactivities signify an excess of production over absorption, increasing core power level; negative reactivities signify a deficit production relative to absorption and cause the core power level to decrease. In most operations, reactivity is zero, which corresponds to a constant power level.

Recriticality—At the point a nuclear mass begins a chain reaction, it is termed "critical." In a reactor, criticality is the point at which constant power production occurs. In the event of an accident with a fast reactor, it is conceivable that the core could melt, at which point it would lose its criticality, fall to the bottom of the reactor and might reform into a critical mass, or become "recritical," possibly resulting in release of radioactivity to the environment.

APPENDIX II. SUPPLEMENTARY INFORMATION

[Prepared by Warren H. Donnelly, Senior Specialist]

Introductory Note

Consideration of the future for alternative breeder fuel cycles inevitably must take place in the environment of non-proliferation policies and supporting measures. To provide background on these matters and at the same time avoid putting too much detail into the body of the preceding CRS analysis, selected supplementary information has been gathered into this Appendix. It includes information on nuclear weapons, the International Nuclear Fuel Cycle Evaluation and the Nuclear Non-Proliferation Treaty.

Effects of Nuclear Weapons and Explosives

Central to concern over the possible further spread of nuclear weapons, and the ability to make them, is their enormous destructive capability.

The U.S. nuclear attack upon Hiroshima, on August 6, 1945, destroyed almost 5 square miles of the city, injured some 70,000 persons, with another 70,000 killed or missing. The weapon used was made with highly enriched uranium and had a yield of about 20 kilotons of TNT. The U.S. attack on Nagasaki, on August 9, 1945, destroyed almost 2 square miles of that city, injuring 40,000 persons, with another 36,000 killed or missing. The weapon used there was made from plutonium and had a yield of about 20 kilotons also.¹

TABLE I.—DAMAGE RADII FOR VARIOUS EFFECTS OF NUCLEAR EXPLOSIONS
[Range in meters]

Effects	Explosive yield					
	1 ton	10 tons	100 tons	1 kiloton	10 kilo- tons	20 kilo- tons
Lethal fallout.....	76	240	760	2,400	7,600	11,000
Onset of radiation sickness.....	230	430	710	1,050	1,400	1,500
Lethal radiation dose ¹	160	325	570	880	1,200	1,300
Severe damage to apartment-type building.....	29	76	185	410	930	1,200
Severe damage to multistory wall-bearing building..	21	56	140	320	700	870
50 percent second-degree burns.....	21	73	260	800	2,200	3,200
50 percent third-degree burns.....	18	61	210	660	1,900	2,600
Spontaneous ignition of dry wood ²	14	46	160	500	1,400	2,000

¹ Without medical attention, 50 percent of the people exposed will die in 60 days.

² Assumed to occur at about 75 percent of the range for 50 percent third-degree burns. At these distances, thin wood, such as shingles, will often continue to burn after the thermal pulse has passed. Thicker wood will usually self-extinguish.

Source: Developed for NRC using methodology contained in reference 51. U.S. Nuclear Regulatory Commission. Safe-guarding a domestic mixed oxide industry against hypothetical subnational threat. May 1978, report NUREG-0414, pp. 3-36

¹ John F. Hogerton. The atomic energy deskbook. New York: Reinhold Publishing Corp.; 1963, pp. 228 and 318.

Nuclear Explosive Materials and Their Sources

The amount of material required to make a nuclear explosive or bomb is comparatively small. About 5 to 10 kilograms of plutonium-239 or uranium-233, or 15 to 30 kilograms of uranium enriched to about 90 percent uranium-235, are the usual estimates. In theory, uranium enriched to as low as 20 percent could be used, but much greater quantities of the more dilute materials would be required and design would be more difficult.²

Congress, in the Atomic Energy Act of 1954 as amended defined "special nuclear materials" to mean:³

(1) plutonium, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission [Department of Energy], pursuant to the provisions of section 51, determines to be special nuclear materials, but does not include source material; or (2) any material artificially enriched by any of the foregoing, but does not include source material.

The term "source material" refers to nuclear materials that are not directly usable to make nuclear explosives or bombs and is defined to mean:⁴

(1) uranium, thorium, or any other material which is determined by the Commission [Department of Energy] pursuant to provisions of section 61 to be source material; or (2) ores containing one or more of the foregoing materials, in such concentration as the Commission [Department of Energy] may by regulation determine from time to time.

Highly enriched uranium can be produced by many processes. The United States and the Soviet Union use the gaseous diffusion process. France is building one commercial plant using this process (Eurodif) and planning construction on another (Coredif). The United Kingdom, the Netherlands, and the Federal Republic of Germany are engaged in the trilateral development of the gas centrifuge process for commercial enrichment and the United States plans to use this process for the next addition to the enrichment plants of the Department of Energy. South Africa is working on an enrichment process that is somewhat simpler than diffusion or centrifugation, but requires more electricity to operate. Several countries also are working on use of lasers to so change the electrical properties of atoms or molecules of uranium-235 and uranium-238 that they can be readily separated. In all of these processes the working material is the hexafluoride form of normal uranium (UF_6) which can be made gaseous at comparatively low temperatures.

Plutonium-239 is made by irradiating atoms of uranium-238 with neutrons. Uranium-233 is made by irradiating atoms of thorium with neutrons. For the moment, the source of neutrons to produce uranium-233 or plutonium-239 continues to be nuclear reactors. In principle, alternative neutron sources to produce fissionable materials from fertile materials could include the controlled fusion process and powerful nuclear accelerators.

² The U.S. Office of Technology Assessment used these figures in its report to Congress. Cf., U.S. Office of Technology Assessment. *Nuclear proliferation and safeguards*. New York: Praeger Publishers, 1977, p. 30. Theodore Taylor, a former weapons designer, estimates the quantities as 4 to 8 kilograms of plutonium depending upon the design, with about the same for uranium-233, and 11 to 25 kilograms of highly enriched uranium. Cf., Mason Willrich and Theodore Taylor. *Nuclear theft: risks and safeguards*. Cambridge, Mass.: Ballinger Publishing Co., 1974, pp. 13, 16, and 18.

³ The Atomic Energy Act of 1954 as amended, sec. 11aa.

⁴ *Ibid.*, sec. 11z, 42 U.S.C. 2014.

The United States, the Soviet Union, France, and the United Kingdom, all produce plutonium for nuclear weapons and do so with special nuclear reactors that are not used to generate electricity.⁵

It should be noted that the production of plutonium-239 within a nuclear reactor is also accompanied by production of another isotope, plutonium-240. The greater the proportion of Pu-240, the more difficult it is to use the plutonium for construction of a predictable explosive. The plutonium-240 concentration depends upon the length of time nuclear fuel is irradiated and is much higher in nuclear fuel that has been used for several years to generate power than in the nuclear fuel from a test reactor or one operated exclusively to produce plutonium for weapons. Reactor-grade plutonium, however, can be used to make a nuclear explosive.

The making of nuclear weapons

In the early days of nuclear energy, it was generally assumed that the design and making of nuclear weapons was difficult to do and demanded highly trained engineers and scarce technical facilities. This assumption has changed in the 1970's. Now, some analysts believe that enough is known about the design and making of nuclear explosives for the principal prerequisite to be access to materials, rather than specially trained personnel or equipment. This position was strongly stated in 1974 by Willrich and Taylor, was underscored in the Wohlstetter report and reaffirmed by the Office of Technology Assessment. All of these analyses looked into the making of comparatively small and simple explosives rather than very large weapons, the so-called hydrogen bombs, that can release energy equivalent to millions of tons of high explosives.

Concerning skills and nonnuclear resources required to make nuclear explosives, Willrich and Taylor think that a few persons could build a crude bomb within a few weeks if they had about 10 kilograms of plutonium oxide. Of this, they said:⁶

Under conceivable circumstances, a few persons, possibly even one person working alone, who possessed about ten kilograms of plutonium oxide and a substantial amount of chemical high explosive could, within several weeks, design and build a crude fission bomb. By a "crude fission bomb" we mean one that would have an excellent chance of exploding, and would probably explode with the power of at least 100 tons of chemical high explosive. This could be done using materials and equipment that could be purchased at a hardware store and from commercial suppliers of scientific equipment for student laboratories.

The key persons or person would have to be reasonably inventive and adept at using laboratory equipment and tools of about the same complexity as those used by students in chemistry and physics laboratories and machine shops. They or he would have to be able to understand some of the essential concepts and procedures that are described in widely distributed technical publications concerning nuclear explosives, nuclear reactor technology, and chemical explosives, and would have to know where to find these publications. Whoever was principally involved would also have to be willing to take moderate risks of serious injury or death.

The authors noted that many people would strongly disagree with this conclusion, but that some experts would not. Whatever opinions

⁵ One exception is a plutonium production reactor at the Department of Energy's facility at Hanford, Wash., where waste heat is used to generate electricity.

⁶ Mason Willrich and Theodore B. Taylor. *Nuclear theft: risks and safeguards*. Cambridge, Mass.: Ballinger Publishing Co., 1974, p. 21.

anyone might have about the likelihood that an individual or a small group would actually steal nuclear materials and use them to make nuclear bombs, those opinions, said the authors, should not be based on a presumption that all types of nuclear bombs are very difficult to make.⁷

Assessment of the risk of the spread, or proliferation, of nuclear weapons clearly depends upon assessment of what, in addition to nuclear explosive materials, are needed to make them. Three notable reports addressing this matter, as noted above, are those of Willrich and Taylor, the Office of Technology Assessment, and Prof. Albert Wohlstetter.

In December 1975, Prof. Albert Wohlstetter and six colleagues submitted to the U.S. Arms Control and Disarmament Agency a report on proliferation.⁸ Concerning design, fabrication, and testing of nuclear weapons, the report said that conceptual design was rather simple and had been described qualitatively in the open literature. All of the qualitative concepts are well known, probably better than some of the technology for production of nuclear materials. "It appears that the actual design of a crude weapon is the least of the technological problems associated with weapon technology."⁹

In 1976, the Office of Technology Assessment reported to Congress on nuclear proliferation and safeguards. Concerning the difficulty of constructing a nuclear weapon, the report said that many nations are capable of designing and constructing nuclear explosives which could be confidently expected to have predictable and reliable yields of up to 10 to 20 kilotons, even without prior testing. * * * A national effort to make a few weapons would require a group of more than a dozen well-trained and very competent persons with experience in several fields of science and engineering. They would need a high explosive field-test facility and the support of a modest, already established, scientific technical and organizational infrastructure. If a weapons program was properly carried out, it might produce devices in about 2 years at a cost of a few tens of millions of dollars, assuming the nuclear explosive material and infrastructure are available.¹⁰

As to whether a group of individuals could build a nuclear explosive, OTA reported that given the nuclear explosive materials and a fraction of a million dollars, a small group none of whom have had access to the classified literature, could possibly design and build a device. There is a clear possibility, although not a certainty, that a clever and competent group could design and construct a device capable of a significant nuclear yield.¹¹

The NRC, in its recently published report on safeguarding a plutonium fuel cycle, commented that there is essentially no likelihood that a terrorist group could fabricate an efficient bomb such as those in military inventories. There is, however, "* * * a low but credible probability that such a group could assemble a crude device which would produce a fission yield," the report said. "It is this possibility

⁷ Ibid.

⁸ Albert Wohlstetter, et al. *Moving toward life in a nuclear armed crowd?* Prepared for the U.S. Arms Control and Disarmament Agency by Pan Heuristics, a division of Science Applications, Inc., Los Angeles, Calif., December 1975, revised Apr. 22, 1976, p. 286.

⁹ Ibid., p. 246.

¹⁰ U.S. Office of Technology Assessment. *Op. Cit.*, p. 16.

¹¹ Ibid., p. 17.

that must be minimized by industry safeguards.”¹² After reviewing what others had said about the prospective groups, the NRC drew the following four conclusions:¹³

To fabricate an illicit nuclear explosive requires a group of individuals with special knowledge, skills, and experience covering several technical fields.

To bring together in a coordinated effort persons who combine the requisite qualifications with the motivation to use a nuclear weapon would be most difficult but not impossible.

Should such a group exist, it might well be deterred by the difficulties involved in the job; for example, the need to acquire significant quantities of a heavily guarded material and the significant hazards of working with the material.

The true challenge of safeguards is to make such difficulties even greater, thereby reducing the likelihood that any attempt will be made.

The International Atomic Energy Agency

The IAEA is an autonomous, intergovernmental organization with its headquarters in Vienna, Austria. It is related to the United Nations by an agreement which recognizes it as “the agency under the aegis of the United Nations responsible for international activities concerned with the peaceful uses of atomic energy.” The IAEA reports annually to the United Nations General Assembly and, when appropriate, to the Security Council. Its functions and responsibilities, as specified in an international statute which entered into force on July 29, 1957, are: “to seek to accelerate and enlarge the contributions of atomic energy to peace, health and prosperity throughout the world” and “to insure that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purposes.” Virtually all nations of the world belong to the IAEA, with membership reaching 109 nations in 1976. The Republic of China (Taiwan) is not now a member, in essence having been expelled for the People’s Republic of China which, however, has not yet taken Taiwan’s seat.

IAEA safeguards.—The IAEA’s function of establishing and maintaining effective safeguards is a heavy responsibility, for many non-proliferation measures would lose their effect without them. So it is important to keep in mind fundamental concepts of safeguards systems and possible criteria for judging these systems.

Fundamental safeguards concepts.—A potential thief or diverter of nuclear materials is confronted with four basic problems:

1. How to gain access to the nuclear materials to be stolen or diverted.
2. How to remove the material from a facility or transport where it is legitimately present.
3. How to conceal the diversion.
4. How to use the material obtained.

Any system of nuclear safeguards which can demonstrate that it effectively blocks one of these requirements is considered as complete and no further action need be taken. To date, however, no one has presented for consideration any safeguards system which guarantees that it effectively precludes a solution to any one of the diverter’s problems, and it seems unlikely that anyone ever will. The result is a search for a combination of systems which somehow provides the desired assur-

¹² U.S. Nuclear Regulatory Commission. Safeguarding a domestic mixed oxide industry against a hypothetical subnational threat. May 1978, NUREG-0404, p. 3-31.

¹³ Ibid., pp. 3-34.

ance by placing major stumbling blocks in the path of a would-be thief or diverter at each step.

Material accounting, containment and surveillance are considered to be the principal safeguards procedures. Of these, containment is generally accepted as being the most effective if two assumptions hold true: First, that the containment system cannot be bypassed; second, that a would-be diverter would wish to conceal his diversion for longer than the period between inspections. Recognition of this limitation has led some experts to the concept of "critical time," which is the minimum time needed by a diverter to convert the stolen or diverted material into usable form. If the critical time is less than the time between inspections, then containment and inspection is not enough for effective safeguards.

The aim of IAEA safeguards is to deter the diversion of nuclear material to military uses, particularly to nuclear weapons or other nuclear explosive devices by exposing a diverter or thief to risk of discovery. This is done by the IAEA verifying records of nuclear facilities and by inspection so that any diversion or theft would promptly be detected by the Agency. If the inspectors find noncompliance, they report to the Director General who is to transmit their report to the Board of Governors. The Board is to call upon the State or States to remend their noncompliance and to report the non-compliance to all members and to the U.N. Security Council and General Assembly.

IAEA safeguards systems commonly include the following elements:

Design review.—The safeguarded nation must supply the IAEA with information on design features of its existing nuclear facilities to be safeguarded and of new ones in their planning stage.

Records.—The nuclear facility operator must keep precise account of all nuclear materials on hand, received, sent out, etc., based on exact measurements.

Reports.—The government agency responsible for internal safeguards sends the IAEA regular reports on the amounts of nuclear material in each safeguarded plant and of all changes in these amounts so that the IAEA can keep its own accounts for verification and comparison.

Inspections.—IAEA inspectors make independent measurements and observations to verify the information submitted by the country concerned. All inspectors have to be approved by the IAEA's Board of Governors and designated with the consent of the country concerned.

Safeguards for non-NPT states.—IAEA safeguards apply within a state either because it has voluntarily asked the IAEA to apply them, or because the state has ratified the NPT and so has committed itself to IAEA safeguards for all of its nuclear facilities.

For non-NPT states, the Agency's safeguards system is defined in detail in its Information Circular No. 66, revision 2 (INFCIRC/66/Rev.2), which outlines general principles of safeguards, circumstances requiring safeguards, and safeguards procedures. It is a public document. Supporting it for each such state is a secret subsidiary arrangement with the Agency that contains information about specific installations and provisions for inspection. IAEA safeguards in a non-NPT

state apply only to those facilities designated by the state, so it is entirely possible for there to be safeguarded and nonsafeguarded materials and facilities side-by-side in a non-NPT state, as in India. The non-NPT system emphasizes inspection and focuses upon material at the specified facilities rather than upon the materials in the state as a whole.

Safeguards for NPT states.—For states that have ratified the NPT, a somewhat different IAEA safeguards system applies, which is defined in IAEA Information Circular No. 153 (INFCIRC/153). These safeguards apply to all materials and facilities within the state, and tend to substitute sampling and statistical analysis of data plus the use of seals and monitoring devices for personal inspection.

Notable differences.—The IAEA safeguards systems for non-NPT and NPT states have a fundamental difference of purpose. The non-NPT system is intended to assure that nuclear assistance provided by the Agency at its request, or under its supervision or control, is not used in such a way as to “further any military purpose.” The NPT safeguards system is intended to assure timely detection of the diversion of significant quantities of nuclear material from peaceful uses to nuclear weapons or other nuclear explosives, or for purposes unknown. This last phrase, “for purposes unknown” is important because it means that the IAEA does not have to prove that a specific explosive device has been manufactured, which would be almost impossible to do in practice. Rather, IAEA need only establish proof of the presence or consumption of the nuclear materials in peaceful uses. The disappearance of such materials in an NPT safeguards system is considered in itself to constitute diversion.

Limitations of IAEA safeguards.—The IAEA’s safeguards system is not intended to prevent diversion or theft and cannot provide absolute assurance that no amount of nuclear material, however small, will be diverted or stolen, and that any thefts or diversions, no matter how small, will be immediately detected and reported. In the real world, complete fulfillment of these criteria is unattainable. At issue is how close to perfect safeguards should be for future use of dangerous materials for nuclear fuel. Is there a point at which costs of increased safeguards outweigh the added assurance provided?

Relation of IAEA safeguards to state systems.—Both IAEA safeguards systems require recordkeeping by the safeguarded states. Each non-NPT state is required to keep records and make reports for its nuclear facilities under safeguards and for all safeguarded nuclear materials outside such facilities, but is not obligated to inform the Agency about nuclear facilities and materials not safeguarded. Each NPT state is required to establish a national system of accounting and control of all nuclear materials covered by the NPT and the Agency is expected to make full use of the State system to avoid duplication. The interaction of IAEA and state safeguards systems is further indicated by the provision in circular 153 that the Agency’s safeguards system should be designed to:

Avoid hampering the economic and technological development of the state or international cooperation in peaceful nuclear activities;

Avoid undue interference in the state’s peaceful nuclear activities; and

Be consistent with prudent management practices required for the economic and safe conduct of nuclear activities.

The IAEA does not specify standards or criteria for state systems.

The International Nuclear Fuel Cycle Evaluation (INFCE)

On April 7, 1977, President Carter, as part of his comprehensive nuclear power policy statement, called for an international nuclear fuel cycle evaluation. The organizing conference was held in Washington in October 1977. INFCE's results are expected early in 1980. INFCE is a unique enterprise, a multinational examination of ways in which nuclear energy can be made available to meet world energy needs while minimizing the danger of proliferation of nuclear weapons, with special attention to the needs of developing countries. Fifty-two nations and four international organizations are participants. They include: all the nuclear-weapons states except the People's Republic of China; the leading nuclear power states; the significant nuclear exporter and importer states; OPEC members and significant importers of oil; countries of Eastern Europe and the Western World; non-aligned countries; industrialized and developing countries; and parties and nonparties to the Nuclear Non-Proliferation Treaty. The four participating organizations are EURATOM, the Nuclear Energy Agency of the OECD, the International Atomic Energy Agency and the International Energy Agency.

The INFCE evaluation is a technical and analytical study that will include different points of view. It is not an international negotiation. Participants are not bound by any results, and the evaluation is to be carried out without jeopardizing the fuel cycle policies of the participating nations or their cooperative agreements. The principal issue addressed is safeguards and perhaps new institutional or other international arrangements sufficient to minimize proliferation risks or the possible limitation of nuclear technologies especially those for producing plutonium and enriched uranium.

INFCE was given a statutory basis in the Nuclear Non-Proliferation Act of 1978. Section 105 provides:

The President shall take immediate initiatives to invite all nuclear supplier and recipient nations to reevaluate all aspects of the nuclear fuel cycle, with emphasis on alternatives to an economy based on the separation of pure plutonium or the presence of high enriched uranium, methods to deal with spent fuel storage, and methods to improve the safeguards for existing nuclear technology. The President shall, in the first report required by section 601, detail the progress of such international reevaluation.

The work of INFCE is divided among eight working groups which are cochaired by groups of three countries, as shown in table II. The United States cochaurs Working Group 8 which is examining once-through use of nuclear fuel in thermal reactors as well as alternative reactor and fuel cycle concepts. U.S. representatives are active in all working groups. The responsibility for U.S. participation was assigned by President Carter to Mr. Gerard Smith, an Ambassador at Large.

The Arms Control and Disarmament Agency, the Department of Energy and the Department of State, all contribute analytical support to INFCE. The principal source is DOE's nonproliferation alternative systems assessment program (NASAP) which is carrying out

a screening of all candidate nuclear power systems, and selecting for detailed analysis those which offer good proliferation resistance and which are attractive technically, economically, environmentally, and for public health and safety.

TABLE II.—MEMBERSHIP OF INFCE WORKING GROUPS

Group number	Subject	Cochairing countries
1	Fuel and heavy water availability	Canada, Egypt, and India.
2	Enrichment	France, Federal Republic of Germany, and Iran.
3	Long-term supply of technology, fuel and heavy water, and services.	Australia, the Philippines, and Switzerland.
4	Reprocessing, plutonium handling, and recycle	Japan and the United Kingdom.
5	Fast breeders	Soviet Union, Italy, and Belgium.
6	Spent-fuel storage	Argentina and Spain.
7	Waste management and disposal	Sweden, the Netherlands, and Finland.
8	Advanced fuel cycle and reactor concepts	United States, Romania, and Korea.

Ambassador Smith cautions that expectations for INFCE should be neither too high nor too low. Recently he said: ¹⁴

It is too much to expect that a universal technological fix or instructional remedy will be discovered—which will eliminate any possibility for misuse of the materials and facilities associated with nuclear power programs. It is too little to conclude that because there exists no absolutely proliferation-proof nuclear fuel cycle, nothing fruitful can emerge from the INFCE progress. But it is reasonable to expect that useful and significant products will emerge from this most intensive and comprehensive review of nuclear power ever undertaken.

Summing up his view of INFCE, Ambassador Smith said: ¹⁵

In my view, a full presentation of the advantages and disadvantages of alternative technologies and institutional arrangements for providing nuclear power while minimizing proliferation dangers would, by itself, be an accomplishment of sufficient value to make INFCE a sound investment for a world full of insecurities.

The Non-Proliferation Treaty (NPT)

The Treaty on the Non-Proliferation of Nuclear Weapons, signed in Washington on July 1, 1968, established an extraordinary set of international commitments to limit the spread of nuclear weapons. It commits both the United States and the Soviet Union to reduce nuclear armaments in exchange for commitments by other states not to acquire nuclear weapons or explosives. The nonweapons states also agree to place all their nuclear power activities under safeguards of the IAEA, including inspection by IAEA inspectors. In return for these commitments, the nonweapons states are assured of United States and U.S.S.R. cooperation in developing peaceful uses of nuclear energy, and of access to whatever benefits may be derived from the peaceful uses of nuclear explosives. The latest nation to ratify the NPT was Japan, on May 24, 1976. The Japanese ratification and the ratification in May 1975 by the Common Market States (EURATOM) mean that the most industrialized nonweapons countries adhere to the NPT and have committed themselves to safeguards and to peaceful uses.

Genesis of the NPT.—The idea of international control for nuclear energy to prevent its misuse for weapons was a key feature of U.S. proposals to the United Nations in the mid-1940's, but nothing came of

¹⁴ Gerard Smith. "Status of International Nuclear Fuel Cycle Evaluation." Remarks before the National Energy Forum VI. May 19, 1978, p. 12.

¹⁵ Ibid., p. 13.

them. The idea revived again in President Eisenhower's atoms-for-peace speech to the United Nations on December 8, 1953. The President proposed to promote peaceful uses of nuclear power as a way to reverse the trend of nuclear military buildup. Nuclear materials committed to peaceful purposes would not be available for weapons. To this end, he proposed that nuclear nations, primarily the United States and the Soviet Union, contribute fissionable materials to an international pool to be administered by an international agency. The agency would be responsible for the impounding, storage, and protection of the contributed nuclear materials. "The ingenuity of our scientists will provide special safe conditions under which such a bank of fissionable material can be made essentially immune to surprise seizure."

In the spring of 1966, after hearings by the Joint Committee on Atomic Energy, a consensus of the Senate was reached in support of negotiations toward a nonproliferation treaty in Senate Resolution 179, which was sponsored by Senator Pastore and 58 other Senators and adopted by a bipartisan vote of 84 to 0, with all absent Senators but one declaring themselves in favor.

After almost 2 years of negotiations, the United States and the Soviet Union presented identical drafts of a treaty to a U.S. disarmament conference on August 2, 1967. The article for safeguards, however, was blank because of inability to reach agreement. That gap was filled on January 18, 1968, when the United States and the Soviet Union submitted a complete treaty draft. On June 12, 1968, the General Assembly approved a resolution commending the treaty by a vote of 95 to 4 (with 21 abstentions). The treaty was opened for signatures on July 1, 1968, in Washington, London, and Moscow, and was signed by the United States, the United Kingdom, and the Soviet Union and 59 other nations.

President Johnson, when he signed the NPT, repeated his earlier offer of December 2, 1967, for the United States to permit the IAEA to apply its safeguards to all nuclear activities in the United States, excluding only those with direct national security significance. The Senate gave its advice and consent to the treaty on March 13, 1969, by a vote of 83 to 15, with two abstentions. The treaty was ratified in Washington on November 24, 1969, and came into force on March 5, 1970.

Objectives of the NPT.—The NPT is a complex set of undertakings and obligations, each of which represents in its own right a highly desirable objective that should be pursued whether or not the NPT itself exists, and irrespective of the success, or lack thereof, achieved in pursuit of other objectives. This statement by Dr. S. Eklund, Director General of the IAEA, introduced his following summary of the NPT's objectives. We cite his views because the IAEA is at the focal point of international efforts to stem proliferation, and it is pertinent to see how the Agency views the NPT. As described by Dr. Eklund, the four major objectives of the NPT are:

(1) To prevent the spread of nuclear weapons to countries other than the five that possessed them at the end of 1966. Obviously, this is the main purpose of the Treaty. It provides the substance of the first three articles and gives the Treaty its name.

(2) To promote international cooperation in developing the peaceful use of nuclear energy, and particularly to help developing countries in this regard.

(3) To afford all parties whatever benefits may be derived from the peaceful uses of nuclear explosions ; and

(4) To pursue negotiation toward the cessation of the arms race, nuclear disarmament, and eventually to a treaty on general and complete disarmament, "under strict and effective international control." Although this is not actually said in the relevant article, it is generally considered that this obligation falls particularly upon those parties of the Treaty that are nuclear-weapons states.

Analysis of the NPT.—Articles I and II of the treaty contain the basic undertakings to prevent the proliferation of nuclear weapons.

Article I states the obligations of the nuclear-weapons states (which are limited to those that had made and exploded a nuclear weapon or device prior to January 1, 1967). Three conditions apply. First, these states agree not to transfer nuclear weapons, or control over them, to any recipient whatsoever. Second, the weapons states agree not to assist nonweapons states to manufacture or otherwise acquire nuclear weapons. Third, these prohibitions apply not only to nuclear weapons but also to other nuclear explosive devices.

Article II deals with the obligations of all parties that are not weapons states. They are committed not to receive the transfer of nuclear weapons or other nuclear explosive devices, or control over them, from any transferer whatsoever. Also, they must not make or otherwise acquire such weapons or devices, or seek or receive assistance in such manufacture.

Article III provides for verification of compliance with the treaty through international safeguards designed to insure that nuclear energy is not diverted from peaceful uses to nuclear weapons or other nuclear explosive devices. Such safeguards apply to all nuclear materials in all peaceful nuclear activities within the territory, jurisdiction or control of the nonweapons states. The nonweapons states agree also to accept safeguards on such material for the exclusive purpose of verification of the fulfillment of their obligations under the NPT. The safeguards are to be specified in agreements to be negotiated and concluded with the IAEA.

Article III also prohibits any party from providing nuclear material or equipment or material especially designed or prepared for the processing, use or production of nuclear material, to any nonweapons state unless the material shall be subject to IAEA safeguards. The safeguards are to be so carried out as to comply with article IV, which deals with furthering the peaceful uses of nuclear energy, and to avoid hampering the economic and technological development of the states or international cooperation in peaceful nuclear activities.

Finally, article III permits the agreements with the IAEA to be concluded by non-nuclear-weapons states either individually or together with other states.

Article III does not require weapons states to place their peaceful nuclear activities under IAEA safeguards, which led to some criticism of the treaty as discriminatory. It was in this context that President Johnson made his offer of December 2, 1967, that when such safeguards are applied under the treaty, the United States would permit the IAEA to apply its safeguards to all U.S. nuclear activities excluding only those with direct national security significance. A parallel announcement was made by the United Kingdom. The Soviet Union, however, has steadfastly refused to permit IAEA inspection, although it does permit such inspection in its satellite states.

Article IV insures that nothing in the treaty may affect the rights of all parties, without discrimination, to use nuclear energy for peaceful purposes. It also contains an undertaking by all parties to facilitate, and affirm their right to participate in, the fullest possible exchange of equipment, materials, and scientific and technological information for the peaceful uses of nuclear energy. Finally, it requires those parties in a position to do so to cooperate in contributing to the further development of peaceful applications of nuclear energy, especially in nonweapons states and with due consideration for the needs of the developing areas of the world.

Article V is designed to compensate non-nuclear weapons States for their commitment not to acquire nuclear explosive devices even for peaceful purposes. It assures such states that they will not lose, by such renunciation the potential benefits from peaceful application of nuclear explosions. It is designed also to eliminate any economic incentive for nonweapons states to try to develop their own devices. The weapons states are agreed to undertake appropriate measures to insure that the potential benefits from such peaceful applications will be made available to nonweapons states on a nondiscriminatory basis and that the charge for the explosive devices will be as low as possible and will exclude any charge for research and development. In essence, this article commits the weapons states to provide a nuclear explosion service under international observation and through international procedures.

Article VI is an undertaking by all parties to negotiate in good faith on effective measures relating to ending the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament.

Article VII makes clear that nothing in the treaty affects the right to conclude regional treaties to establish nuclear-free zones.

Article VIII sets procedures for amending the treaty.

Article IX designates the depository governments and specifies when the treaty entered into force.

Article X provides a right of withdrawal upon 3 months' notice if a party finds that extraordinary events related to proliferation have jeopardized its supreme interests. In addition, article X provides for a conference in 1995 at which a majority of the parties will decide whether the treaty shall continue in force indefinitely, or be extended for an additional fixed period, or periods.

Parties to the NPT.—As of April 1977, there were 102 parties to the treaty and 10 other states that had signed but not ratified it. More importantly, 40 non-nuclear-weapons states had neither signed nor ratified. These included substantial industrial countries and countries with large oil incomes. Two nuclear-weapons states, France and the People's Republic of China, also have not signed the NPT. Industrial states which have not signed include Argentina, Brazil, Chile, India, Israel, Portugal, South Africa, and Spain. Oil-rich nations which have not signed include Algeria, Qatar, Saudi Arabia, and the United Arab Emirates. Two other countries notable for other reasons that have not signed are Cuba and Pakistan.

APPENDIX III. NOTABLE ANALYSES OF NUCLEAR POWER AND PROLIFERATION

(Prepared by Warren H. Donnelly, Senior Specialist)

To provide background and further insight into recent thinking about the relationship between nuclear power and the possible further spread of nuclear weapons, there follows highlights of notable statements and reports, organized into two categories. The first includes three notable reports from the Committee on Science and Technology about foreign nuclear programs. The second includes notable recent statements and analyses, presented in chronological order.

REPORTS OF THE COMMITTEE ON SCIENCE AND TECHNOLOGY

During 1977 and 1978 the chairman and other members of the Committee on Science and Technology visited countries that have strong nuclear power programs, particularly those interested in breeder reactors. Out of these visits came three reports: one by the chairman and members who visited Europe in 1977, and two by Mr. Wydler as ranking minority member of the committee. Each of these reports makes notable statements about nuclear power and breeder reactors.

The European visit of the House Committee on Science and Technology.—Following President Carter's announcements of U.S. nuclear energy development policies, the Committee on Science and Technology decided to conduct a thorough review of the recommended policy changes and to assess their impact on the Nation's long-range energy planning options. This review included a visit to Europe by eight members of the Committee on Science and Technology and three members of the Committee on Public Works and Transportation.¹ The Committee on Science and Technology subsequently published a report on its visit,² from which the Committee's summary statement of findings follows.³

(1) France, West Germany, and Japan do not intend to go along with the U.S. position on the breeder reactor program.

(2) With the discovery of the oil and gas deposits in the North Sea, Great Britain can now afford to side with the U.S. breeder reactor policy for the time being.

(3) Officials of the International Atomic Energy Agency were not consulted before the policy changes were formulated.

¹ Members of the Committee on Science and Technology included Representative Olin E. Teague, chairman, and Representatives John Wydler, Dale Milford, Gary Myers, James Scheuer, Tom Harkin, Robert Dornan, and Harold Hollenbeck. Members of the Committee on Public Works and Transportation who went were Representatives John Breaux, John Paul Hammerschmidt, and Norman Mineta.

² U.S. Congress. House. Committee on Science and Technology. European oversight trip. Report of the Committee on * * * 95th Cong., 1st sess. June 1977, 154 pages [committee print].

³ Ibid., pp. 3-4.

(4) France presently has an operating breeder reactor, the Phenix, which is approximately the size of the proposed U.S. Clinch River project.

(5) It was the consensus of the European countries that the United States is 5 to 8 years behind in breeder reactor technology and that the gap is widening.

(6) The United States possesses the greatest amount of known uranium reserves and therefore it is looked upon as having motives of self-interest particularly by developing nations who must sustain high energy growth rates with limited domestic resources of energy.

(7) Almost all foreign nations must rely on the United States for uranium resources for light water reactors. To provide some degree of independence, the nations feel they must press forward with the breeder reactor technology and the plutonium fuel cycle.

(8) Everyone agrees with the idea of the nonproliferation goal as expressed by the President. The issue is whether the United States can afford to terminate technology demonstration and delay the availability of breeder technology.

(9) The International Atomic Energy Agency was established 20 years ago with the basic objective of safeguarding the development of the peaceful atom and provides existing mechanisms for maintaining safeguards through the nonproliferation treaty.

(10) The European Community agrees the U.S. Clinch River breeder reactor program is the next logical step in the U.S. breeder reactor technology program and this view is based on the historical development trends both in the United States and foreign countries.

(11) The Europeans stressed that the world is running out of potential energy resources of oil, coal, gas, and uranium. Alternative energy sources must be developed and the pressures are greatest in countries with limited fossil supplies.

(12) The vacillation of the U.S. policy by the Carter administration has left leaders of foreign countries confused and apprehensive. The February Carter position was to fund the Clinch River breeder reactor program up to \$150 million. The revised Carter position of two months later reverses that position. Both of these positions differ from the original Ford position on the breeder reactor program.

(13) The nations possessing some nuclear capability will continue to keep security and safeguards of nuclear fuel as a top priority item in their plans.

(14) The French feel confident about breeder technology development and expect that development problems which are being resolved in the normal course of a research program with Phenix will not be encountered in the Super-Phenix operations.

(15) The U.S. agreement with the Federal Republic of Germany has important implications for technology development of the high-temperature gas reactor concepts and their ultimate commercialization.

(16) The West Germans have considerable experience with the thorium fuel cycle which is important for the United States since

we are interested in determining the degree of proliferation-resistance which this cycle offers.

(17) In examining the long-term nuclear waste disposal problems, one of the critical factors is the determination of the age and stability of the salt formation to be used as underground storage for the deposit.

Report on oversight of European nuclear energy development.—In May 1978 Mr. John W. Wydler, ranking minority member of the Committee on Science and Technology, forwarded to the committee his report on his trip to Vienna, Yugoslavia, and Spain.⁴ Excerpts follow from his summary of findings that relate to development of nuclear power technology and breeder reactors:⁵

To the rest of the world, the United States policy of deemphasizing atomic power is a no-growth policy of "pullback." Other nations look in amazement at a policy designed to keep us on an oil binge and destined to let the world leave us behind in nuclear technology. Our shifting position on nuclear safeguards has given our Nation a reputation as being an unreliable nuclear partner.

This country's radical change in policy toward the development of nuclear energy and peaceful export of nuclear technology has raised grave doubts among our friends. We are losing credibility with these nations and losing business in the export of peaceful applications of nuclear energy as well.

* * * * *

The limitations of our unilateral policy are becoming clear. Developed countries in Western Europe have no intention of slowing their breeder development programs. Our present policy on the breeder and reprocessing ignores the advances which have been made in safeguards technology as well as the chief mechanism for implementing these safeguards, namely the International Atomic Energy Agency.

Mr. Wydler included many recommendations. Those relating to the technology for nuclear power would have the United States do the following:⁶

1. Accelerate the breeder development to maintain U.S. preeminence in international breeder technology. The Clinch River breeder should be kept on track and the LMFBR base program should be strengthened.
2. Reinstitute the plan to reprocess light water reactor fuel at Barnwell under modern safeguards.
3. Reexamine its nuclear export policy so as to restore U.S. credibility as a strong nuclear partner.
4. Commit itself to the diversion-proof Civex process.
5. Accelerate the expansion of U.S. uranium enrichment capacity.
6. Make a strong commitment to nuclear power in the United States.
7. Encourage export of U.S. safeguards technology.
8. Develop a comprehensive plan for nuclear waste management.

Report on oversight of Soviet nuclear energy development.—In June 1978, Mr. Wydler also forwarded his report on a trip to the Soviet Union.⁷ Mr. Wydler summarized his views in a letter to President Carter, included in the report. He urged the President to support a strong

⁴ U.S. Congress. House. Committee on Science and Technology. Oversight of European nuclear energy development. Report to the committee. 95th Cong., 2d sess., May 1978, 12 pages (committee print).

⁵ Ibid., p. 1.

⁶ Ibid., p. 3.

⁷ U.S. Congress. House. Committee on Science and Technology. Oversight of Soviet nuclear energy development. Report to the committee. 95th Cong., 2d sess. June 1978 66 pages (committee print).

breeder program and warned that other nations are far ahead of the United States in breeder development. The Soviet Union is much farther down the road to the breeder option than the United States and the U.S. fallback position of a research and development program is simply not enough. "We must tell the world we are a strong player in breeder development, and the only convincing way to do that is to build a plan and make a visible national commitment."

The text of Mr. Wydler's letter to the President follows:

COMMITTEE ON SCIENCE AND TECHNOLOGY,
U.S. HOUSE OF REPRESENTATIVES,
Washington, D.C., April 4, 1978.

The PRESIDENT,
The White House.

DEAR MR. PRESIDENT: Today I am writing you from the perspective of a series of international energy discussions which I have just had with the Soviets. It is no exaggeration to say that we are on the verge of an "Atomic Sputnik" in terms of our nuclear policy vis-a-vis the Soviets. They are rapidly moving to build breeder reactor plants and deploy light water nuclear power plants so as to put us clearly in second place in the nuclear league. In particular, I discussed the status of breeder reactor development with Mr. Igor Morozov, deputy chairman of the Soviet State Committee for Atomic Energy. As you know, the critical question of which direction the U.S. breeder program will take is before our Science and Technology Committee this week. I hope this letter will provide you additional insight on why our committee is still concerned about the absence of a strong commitment in the U.S. program.

I am pleased that you have initiated an effort to come to some accommodation with the Congress on the breeder program and the Clinch River Reactor Project in particular. I share your view, as Secretary Schlesinger has related it, that continued confrontation on this issue is not in the best interest of the country. Chairman Teague has told me that you do feel that our Nation needs a strong breeder program.

The fact is, however, that our program cannot really be strong without a demonstration of fast breeder technology in an operating plant. This plant does not have to be the one currently planned for Clinch River, but could incorporate more advanced breeder technology. However, until we make a large commitment, we must keep the Clinch River Plant option open.

I have come to this conclusion about the breeder after my discussion last week with the Soviets in Moscow. I have also had extensive discussions with the International Atomic Energy Agency in Vienna and the French Atomic Energy Commission, all within the past year. In all cases the evidence is irrefutable. Other major developed nations are far ahead of us in breeder development. Our continuing technology program is simply not sufficient to keep this energy option open to the United States in a timely manner.

The Russians have no intention of slowing their already ambitious breeder program. They have been operating a 350 megawatt plant on the Caspian Sea; this "Clinch River" plant has been on line for over 3 years. They plan to complete and begin operation of a 600 megawatt plant in 1980. Thus within the next several years they will have accumulated operating experience of 6-8 years on two different breeder plant designs. Mr. Morozov told me that design of a 1,600 megawatt plant is about to begin and construction will start in the next few years. The Soviets expect that it will take only 7 years to build this commercial-sized plant.

Mr. President, I think you will agree that the Soviets are much farther down the road toward the breeder option than ourselves particularly when one considers the stringent U.S. requirements on breeder licensing. I'm afraid our fall-back position of an R. & D. Program is simply not enough. As we found in our space program, it is not enough to merely design successively more powerful rockets—one must build and fly them as well. We must tell the world we are a strong player in breeder development, and the only convincing way to do that is to build

a plant and make a visible national commitment. The Russians' timetable calls for operation of a commercial size breeder reactor by as early as 1987. We cannot guarantee operation of the Clinch River Plant, which is far from commercial, by that date even if we "pulled out all the stops" on that project.

It is necessary, but not sufficient, to merely say that the United States will pursue a strong breeder program. That is a commitment to nothing. We cannot expect the Russians, French, British, Germans or Japanese to take it seriously. Mr. President, we either play the breeder ballgame or become a spectator. What we have now, even if we keep the Clinch River team together, is only "half a program."

I think it is also important to tell you something about the Soviet commitment to light water reactor technology. The Soviets have decided to build and rely completely on nuclear-electric plants west of the Urals in the European sector of the U.S.S.R. This decision is based on the fact the Soviets are running out of oil, gas and good coal. Dr. Stanovnik of the Economic Commission of Europe said the Soviets have informed Eastern Bloc nations that they cannot count on any oil, and only on limited amounts of gas from the U.S.S.R. If one looks at Siberia as having potentially more resources than Alaska, I think it is inescapable to conclude that we face even a bleaker future than the Soviets for fossil fuel supplies. Yet we are limping indecisively on the nuclear option.

The Supreme Soviet of the Ukraine told me in Kiev that they will complete six large nuclear powerplants in the next 5 years or so. The first unit is already on-line and facilities will be completed to reprocess nuclear fuel on-site to recover the precious energy stored in the uranium and plutonium.

I understand that you plan to make a strong public statement on the need to speed the deployment of light water reactors. I urge you to do so in the very near future so as to improve the climate for public acceptance of nuclear power. Your licensing bill was an important first step in this direction and I applaud you for it. I hope that you can accelerate a nuclear waste management program in the light of the recent DOE report on this issue. The technology for safe disposal of waste exists; the country is waiting for a program which matches the technology.

It seems to me, Mr. President, that you have brought about solidly constructive evaluation of the real concerns about nuclear weapon proliferation since last April. However, I believe that two basic facts remain unchanged. First, our cut-back of the breeder program and lack of commitment to build a fast reactor plant is a clear signal to other nations that we are not serious about preserving this long-term option.

Second, this country's indication that nuclear power is "a last resort" has undermined our credibility abroad and made us an unreliable nuclear partner. I think it has become clear that it should not require the arresting of our technology development to address your proliferation concerns.

The Soviets contend that they are just as serious as the United States about preventing the proliferation of nuclear weapons but "collective decisions" must be made on safeguards.

The CIVEX process appears an attractive route to blunting the terrorist threat for atomic weapons by a diversion-resistant fuel cycle for breeders. Reprocessing of light water reactor fuel could proceed in the near future under strict U.S. safeguards. Such activity could serve as a demonstration of U.S. concerns to the International Atomic Energy Agency (IAEA) and a basis for international safeguards agreements.

The Soviets clearly recognize the urgency of pursuing the breeder option based on world uranium reserves, common sense economics and the need for some degree of energy independence from fossil fuels. However, their goals for nuclear power go beyond the generation of electricity. The Soviets intend to satisfy one-third of all their energy requirements for heat and electricity thru nuclear power by the end of the century. They feel so confident about this that they are promising Eastern European nations all the electricity that these countries will require for future decades. The ambitious building program for atomic plants in the Ukraine is dramatic evidence of this commitment. I think you will agree that our own program pales beside the Soviets despite our clear need and technological edge. It is frightening to speculate on the degree of control of the world market they might achieve by implementing this program.

Mr. President, I think it is time we moved ahead on the nuclear option. We have spent the last year rethinking our nuclear future. We must now commit

strongly to breeder technology including a demonstration plant to get valuable operating experience. We must also get many more nuclear powerplants in place so that coal can be converted to critically needed liquids and gas. I hope you will move ahead boldly on both these fronts.

Sincerely yours,

JOHN W. WYDLER,
Ranking Minority Member,
Committee on Science and Technology.

Notable analyses of nuclear power and risks of proliferation

Returning to the conclusions of many, but not all, analysts that increasing the use of nuclear power, particularly breeding fuel cycles, will increase the risks of proliferation, it is pertinent to note the evolution of recent views on this relationship.

The linking of plutonium breeders and the use of plutonium as a nuclear fuel with the spread of nuclear weapons stands out in several statements and reports of the mid-1970s including the influential report of the Ford Foundation's nuclear energy study group of 1977, President Carter's major nuclear policy statements of April 1977, the annual report of the Arms Control and Disarmament Agency for 1977, the Rockefeller Foundation's report on the breeder, and the Atlantic Council's report on nonproliferation policy.

Secretary Kissinger's views.—On March 9, 1976, Secretary of State Kissinger described U.S. nonproliferation policies and measures to the Senate Committee on Government Operations. He cited nuclear proliferation as one of the most urgent problems facing the United States and the world community, saying that the security of all nations will be vitally affected by the issue of nuclear proliferation for the rest of this century.

The basic premise of U.S. nuclear cooperation, according to Dr. Kissinger, had been worldwide cooperation in peaceful uses of atomic energy under effective controls. The United States had worked to offer a long-term assurance of enriched uranium supply in exchange for agreements to apply effective safeguards.

Secretary Kissinger described the Ford administration's nonproliferation strategy as consisting of:

(1) Proposals for major nuclear suppliers to strengthen nuclear safeguards.

(2) Efforts to gain widest possible support for international safeguards and the NPT.

(3) Physical security measures to protect nuclear material against theft or diversion.

(4) Prevention of unrestrained spread of nuclear facilities such as national reprocessing plants.

(5) Adoption of six principles governing nuclear exports: (a) application of IAEA safeguards to exports of materials, equipment, and technology; (b) prohibition against using U.S. assistance for any nuclear explosions; (c) requirements for physical security protection; (d) restraint in transfer of sensitive technologies (enrichment and reprocessing); (e) encouragement of multinational regional nuclear facilities; and (f) special conditions governing use or retransfer of sensitive material, equipment, and technology.

(6) Continued effort to increase support of the NPT and to get more nations to ratify it.

(7) Continued support for IAEA safeguards.

Candidate Carter's views.—As a Presidential candidate, Mr. Carter, in an address to a United Nations-sponsored conference on Nuclear Energy and World Order on May 13, 1976, warned of the hazards of proliferation and of limitations on IAEA safeguards.⁸ Nuclear energy, he said, must be at the very top of the list of global challenges that call for new forms of international action. He suggested that new lines of such action should be considered in three main areas: Action to meet the energy needs of all countries while limiting reliance on nuclear energy, action to limit the spread of nuclear weapons, and action to make the spread of peaceful nuclear power less dangerous.

On September 25, 1976, at San Diego, Mr. Carter said that as President he would take the following steps to control further nuclear proliferation:

(1) Call upon all nations to adopt a voluntary moratorium on the national sale or purchase of enrichment or reprocessing plants, to apply retroactively to such agreements between Germany and Brazil, and France and Pakistan.

(2) Make no new commitments for the sale of nuclear technology or fuel to countries that refuse to forgo nuclear explosives, to refrain from national nuclear reprocessing, and to place their nuclear facilities under IAEA safeguards.

(3) Seek to withhold authority for domestic commercial reprocessing until the need for and economy and safety of this technology are clearly demonstrated. If commercial reprocessing is undertaken, it should be on a multinational basis.

(4) Call for an international conference on energy.

(5) Support a strengthening of the safeguards and inspection authority of the IAEA and place all of this country's peaceful nuclear facilities under those safeguards.

(6) Seek to renegotiate existing agreements for cooperation.

(7) Explore international initiatives such as multinational enrichment plants and multinational spent-fuel storage as alternatives to the establishment of enrichment or reprocessing plants on a national basis.

(8) Take steps to ensure that the United States is once again a reliable supplier of enriched uranium by supporting enlargement of Government-owned facilities.

(9) Redirect U.S. energy research and development to correct the disproportionate emphasis placed on nuclear power.

(10) Follow through on the belief that the United States can and should negotiate a comprehensive test ban treaty with the Soviet Union and, through SALT talks, reduce strategic nuclear forces and technology.

(11) Encourage the Soviet Union to join the United States in a total ban of all nuclear explosives for at least 5 years, including so-called peaceful nuclear devices.

The Wohlstetter report.—In mid-1976, Prof. Albert Wohlstetter, of the University of Chicago, and his colleagues completed a report for the U.S. Arms Control and Disarmament Agency that defined trends in the spread of nuclear technology and analyzed the problems (po-

⁸ Jimmy Carter. Three steps toward nuclear responsibility. Bulletin of the Atomic Scientists, vol. 42, October 1976, pp. 28-41.

litical, military, and economic) that these trends posed for national policy.⁹ This report attracted considerable attention. Probably its most notable aspect was its concept of the shrinking critical time needed for a state to make nuclear explosives as nuclear power spreads throughout the world. Of this, the reports said:¹⁰

The most fundamental problem displayed by our analysis is that, for an increasing number of "non-weapons" states, the critical time to make an explosive has been diminishing and will continue to diminish without any necessary violation of the clear, agreed-on rules—without any "diversion" needed—and therefore without any prospect of being curbed by safeguards that have been elaborated for the purpose of verifying whether the mutually-agreed-on rules have or have not been broken. This definition of the problem permits us at the very least to observe how much of our efforts (useful though they are for other purposes) are aimed at this basic trouble.

The cause for this problem is "overhang" which the report defines as the approach of countries increasingly near to the edge of making bombs through production and use of plutonium and weapons-grade enriched uranium. "All of this can happen without violating agreements—at least any clearly understood, unambiguous agreements: A kind of growing legitimate—but Damocletian—"overhang" of countries increasingly near the edge of making bombs."¹¹

The 14 points of the Wohlstetter report can be summarized as follows:

1. Many countries, including many agreeing not to make bombs, will come very close to it without violating non-proliferation agreements.
2. Because of a growing legitimate "overhang," safeguards will become increasingly irrelevant. The "overhang" requires no diversion, and therefore no violation of safeguards.
3. A safeguard system is supposed to be a kind of early-warning alarm bell. However, the IAEA safeguards system may actually muffle signs of the critical changes taking place without diversion.
4. The most immediate prospects for acquiring nuclear explosives tend now to be small or less developed countries (LDCs), especially those outside the Soviet orbit, not—as once expected—the most advanced industrial powers.
5. The problem of subnational or transnational nuclear terror seems most acute in those countries that have the most immediate prospects for acquiring nuclear power.
6. The most likely countries to decide for nuclear weapons appear to be non-aligned by choice or to be outcasts, dropouts or fading members of alliance systems, especially the U.S. alliance system.
7. For most of the less developed countries whose civilian nuclear programs are moving them closer to a military capability, the economics of nuclear power look particularly poor. Nuclear electric power is capital-intensive and more likely to be economic on a very large scale. But less developed countries usually are short of capital and need smaller electric power plants.
8. Trends in the relative cost of some forms of nuclear electric power most dangerous from a military standpoint [breeders] make them look much less attractive even from a strictly economic point of view. Programs for such nuclear processes need to be looked at with particular sobriety and skepticism.
9. The current public debate tends to pit extremes against each other: on the one hand are advocates of stopping and dismantling all nuclear electric power, and on the other, those who defend all forms of nuclear energy as vital to the growth of U.S. and other advanced industrial societies and as critical to the economic development of the poorer countries.
10. If nuclear weapon or near-weapon capabilities spread among less developed countries, the spread may later alter the non-proliferation decisions

⁹ Albert Wohlstetter, Thomas A. Brown, Gregory Jones, Daavid McGarvey, Henry Rowen, Vincent Taylor, and Roberta Wohlstetter. *Moving toward life in a nuclear armed crowd?* Los Angeles: Pan Heuristics Division of Science Applications, Inc. Apr. 22, 1976, 286 p.

¹⁰ *Ibid.*, p. 19.

¹¹ *Ibid.*, p. 2.

of advanced industrial countries that so far have deliberately foregone the development of nuclear weapons.

11. Several branching processes may accelerate the increasing nuclear instability. Nuclear exports create not only users of nuclear electric power with its byproducts of fissile material, nuclear exports also create other nuclear exporters.

12. A feeling of fatalism on proliferation is growing. A few years ago two views seems to be emerging. One held that there was no problem (the Non-Proliferation Treaty would take care of it). The other held that there was no solution (nothing could be done about it). Today many seem to hold both of these positions.

13. Analysis of what it would be like to live in a crowd of nations with nuclear weapons leaves little doubt that their potential spread would introduce new and very threatening dangers in the world. However, while it is very likely that there will be some further spread, how much and how rapidly are not matters of fate but of policy. So is the management of the additional spread that does take place.

14. Affecting the spread and/or managing it will depend on shaping political desires and this, in turn, will depend on the conduct of alliance relationships, as well as on a sober and clearheaded view of the economics and politics of nuclear exports.

President Ford's policy statement.—On October 28, 1976, President Ford, in the final days of his campaign for election, issued a statement on nuclear policy and nonproliferation.¹² He announced decisions to accelerate U.S. diplomatic initiatives to control the spread of plutonium and the technologies for separating plutonium from nuclear fuel, and to change U.S. policy on reprocessing of nuclear fuel so that the United States would not reprocess and recycle plutonium unless there was sound evidence that the world community could effectively overcome the associated risks of proliferation. President Ford said that the United States and other nations would and should increase their use of nuclear power for peaceful purposes even if reprocessing and recycling of plutonium are found to be unacceptable. He announced the following decisions to carry out this overall policy:

(1) a change in domestic policies to conform with the decision to defer commercialization of chemical reprocessing;

(2) a call to all nations to avoid transferring or making commitment to transfer reprocessing and uranium enrichment technology and facilities for at least three years;

(3) a call to nuclear supplier nations for new cooperative steps to help insure an adequate and reliable supply of fuel for customer nations that forgo reprocessing and uranium enrichment and accept strengthened and effective proliferation controls;

(4) a decision to maintain the United States as a major and reliable supplier of nuclear reactors and fuel services for peaceful purposes;

(5) new steps to urge all nations to join in a full-scale international cooperative effort to develop effective proliferation controls;

(6) new steps with respect to U.S. nuclear exports to control proliferation while seeking to strengthen multilateral guidelines;

(7) sponsorship of a program to evaluate reprocessing in support of the new international policies;

(8) new steps to ensure that long-term nuclear waste storage and disposal are in place when needed both in the United States and around the world.

¹² Nuclear policy. Statement by the President. Oct. 28, 1976. Weekly Compilation of Presidential Documents, vol. 12, Nov. 1, 1976, pp. 1624-1631.

*The Ford Foundation report on nuclear power.*¹³—In March 1977 the Ford Foundation issued the report of its Nuclear Energy Policy Study Group on Nuclear Power Issues and Choices. A dominant issue considered was nuclear proliferation. The study group recommended strongly against commercial reprocessing and recycling of plutonium because of increased risks of the spread of nuclear weapons. Plutonium, said the study group, is not needed as a nuclear fuel because there is enough uranium to supply the nuclear generation it thought could reasonably be expected. The study group also observed that “* * * with concerted efforts by the United States and the international community to meet national security concerns and to reduce international tensions, the risk that nuclear power will lead to proliferation can be substantially reduced.”¹⁴

This rationale for deferring the use of plutonium for nuclear fuel is the foundation of the administration's nonproliferation policy. However, the study group's assessment, and also that of the administration, has been called into question by a recent report to the National Research Council.¹⁵ Here a special panel, which advised the Council, made the controversial finding that current U.S. uranium exploration efforts will not provide the discoveries needed to meet the uranium demand forecast by the study group and by the Energy Research and Development Administration, now the Department of Energy. The panel forecast major shortfalls in domestic uranium oxide production relative to the 1976 ERDA projects for uranium requirements if present conditions affecting the uranium exploration industry continue.¹⁶

Concerning nuclear terrorism, the study group termed this a particularly disturbing prospect because it is conceivable that a well-organized group supported by knowledgeable individuals could construct an explosive device with a yield equaling a few hundred tons of TNT. Nuclear terrorism is international and nuclear terrorism in the United States could result from materials or devices seized abroad and smuggled into this country. The study group called for additional measures to reduce the possibility of terrorist theft of nuclear materials or sabotage of nuclear facilities. Adequate security measures, it said, can be taken without infringing upon civil liberties of employees and the general public.

Regarding proliferation counter measures, the study group would defer commercial reprocessing of plutonium indefinitely, postpone commercialization of the breeder beyond the end of the century, maintain a U.S. enrichment capacity adequate to meet worldwide requirements, and prevent export of nuclear facilities to separate plutonium or to produce highly enriched uranium. Such facilities would provide a capability for all but the final steps in production of nuclear weapons and could significantly influence a nation's political decision on whether or not to develop nuclear weapons in a time of crisis. Such facilities

¹³ Nuclear power issues and choices. Report of the Nuclear Energy Policy Study Group sponsored by the Ford Foundation. Cambridge, Mass., Ballinger Publishing Co., 1977, 418 p.

¹⁴ Ibid., p. 25.

¹⁵ Problems of U.S. uranium resources and supply to the year 2000. Supporting paper 1. Study of nuclear and alternative energy systems. The report of the Uranium Resource Group Supply and Delivery Panel of the Committee on Nuclear and Alternative Energy Systems. National Research Council. Washington, D.C.: National Academy of Sciences, 1978, 73 p.

¹⁶ Ibid., pp. 2, 3.

also would greatly increase the threat that weapons materials might be stolen by terrorists.

Emphasizing the importance of reliable supply as a nonproliferation incentive, the study group called for export policies to permit the United States to make credible guarantees for nuclear fuel supply for light water reactors to countries that comply with the NPT or comparable nonproliferation agreements. Above all, the study group believed that the United States should discard its promotional approach to nuclear energy, should encourage countries to make realistic assessments of their energy needs and options, and should not press the nuclear option.

Comments to the House Committee on Science and Technology.—On March 31, 1977, the Subcommittee on Fossil and Nuclear Energy Research of the House Committee on Science and Technology called a hearing on the Ford Foundation report at which several of its key participants appeared.¹⁷

In publishing the hearings, subcommittee chairman Walter Flowers included the following statement of staff comments on the Nuclear study:¹⁸

(1) The data used for the uranium supply is not well documented and is based on the conclusion that if the price rises that the supply can be located and recovered. These assumptions are different from most conservative estimates projected by the Government of 1.8 to 3.7 million tons and are based on a classic economic theory that when the price rises an adequate supply will follow.

(2) The report relies on a widely used model, the energy technology assessment model, where outcomes are dependent on the choice of the supply function. Therefore, staff concludes that the panel relies upon an argument based upon a model that could produce equivocal results.

(3) The cornerstone of the report appears to be a concern with the implications of plutonium reprocessing for nuclear weapons proliferation. The report concludes that the costs of not developing the breeder are small. Its primary concern is that the commercialization of breeder technology will require reprocessing which will further the international problems of plutonium proliferation. This conclusion is not shared by other responsible persons and groups, some of whom testified during the authorization hearings.

(4) The Ford study was put together by a group drawn heavily from academe. They have little direct experience of utility problems or international markets. Thus, they have not assessed the potential impact of program cuts on the attitude of the lending community in terms of the availability of investment capital. Also, their view that nuclear plant construction can be expedited does not recognize NRC rulings which have not implemented standard plant design.

¹⁷ U.S. Congress. House. Committee on Science and Technology. Subcommittee on Fossil and Nuclear Energy Research Development and Demonstration. Hearing. ERDA authorization hearings for fiscal year 1978 on nuclear power: issues and choices. A report of the Nuclear Energy Policy Study Group. 95th Cong., 1st sess., April 1977, 107 p. [committee print].

¹⁸ Ibid., pp. vii, viii.

(5) In addition, the group appears to have been funded to write a report and was responsible to itself for the writing and conclusions contained in the report. The usual process of review by others of each particular section or a peer review for the overall effort was not followed. Furthermore, now that the report has been written the group has disbanded. Questions and other comments cannot be addressed to the group as a whole. Follow-up studies are not ongoing activities of the group. Therefore, the panel is no longer a resource for careful examination of the issues.

(6) The study does not deal in depth with the issue of development and demonstration for breeder technologies. The technology for LMFBR applications in this country is some years away since a demonstration facility has not yet been constructed. By their own admission, the group stated on the record at our hearing that they did not consider the question of whether the breeder program should be larger or smaller. This issue is also key to nuclear technological development and needs to be addressed in any report which purports to be a discussion of nuclear choices and alternatives.

(7) The timing of the arresting of U.S. breeder development as a gesture to reduce the risks of international proliferation is not discussed. There is no comparison of the merits of completing technology development on the LMFBR and then offering to defer commercialization versus deferring technology demonstration (CRBR) indefinitely. Neither is there any discussion of the economics of various "technical fixes" which might be employed to limit proliferation in a plutonium economy such as transporting the reprocessed fuel in "hot" form so as to preclude terrorism or "spiking" the plutonium with uranium to make separation more difficult. Indeed, the study does not separate out the risk of terrorism from the danger of third-world separation capability for weapons production. Alternate fuel cycles are mentioned but there are no outlines of an alternate program to the uranium-plutonium cycle which requires accelerated R. & D.

(8) The resource data is also quite inadequate in its discussion of coal availability. Coal resources are indeed large and constitute many years of available supply. However, the problems in mining the coal and using it in this country have not been overcome so that any projections which call for four billion tons of coal production by the year 2000 can only be labeled extremely optimistic and are open to serious debate.

(9) The utility industry would be the ultimate customers for a breeder technology. As regulated industries, profit is not the sole driving force for investment. Their systems must be reliable. Their regulatory situation, economic and environmental, must be stable rather than uncertain. The Ford-Mitre study assumes that economics is the sole motive force for utility behavior. To those familiar with utilities this makes some of the conclusions unrealistic.

The Office of Technology Assessment's report.—On April 4, 1977, the Office of Technology Assessment presented its report, "Nuclear Proliferation and Safeguards," to the Senate Committee on Govern-

mental Affairs.¹⁹ The report identified 14 issues and findings concerning pressures on nations to seek nuclear weapons and 10 issues and findings concerning control of proliferation, and presented 18 propositions for policy planning and legislation for proliferation control. The OTA analysis cautioned that policy and legislation for nonproliferation may conflict with other national and international goals and that tradeoffs will have to be made. It warned that the spread of national reprocessing and enrichment plants would directly increase the risks of proliferation.

The OTA recommended that an effective nonproliferation policy response be devised along political, economic, institutional, and technological dimensions. Multinational and international cooperation would be essential, especially for imposition of sanctions against nations that break nonproliferation commitments. The report noted that requiring the return of spent fuel would reduce risks.

The OTA underscored the need for the United States to establish itself as a reliable supplier of enriched uranium and called for weighing of the "extremely unfavorable proliferation characteristics of the breeder" against its potential advantages. It saw good safeguards systems as raising the costs and risks of diversion to the point at which it becomes unattractive to a potential proliferator. The NPT would remain an important political constraint.

The OTA warned of the costs of effective nonproliferation policy and called for contingency plans. It made clear that diversion from nuclear power was only one of several ways in which a nation desiring nuclear weapons could get the needed materials and noted the need for intelligence capability to detect secret production facilities.

President Carter's nonproliferation policy statements.—On April 7, 1977, President Carter, in a major shift in U.S. nuclear energy policy, ended Government support for the commercial production of plutonium and called on other nations to join the United States in halting the use of plutonium for nuclear fuel.²⁰ The President said that the United States will:

(1) defer indefinitely the commercial reprocessing and recycling of plutonium produced in U.S. nuclear power programs;

(2) restructure the U.S. breeder program to give greater priority to alternative designs of the breeder other than plutonium [producing] and to defer the date when breeder reactors would be put into commercial use;

(3) direct funding of U.S. nuclear research and development to accelerate U.S. research into alternative nuclear fuel cycles that do not involve direct access to materials usable for nuclear weapons;

(4) increase the U.S. capacity to produce nuclear fuels—enriched uranium in particular—to provide adequate and timely supplies of nuclear fuels to countries that need them so that they will not be required or encouraged to reprocess spent fuel;

¹⁹ U.S. Congress. Office of Technology Assessment. *Nuclear proliferation and safeguards*. New York: Praeger Publishers, 1977. 270 p.

²⁰ Nuclear power policy. The President's remarks announcing his decisions following a review of U.S. policy and a question-and-answer session with reporters. *Presidential Documents*, vol. 13, Apr. 11, 1977, pp. 502-507.

(5) propose to the Congress the necessary legislative steps to permit the United States to sign enrichment supply contracts and to remove the pressure for the reprocessing of nuclear fuels by other countries that do not now have this capability;

(6) continue to embargo the export of either equipment or technology that could permit uranium enrichment and chemical reprocessing; and

(7) continue discussions with supplying countries and recipient countries as well of a wide range of international approaches and frameworks that will permit all countries to achieve their own energy needs while at the same time reducing the spread of the capability for nuclear explosive development.

On April 27, 1977, President Carter announced additional nonproliferation policy conditions which included:²¹

A requirement for new conditions for nuclear export licenses;

A requirement for new conditions in new U.S. agreements for cooperation;

Executive branch policies for making recommendations to the NRC on the export of sensitive nuclear items;

Executive branch policies for action on requests by other nations to transfer U.S.-supplied fuel for reprocessing; and

Policies to improve U.S. reliability as a nuclear fuel supplier, to place the United States in a leadership position among nuclear suppliers and to establish a strong and effective nonproliferation policy.

President Carter announced that in addition, the executive branch would adhere to policies not detailed in the proposed act. The executive branch would:

Continue to embargo the export of enrichment and reprocessing plants;

Avoid new commitments to export significant quantities of separated plutonium except for gram quantities for research and analysis;

Require direct Presidential approval for any supply of highly enriched uranium larger than 15 kilograms;

Undertake efforts to identify projects and facilities that might be converted to use of low-enriched uranium instead of highly enriched uranium; and

Take steps to minimize inventories of weapons-usable uranium abroad.

The 1977 report of the U.S. Arms Control and Disarmament Agency.—A focal point for analysis and thinking about the relation of nuclear power to the spread of nuclear weapons is the U.S. Arms Control and Disarmament Agency (ACDA). In its latest annual report to Congress²² the Agency observed that although weapons-usable nuclear materials are not needed as fuel for current nuclear power reactors, unless modifications are made in planning for the next generation of nuclear power reactors, these materials will be produced,

²¹ Nuclear nonproliferation. The President's message to Congress transmitting the proposed Nuclear Non-Proliferation Policy Act of 1977. Apr. 27, 1977. Presidential Documents, vol. 13, May 2, 1977, pp. 611-613.

²² U.S. Arms Control and Disarmament Agency. Seventeenth annual report to Congress, March 1978, 149 p.

used as fuel, and circulated in quantities large enough to make thousands of nuclear bombs a year. Amplifying, the Agency said:²³

The ready accessibility of such material would not only spread and magnify the capability to produce weapons, but could also affect the motivation to do so by presenting a temptation not now present in most countries. Thus one of the principal challenges we face is how to minimize this risk without sacrificing the substantial contribution that nuclear power can make to meeting energy needs.

To deal with this risk, the Agency would supplement international safeguards of nuclear materials with measures to reduce the accessibility to weapons-usable materials; and to reduce the temptation to develop nuclear explosives, and the ease and speed of doing so. However, to be acceptable, such measures should not impair the energy supply of the countries accepting the restrictions.

One line of thought favored by the ACDA is to develop "safer" nuclear technologies, where "safety" refers to risk of proliferation. In March 1977, ACDA officials spelled out the need to minimize access to weapons-usable materials.²⁴ Arguing against separation and use of plutonium for fuel, they observed that institutional and legal measures are not, by themselves, sufficiently effective to comprise a sound U.S. nonproliferation policy. If little reliance is placed on institutional and legal constraints, they said, countries could acquire all the materials and facilities needed for an entire weapons force without violating any of their international agreements.

With these materials under its national control, a state could if it felt this step was vital to protect its vital national interests, violate, abrogate, or legally terminate its international obligations and be able to fashion such weapons within months, weeks or even days.

Amplifying this thought, the ACDA officials outlined three reasons for the United States to seek safer nuclear technologies as part of its overall nonproliferation strategy:

(1) To the extent that safer nuclear technologies and approaches make the acquisition of weapons-usable nuclear materials in national hands inherently more difficult or more time consuming, our nonproliferation interests would be significantly enhanced.

(2) To the extent that safer nuclear technologies actively assist the strengthening of the institutional and legal approach, by improving safeguards, and by giving the international community greater warning time to react to a violation and apply sanctions, our interests are similarly advanced; and

(3) To the extent that safer nuclear technologies permit countries to obtain the benefits of nuclear power without the risks of cycles which involve direct access to weapons-usable materials or facilities, our chances for controlling the problem will be substantially increased.²⁵

According to ACDA, a large number of relatively safer technologies were currently under investigation by that agency, ERDA (now the Department of Energy) and others. Some improved technologies were clearly possible, such as enhanced burnup in LWR reactors to reduce the incentive for reprocessing. Others were more speculative.

Non-proliferation principles of the Atomic Industrial Forum.—In March 1978, Carl Walske, president of the Atomic Industrial Forum,

²³ Ibid., p. 50.

²⁴ Thomas D. Davies, Richard L. Williamson, and Marvin K. Moss. The role of alternative technologies in U.S. nonproliferation strategy. Paper presented to the Atomic Industrial Forum, New York City, Mar. 15, 1977.

²⁵ Ibid., p. 12.

proposed the following seven principles to deal with the future relationship of civil nuclear power to the further spread of nuclear weapons:

(1) Primary dependence on cooperation by sovereign nations acting in accordance with their own best interests.

(2) Secondary dependence on inducements by nuclear exporting nations, including the availability of assured supplies of uranium, enrichment services, and spent fuel disposal at competitive prices. These inducements would be coupled to an agreement among nuclear exporting nations to require adherence to the NPT or full scope safeguards for importing countries.

(3) General agreement to limit the spread of weapons-usable plutonium and highly enriched uranium to economically justifiable projects. Such projects would include multinational facilities dictated by economy of scale. In general, an effort would be made to limit the number of locations within a single nation where plutonium and highly enriched uranium was present in a weapons-usable form.

(4) Strengthened IAEA safeguards, including continuous international oversight of facilities with weapons-usable plutonium and highly enriched uranium.

(5) General agreement on the need for continued secrecy for uranium isotope enrichment processes.

(6) Agreed international sanctions to be enforced against nations which fail to observe their commitment to forgo nuclear weapons, including a cutoff of civil nuclear cooperation.

(7) International cooperation to develop technical approaches which eliminate the restrictive aspects of some of the above principles.

President Carter's press conference in Brazil.—On March 30, 1978, President Carter at a press conference in Brasilia, Brazil, said the United States strongly favors the right of any country to have part of its energy come from nuclear power. U.S. nonproliferation policy, however, tries to distinguish between this right and the right of a country to evolve weapons-grade nuclear materials through enrichment or reprocessing. The President endorsed the thorium fuel cycle for its proliferation resistance, saying:

The new thorium technology is a much safer one to provide power without going to plutonium. Recently Brazil—and I think very wisely—signed an additional agreement with West Germany which would open up advice and technological ability to use thorium.²⁶

The Rockefeller report for international breeder development.—On May 10, 1978, the Rockefeller Foundation released a report, "International Cooperation on Breeder Reactors," containing recommendations which, if adopted, would have substantial significance for U.S. nonproliferation policies. Written by John E. Gray and his colleagues of International Energy Associated, Ltd., a Washington consulting group, the report focused on international cooperation in breeder development.²⁷

²⁶ The President's news conference on Mar. 30, 1978, held in Brasilia, Brazil. Presidential Documents, vol. 14, Apr. 3, 1978, p. 630.

²⁷ John Gray, Myron Kratzer, Karen E. Leslie, Hilliard W. Paige, and Steven B. Shantzis, International cooperation on breeder reactors. New York: The Rockefeller Foundation, May 1978, various pagings.

According to the report, any effort by the United States to delay other nations' breeder programs is likely to be ineffective and disruptive for two reasons. First, a U.S. plea for delay would come at a time when weaknesses in the U.S. energy posture (high levels of oil imports, subsidized energy consumption, and doubtful capacity to proceed with expansion of coal and nuclear energy sectors) appear to its industrialized allies to pose an increasing threat to their own economic and political security. Second, any plea by the United States for delay is likely to be viewed with suspicion by Western European countries cooperating on breeder development (France, the Federal Republic of Germany, Italy, Belgium, and the Netherlands) since they believe they have a substantial lead in the commercial demonstration of the breeder reactor.

More important, the report concluded, there are strong reasons for the United States to view positively the intensive international cooperation on breeder reactors that has evolved in Western Europe. If it succeeds, this development would ease the long-term energy problem this region faces, and hence would make more manageable the world energy situation as a whole. Moreover, such cooperation in development and demonstration may make possible the creation of a Europewide market for commercial sales of breeder reactors, and a European industry to produce them, thereby preventing premature national competition for export sales.

The breeder reactor is likely to remain the centerpiece of the energy research and development of most, if not all, of the major industrial countries, according to a survey of global energy policies made for the report. Major emphasis in most programs is likely to remain on the liquid metal fast breeder reactor (LMFBR).

The nuclear energy proliferation risks of a plutonium economy are described as major concerns of countries with breeder reactor programs. The report advocates effective assurances that materials usable in nuclear explosives will not be diverted by governments or stolen by terrorists from civilian nuclear power industries. The main incentives for acquisition of nuclear weapons capabilities, according to the report, are national security and perhaps prestige. Rather than rely on "technological fixes," the main assurances against weapon proliferation are most likely to be found, in political arrangements—safeguards, physical security, sanctions, and various forms of innovative international cooperation.

It is of paramount importance that commercial use of breeder reactors should occur in a manner that will effectively deal with weapon proliferation risks, so it will be necessary to engage in much deeper forms of international cooperation in the fuel cycle than presently exist. Based on history, it seems clear that this kind of international cooperation will be very difficult to bring about and even more challenging to hold together over time.

*The Atlantic Council's report.*²⁸—On June 19, 1978, the Atlantic Council²⁹ released a report on nuclear power and nuclear weapons

²⁸ The Atlantic Council of the United States. Nuclear power and nuclear weapons proliferation. Report of the Atlantic Council's Nuclear Fuels Policy Working Group. Washington, D.C., 1978, vol. 1, 129 p., vol. 2, 83 p.

²⁹ The Atlantic Council of the United States is a private organization through which individual citizens exchange diverse, often divergent information and views, and evolve policy recommendations on matters of national interest. Its Nuclear Fuels Policy Working Group in 1976 undertook to define the relationship between the production of nuclear power and the proliferation of nuclear weapons. This report is the outcome of its work.

proliferation. Of its many conclusions, those relating most directly to the future of alternative breeders included the following:

Just as there is no unilateral solution [for proliferation] which the U.S. can impose, neither is there a technological panacea, a "technical fix" which could be applied to enrichment, reprocessing and recycle, and to the breeder fuel cycle, to sever their potential link with proliferation. On the other hand, it is both possible and practical to seek out technical measures which might make it more difficult for nations to divert nuclear materials from peaceful uses toward nuclear weapons and would strongly inhibit access to fissile material by subnational groups. Though it is not technically feasible to prevent national diversion of special nuclear material and facilities, technology can and should continue to be developed which would further reduce the possibility of theft by terrorists.

The prevention of proliferation will not be assured by unilaterally developing alternative full cycles or delaying reprocessing or the breeder reactor.

Notable among the 17 specific recommendations of the working group are the following: Multinational spent fuel storage facilities should be established by 1985 at the latest. These should be planned and built in stages, leaving open the possibility of eventually colocating with them other fuel cycle facilities. Likewise, multinational radioactive waste management should be provided as an incentive to countries to place their reprocessing facilities under international control in a multinational nuclear fuel supply system. The U.S. breeder program should develop and demonstrate proliferation-resistant breeder technology for reactors, fuel preparation and use, storage and transportation, reprocessing and radioactive waste management. In doing so, the United States should create a positive basis for close cooperation with other nations on breeders, including those fueled with plutonium. National fuel cycle facilities should be constructed and organized to permit maximum effectiveness of IAEA inspection and accountability for material flows, and improved reliability, standardization, accuracy and quality of safeguards measurements. The United States should continue to press for effective domestic and international safeguards with prompt attention to development of safeguards for new enrichment technologies as well as reprocessing. The international nuclear fuel cycle evaluation should have as its primary goal a thorough, balanced, and objective analysis of the advantages and disadvantages of each nuclear fuel cycle with reference to economics, nonproliferation, and other factors.



