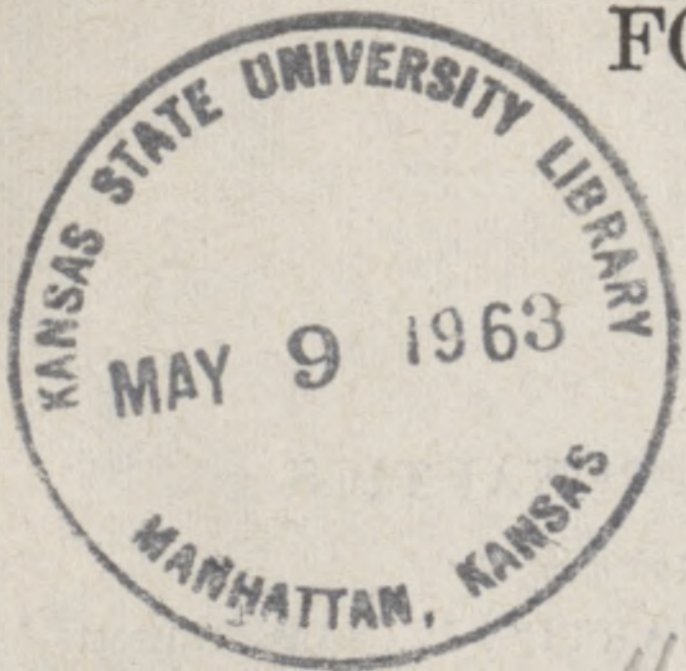


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PANEL ON SCIENCE AND TECHNOLOGY
FOURTH MEETING



REPORT

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS
U.S. HOUSE OF REPRESENTATIVES
EIGHTY-SEVENTH CONGRESS
SECOND SESSION

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., October 8, 1962.

HON. GEORGE P. MILLER,
Chairman, Committee on Science and Astronautics.

DEAR MR. CHAIRMAN: I am forwarding herewith for committee consideration a report entitled "Meeting of the Panel on Science and Technology," prepared by Earl G. Peacock and Joseph M. Felton of the committee staff.

This report is based upon information developed during the fourth annual meeting of the committee's panel on Science and Technology, and is designed to review those areas of science requiring particular emphasis in the opinion of the panel.

The committee sincerely appreciates the cooperation and assistance of Dr. George P. Wollard, Director, Geophysics and Polar Research Center, University of Wisconsin, Dr. Edward Dyer, Jr., Secretariat, Space Science Board, National Academy of Sciences, and Harold B. Finger, Director of Nuclear Systems and Manager of Space Nuclear Propulsion Office, National Aeronautics and Space Administration, in the preparation of this report.

CHARLES F. DUCANDER,
Executive Director and Chief Counsel.

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MEETING OF THE PANEL ON SCIENCE AND TECHNOLOGY

(Covering the fields of geodesy, propulsion, radio astronomy, scientific manpower and education, and the metric system)

INTRODUCTION

The purpose of this report is to review the information discussed and consider the recommendations made by the Panel on Science and Technology at their fourth annual meeting held in Washington, D.C., on March 21 and 22, 1962.¹

The mission of the Panel is to advise and counsel the members of the Committee on Science and Astronautics, House of Representatives, U.S. Congress, on scientific and engineering subjects in order that the committee may wisely recommend objective and timely legislation to the Congress. In addition, the individual members of the Panel act as expert consultants to the committee in each of their respective fields of science and engineering. The Panel also acquaints the committee with attitudes in the scientific and technical communities, thereby stimulating interests in problems less likely to be brought to the committee's attention through routine testimony by government witnesses or industry representatives.

The Panel is composed of the following permanent membership:²

Dr. Edward J. Baldes, Mayo Clinic (biophysics).

Dr. Lee A. DuBridge, California Institute of Technology (physics).

Dr. Clifford C. Furnas, University of Buffalo (chemical engineering).

Martin Goland, Southwest Research Institute (applied mechanics).

Dr. Thomas F. Malone, Travelers Insurance Cos. (meteorology).

Dr. W. Albert Noyes, Jr., University of Rochester (chemistry).

Dr. Clarence P. Oliver, University of Texas (zoology).

Dr. Sverre Petterssen, University of Chicago (meteorology).

Dr. Roger Revelle, Scripps Institution of Oceanography (geophysics).

Dr. Richard J. Russell, Louisiana Coastal Studies Institute (physical geography).

Dr. H. Guyford Stever, Massachusetts Institute of Technology (aeronautical engineering).

Dr. James A. Van Allen, State University of Iowa (physics).

Dr. Fred L. Whipple, Smithsonian Astrophysical Observatory (astronomy).

Dr. Maurice J. Zucrow, Purdue University (jet propulsion).

¹ See app. A for the program of the Panel meeting.

² See app. B for a biographical sketch of each member and guest.

During session the regular members were joined by the following guests:

Guest moderators:

Dr. George B. Kistiakowsky, professor of chemistry, Harvard University.

Dr. Harrison S. Brown, professor of geology, California Institute of Technology.

Guest participant:

Sir Bernard Lovell, O.B.E., F.R.S., director, Jodrell Bank Experimental Station, England.

Two formal papers were presented at the meeting: one, on "Mapping and Geodetic Satellite Program" by Dr. Fred L. Whipple, Director, Smithsonian Astrophysical Observatory and professor of astronomy, Harvard College Observatory, and the other, on "Advanced Propulsion for Space" by Dr. Maurice J. Zucrow, Atkins professor of engineering, Purdue University. In addition to the two formal papers, various areas of interest were discussed informally, among which were (1) radioastronomy, (2) scientific manpower and education, (3) metric system in the United States, (4) biological sciences, (5) international scientific activities, (6) research and development, and (7) the scientific revolution and space exploration.

The two formal papers and the first three topics mentioned above will be elaborated upon in the pages that follow. The Panel deemed all the subject areas which were discussed to be of importance in this space age; however, it is felt that the topics selected for this report need particular stress at this time.

SUMMARY OF RECOMMENDATIONS

The following is a summary of the recommendations made by the Panel on Science and Technology to the committee. Although the committee endorses the objectives sought to be accomplished by these recommendations, it wishes to emphasize that the views expressed are primarily those of the Panel.

1. Mapping and geodetic satellite program

That the United States sponsor through the National Aeronautics and Space Administration an unclassified worldwide mapping and geodetic satellite program similar in scope to the national meteorological satellite program for the purpose of discovering and delineating the geometrical and physical characteristics of the earth and the other planets.

2. Advanced propulsion for space

(a) That Congress provide adequate financial support for the development of nuclear heat transfer rocket engines, electric rocket thrusters, and nuclear electric powerplants in the megawatt class to be operational in the 1970's for future deep-space probes.

(b) That large chemical booster rockets (first stage), and large rockets burning high-energy propellants for the intermediate stages should be developed as soon as possible in order to achieve the objectives of the manned lunar mission.

(c) That as a means of facilitating cost reductions in the space program, a major effort should be expended to make reusable as much of

the space vehicle as possible; at least the booster stage and possibly the second stage.

3. Radio astronomy

That the United States support the recommendations of the radio astronomers for the allocation of more bands in the frequency spectrum to radio astronomy on a primary basis in order to effectively utilize the sensitive radio-astronomical receiving equipment (radio telescopes) and to minimize the interference caused thereto by other users of the radio spectrum.

4. Scientific manpower and education

(a) That a partnership be established between the Federal Government and the universities, similar to that which has existed for many years between the States and the State universities, in which the Federal Government recognizes its primary role in the support of university research.

(b) That the Federal Government undertake a program to provide financial support to universities for the construction of research facilities.

(c) That the Federal Government channelize a greater proportion of the funds of national programs into the universities for basic research.

(d) That grants and contracts awarded to universities cover a period in excess of 1 year whenever possible, and that the universities be given additional latitude to expend these funds on projects which they deem most appropriate consistent with reasonable governmental supervision.

(e) That State, industrial, and private funds for university support be encouraged in every possible way.

5. Adoption of the metric system

That Congress pass the bill providing for a survey to determine the practicability of adopting the metric system of weights and measures in the United States (H.R. 2049).

I. MAPPING AND GEODETIC SATELLITE PROGRAM¹

The advent of space tools has had a profound impact on Earth science, both in terms of the impetus given to the development of new techniques and instrumentation for studying the Earth and its environments, and the specific information obtained concerning the Earth and outer space. The combination of being able to make physical measurements on satellite vehicles and telemetering the results back to Earth, plus ground observations of a satellite trajectory, and using the satellite on a command basis as a working partner in conducting certain Earth-based experiments, has given man a research capability that he never enjoyed before. One branch of science that stands to benefit greatly from the satellite program is geodesy.

Geodesy is the science which deals with the shape and size of the Earth. It is defined as that branch of applied mathematics which determines the exact position of points on the surface of the Earth, the figures and areas of large portions of the Earth's surface, the shape and size and the center of mass of the Earth, and the Earth's gravitational field. It provides the basis for cartography which is the visual representation of the Earth in the form of maps, and it is intimately related to navigation, which is concerned with methods and techniques for positioning and guiding a ship, plane, or missile from one point to another. Geodesy is also directly concerned with astronomy and the Earth's gravitational field. The stars still provide man his only method of position determination that has general application on a global basis, and all optical methods of surveying and stellar observation use the equipotential gravitational surface defined by a level bubble as a reference datum. The Earth's surface gravity field is also an indirect expression of its form. However, the form represented is not the geometric one, but rather a dynamic one representing the effect of not only the Earth's shape, size, and mass distribution but also its rotation. By removing the rotational effect, which can be calculated very exactly, geodetists can use gravity data as an independent method for determining the geometric shape of the Earth. These same data are also invaluable for determining the effect of local warping of the gravity equipotential surface on astronomic and geodetic measurements. Because one of the major elements controlling the orbit of a satellite around the Earth is the Earth's gravitational field, it was clear from the inception of the satellite program that here was a powerful tool for studying directly the dynamic form of the Earth. This tool, incidentally, has been badly needed, for it has not been possible up to now to obtain gravity information in any detail for more than about 20 percent of the Earth's surface.

The reason for this has been largely twofold: first, over 75 percent of the Earth is covered by water, and it has not been possible to make very many measurements of gravity at sea since the standard geodetic

¹ See app. C for the text of Dr. Whipple's presentation to the committee.

measuring techniques in the past have been confined primarily to land; the second, some countries have regarded continental data as having military significance and have, therefore, restricted its availability.

Fortunately, artificial Earth satellites now resolve both difficulties, for they can provide gravity data in a relatively simple way that can embrace all the Earth.

THE NATURE OF GRAVITY

Although gravity is a basic phenomenon, its nature is far from understood despite intensive study by many of the world's greatest scientists. The most that can be said at the present time is that there are two schools of thought regarding gravitation: (1) gravity is purely a geometric phenomenon which involves no radiational transfer of energy between bodies and hence is not subject to modification and (2) gravity is in part the result of energy-carrying "gravitational waves" which are characterized by energy quanta called "gravitons." Even under the latter view, the amount of energy transported is believed to be so small as to be negligible and hence any transmutation of gravitons would have little effect on the gravitational attraction between bodies.

These conclusions are important in satellite studies because of (1) the numerous bodies in space and their gravitational effect on the path of a man-launched space vehicle, (2) the possibility of gravitational shielding when a third body is introduced between two bodies in space, and (3) because of the advantages to be gained through an antigravity device in designing space probes.

Even though the nature of gravitation is not understood, its effect can be accurately evaluated. As long ago as 1670, Sir Isaac Newton showed that the gravitational attraction between two bodies could be expressed as a constant times the product of their respective masses divided by the square of the distance between them. Although the value of the constant was not known then, Newton was able to demonstrate the validity of the gravitational expression in what was a pioneer quantitative analytical study of a satellite. Newton reasoned that the Moon was held in orbit about the Earth by the gravitational attraction of the Earth, and that it should be falling toward the Earth by some amount in a given interval of time that was a function of its velocity, gravitational attraction, and the horizontal distance traveled during the same time interval. He was able to show that the period of the Moon's rotation about the Earth, which is 27.3 days, is exactly what would be expected if it were falling toward the Earth by approximately 6,300 miles a day under the influence of the Earth's gravitational field.

Although the orbit of an artificial satellite about the Earth is governed by the same forces (gravity and velocity) that determine the orbit of the Moon, the fact that the satellite is much closer to the Earth than the Moon results in its sensing many localized variations in the Earth's gravitational field that have lost their individual identity at the distance of the Moon. An analogy would be the integration of the beams from two flashlights from a distance. Close to the source the two beams of light are distinct and recognizable, but at a distance the light appears to come from a single source rather than two. As a

consequence of this proximity effect, the orbit of an artificial satellite is characterized by deviations in orbital path (perturbations) that can be utilized for studying both the basic shape of the Earth and inhomogeneities in terrestrial mass distribution.

The principal perturbing effect on a satellite is the change in gravitational attraction between the equator and the poles, due to the rotation of the Earth and the induced oblateness. But secondary effects are also present. For example, the distribution of continental masses between the Northern and Southern Hemispheres is not symmetrical. There are changes in mass distribution within the Earth. There are also surface and near surface inhomogeneities in mass distribution of geologic origin. Then too, there are mass effects associated with possible geometric abnormalities, such as the Earth having an elliptical equatorial section.

Because the observed perturbation of the orbit of a satellite at any one point may be caused by the total gravitational effect derived from several unrelated sources, analytical studies of the observed orbital perturbations are formidable. Further, the reliability of any analytical solution regarding a single factor—such as the departure of the Earth's shape from that of a sphere—will depend not only on how well the various factors affecting the gravitational field sensed in space can be separated and identified, but also on how well other perturbing effects related to atmospheric drag, solar radiation pressure, and other influences can be determined and allowed for.

Studies to date of the orbital perturbation of artificial satellites suggest that we do not know the gravity field of the Earth too well. This is not surprising, for, as indicated earlier, surface gravity observations in any detail have been made over less than 20 percent of the Earth's surface. These orbital studies also suggest that the Earth has not only a flattened "tomato shape," which is the basic form that has been accepted and used for all geodetic work since the time of Sir Isaac Newton, but also a superimposed "pear shape."

Although the "pear shape" theory may be modified or even disappear entirely as more data become available, the basic data obtained regarding the dynamic form of the Earth have already proved invaluable in resolving discrepancies related to the overall oblateness of the Earth. Standard geodetic methods for determining the Earth's shape, when applied in different parts of the world, have not yielded compatible data. This condition is a result of the fact that the basic measurements required—namely, earth curvature and the distance between intercontinental points—cannot be measured directly and must be calculated using the celestial positions of heavenly bodies as reference points. The key measurement, that of angular relationship between a terrestrial point and a celestial point, of necessity must be referred to the direction of gravity as defined by a plumb bob or a level bubble whose position in the gravitational equipotential surface is perpendicular to the vertical defined by the plumb bob. Therefore, any gradient in the gravitational field will tilt the reference system and thus affect any measurement referred to it.

The problem of determining the relative positions of points on the Earth's surface is particularly well illustrated in the case of oceanic islands. Dr. Whipple stated that whereas positions on the surface of the Earth located in the geodetic systems of the various continents are known on a worldwide basis to an accuracy of perhaps 500 feet, with

an internal accuracy of the systems on the individual continents on the order of 50 feet or less; positions of isolated islands are more poorly determined, and in some cases the errors are a mile or more.

The gross shape and size of the Earth were known to a comparable accuracy—that is, 500 feet—until the advent of artificial satellites. Artificial Earth satellites have aided immensely in resolving these problems of position as well as those of the Earth's geometric shape and dynamic form, but the placing of a specially instrumentated and designed satellite in orbit would yield a maximum amount of geodetic information.

At first glance a special geodetic satellite might appear to be unnecessary now that so many satellites have been launched whose orbital perturbations can be studied. However, when one considers the various factors that can influence the orbit of these satellites—most of which travel along highly elliptical paths and are subject to variable degrees of atmospheric drag, solar radiation pressure, ionospheric charge, magnetic field strength, and other influences plus the fact that few satellites can be sighted simultaneously from widely separated points on the Earth's surface, or tracked continuously with the requisite precision—it is clear that a special geodetic satellite has much to offer.

Consequently, Dr. Whipple recommended that the United States undertake an unclassified geodetic satellite program with satellites specifically designed to overcome these difficulties by providing instrumentation utilizing optical, radar, and radio capabilities such as are incorporated in the ANNA satellite. By having a number of such satellites at different altitudes and inclinations, it would be possible to measure the geometric shape of the Earth directly, both to learn the distribution of mass and density in the Earth and to tie together the geodetic nets for mapping purposes.

The benefits of such a program would be numerous. It is particularly evident that the program would be a tremendous aid to the space program by providing an improved satellite tracking capability for manned space flight and space orbital rendezvous. In addition, such a program provides an excellent opportunity for international cooperation since in order to obtain the gravitational and geodetic data from satellites, it is necessary to have global network of ground tracking stations capable of determining precise range and bearing data.

PROJECT ANNA

In 1959, NASA undertook a preliminary study of the design of a geodetic satellite and plans were formulated for the development of such a program. In mid-1960, the Department of Defense recommended that the program should be classified and NASA canceled its plans for the geodetic satellite. The Department of Defense then undertook a program having geodetic applications. The ANNA project actually got underway in January 1961 within the Department of Defense with the overall direction and responsibility for the project being given to Bureau of Naval Weapons, Department of the Navy, while technical direction and responsibility for development of the satellite was given to the Applied Physics Laboratory of Johns Hopkins University.

In May 1962, the Department of Defense declassified the ANNA project after concluding that the program would not result in any appreciable improvement in a potential enemy's ability to conduct military operations against the United States.

On May 10, 1962, the first attempt was made to launch the ANNA satellite into a nearly circular orbit inclined at 50° to the Equator with an altitude of about 600 nautical miles. The attempt was unsuccessful due to a failure in the second stage of the Thor-Able Star launch vehicle to ignite. A second attempt to orbit an ANNA satellite is scheduled for late 1962; the same orbital parameters are desired and the same type launch vehicle is expected to be used. These two shots are all that are authorized under the present program. If the second attempt should end in failure, the Department of Defense would probably program funds available under Defense R.D.T. and E. appropriations to provide for an additional launch attempt.

On May 14, 15, and 16, 1962, the Subcommittee on Space Sciences conducted hearings to review the nature and extent of the U.S. effort to develop a geodetic satellite program. In a report issued by the committee (Project ANNA—Geodetic Satellite System, H. Rept. 2151), the Subcommittee on Space Sciences reviewed the background of Project ANNA as mentioned earlier, and discussed the instrumentation contained in the ANNA satellite.

The report states that the ANNA satellite will contain three different types of instrumentation, each providing a distinct technique or method of developing worldwide geodetic control; these are (1) optical, (2) radio ranging, and (3) radio Doppler.

The optical method is an extension of the classical astronomical approach. It will make use of observations of a flashing light contained in the satellite. The flashing light is turned on at accurately known, predetermined times, and is photographed against the star background. Each flash of light is treated as an unoccupied triangulation station. Using existing star charts, it will be possible to obtain the apparent right ascension and declination of the satellite as seen from the camera at a known time. The resulting data will be measures of angle versus time. The estimated accuracy is 2 seconds of arc, which is equivalent to an accuracy of 10 to 30 meters for ANNA satellite ranges. The satellite instrumentation for the light beacon and the optical observation program are the responsibility of the Air Force, with coordination responsibility being exercised by the Office of the Chief of Staff.

The radio ranging method makes use of an apparatus designated by the acronym Secor (sequential collation of range). A frequency modulated radio signal is transmitted to the satellite and detected in a receiver; the modulation is then applied to a transmitter in the satellite which transmits to the ground stations. The path length in wavelengths (of the modulation) from the ground station to the satellite and back to the ground station can be determined by measuring the phase difference (at the ground stations) between the transmitted and received modulation. Since the modulation frequency is known accurately, it can be combined with the velocity of propagation of the radio signals to obtain the round trip distance. The output of the Secor equipment is therefore range versus time. It is estimated that relative ground station positions can be measured to within 10 to 30

meters. Unlike the flashing light, which will be useful only when skies are clear, Secor is an all-weather system. The ranging instrumentation, both satellite borne and ground complex, and observations on the satellite using range measurements are the responsibility of the Army, with specific responsibility being vested in the Office of the Chief of Engineers.

The radio Doppler technique utilizes a satellite transmitter whose frequency is controlled by a very stable quartz crystal oscillator. (This oscillator is also used to control the clock which triggers the flashing light.) The Doppler effect produces a shift in the frequency of this transmission as received on the ground that is proportional to the rate of change of the satellite-ground station slant range. The Doppler data thus consists of measurements of range rate versus time. The precision of the Doppler measurements that have been made using the earlier Transit satellites was 0.1 meter per second. By the time ANNA I is launched, the accuracy of the Transit system will be limited principally by lack of accurate geodetic information. The precision of the measurements at that time will be 0.01 to 0.02 meter per second, which is roughly equivalent to position errors of 15 to 50 meters. This is also an all-weather system. The Doppler satellite instrumentation and the range rate tracking program are the responsibility of the Navy, with specific responsibility assigned to the Bureau of Naval Weapons.

Thus, the three methods produce three basically different types of data—angle, range, and range rate. It is also evident from the high accuracies that can be achieved that each method by itself is a powerful geodetic tool. Nonetheless, there are substantial advantages in combining all three. First, each method is subject to quite different sources of error, so that direct comparison of the several results will help to define and perhaps correct to some extent the errors peculiar to each approach. Equally important, the use of all three types of data in combined analyses will strengthen the control of the computing process itself, so that the resulting geodetic parameters will not only be more accurate than the results obtained by analyzing a single type of data, but will also be more accurate than a simple average of the results of three separate computations.

The subcommittee concluded that although Project ANNA is a useful first step in developing a geodetic satellite system, it is not conceived to do the complete job in geodesy, and a truly effective program would have to include a number of satellites at different altitudes and inclinations.

As a result of the hearings, the committee recommended that NASA should prepare a detailed proposal for a follow-on geodetic satellite program designed to meet the needs of all interested parties, scientific and military, and should assume management responsibilities for such a program, arranging for the necessary international cooperation and providing for the utilization of the talent and capabilities which exist in the other agencies of the Government.

POSSIBLE FOLLOW-ON PROGRAM

With the conclusion of the geodetic satellite program, a second program could be undertaken by utilizing low-flying satellites to photograph the Earth for making maps that would then be integrated into

the worldwide grid system provided by the geodetic satellites. The Army Map Service estimates that, considering the present state of the art, it would be possible to produce 1:250,000 scale maps to give complete coverage of the world and to produce larger maps as additional experience is gained using geodetic satellites.

It is foreseeable that such a mapping program would eventually be able to portray not only the basic physical features of the Earth, but also to topographically portray a host of natural and manmade features such as streams, lakes, roads, powerlines, cities, railroads, airfields, and many others. Such information would be vital in planning the economy of any country. In addition, an accurate picture of a country's physical features, with the imprint of man's activities thereon, would prove invaluable in assessing the strengths and weaknesses of any political entity.

II. ADVANCED PROPULSION FOR SPACE ¹

CHEMICAL PROPULSION

Chemical propulsion is the only means available to us at this time for space exploration missions. There are more advanced forms of propulsion under study—notably nuclear and electric propulsion—but these are still in a developmental stage. For now, and for some time to come, the United States must rely on the energies released by chemical reactions to propel vehicles and spacecraft in space exploration.

The liquid rocket engines used in today's launch vehicles are basically the same as, but improved versions of, engines developed 20 years ago. While this is certainly true, it does not follow that the remaining work to be done in chemical propulsion is merely product improvement. This would imply that most everything to be done is done and the rest is a sort of mopping-up action. This would be like Wilbur Wright saying to Orville, after their historic flight: "Powered flight has now been successfully demonstrated; the rest is only a matter of product improvement."

In the broadest sense, the job in advanced research and technology of chemical propulsion is to increase our knowledge about processes that release chemical energy and to investigate methods for most effectively converting this energy into useful work. NASA plans to conduct theoretical and experimental investigations in these areas, both within the NASA organization itself, and by contract to universities and industry. Propellant investigations center on finding and evaluating promising propellants with high energy and desirable chemical and physical characteristics.

The propulsion requirements for manned flights to the Moon or other planets will be enormous. At Earth takeoff the propulsion system must deliver the greatest thrust. Additional thrust from an upper stage propulsion unit is required to inject into Earth orbit, and then to leave Earth orbit on a path to the Moon. Approaching the Moon, additional propulsion will be necessary to slow down or to orbit with another spacecraft. Leaving the Moon or other planet requires the same types of propulsion as needed to arrive except that atmospheric braking is employed in return to the Earth. To satisfy this type of mission requirement, NASA is searching for solid and liquid propellants with high-energy potential.

LIQUID PROPULSION

The purpose of the liquid propulsion program is to develop liquid propellant rocket engines of improved reliability and performance to support launch vehicle development; to anticipate requirements for

¹ See app. D for the text of Dr. Zucrow's presentation to the committee.

space operations involving rendezvous between vehicles, lunar orbiting and landing operations, and long-duration flights to planets or deep space; and, further, to undertake the required advanced design and experimental investigations so that the basic technology will be available when specific equipment developments are needed.

Since one of the NASA objectives in space exploration is manned operation in space, improved propulsion systems of greater thrust, improved reliability, better performance, and lower cost will be required. The liquid propulsion program is oriented to the development of a small number of reliable, appropriately sized engines to meet these requirements. Supporting this effort is the propulsion technology for spacecraft that will provide a technological base for the propulsion developments necessary to carry out space exploration missions planned by NASA for the next decade.

NASA is currently engaged in the development of three major new engines to support the launch vehicle requirements for the manned lunar exploration mission. These are the 1,500,000-pound thrust RP-1-oxygen engine (F-1), the 200,000-pound-thrust hydrogen-oxygen engine (J-2) and a 1-million-pound-thrust hydrogen-oxygen engine (M-1). The latter engine was undertaken in 1962 to meet the requirements of the NOVA vehicle. Also provided, as a continuing effort, is a program of analysis and experimental development to provide design specifications and to demonstrate the practical application of advanced design concepts for spacecraft propulsion.

F-1 engine

The 1,500,000-pound-thrust engine will be clustered to provide the high thrust required in the Advanced Saturn and NOVA vehicles to launch manned spacecraft and to conduct manned lunar explorations. Development of the engine is being performed by Rocketdyne, a division of North American Aviation, Inc., under the technical direction of the Marshall Space Flight Center. Engineering design and fabrication are accomplished at the Rocketdyne plant in Canoga Park, Calif. Component test operations are conducted in the Santa Susana, Calif., facility of Rocketdyne and engine tests are run on test facilities provided at Edwards Air Force Base in California. The current development program is scheduled to complete preliminary flight rating tests of the engine during 1963. These tests will be followed by a continuing improvement program leading to engine qualifications for launch vehicle use during 1965.

The development of the 1,500,000-pound-thrust engine has progressed through design and component development to operation of the engine for long duration and rated thrust. The first full-scale engine run was made in August 1961 at reduced thrust. In December 1961, the engine was operated at full thrust. A major phase of engine system design effort, which began in 1959, will terminate in 1963 with the completion of the preliminary flight rating tests; engineering effort will continue thereafter for full engine qualifications, reliability improvement, product improvement, and support of flight programs. Engines funded under the respective vehicle development programs will be delivered for use in vehicle development programs in the first half of 1963.

J-2 engine

The 200,000-pound-thrust hydrogen-oxygen engine is a high specific impulse rocket engine that will be used in upper stages of advanced vehicles. It is specifically planned for use in the second and third stages of the advanced Saturn configuration and in the third stage of the NOVA vehicle. The 200,000-pound-thrust engine project is also being produced by Rocketdyne under the technical direction of the Marshall Space Flight Center. The development program is scheduled to complete preliminary flight rating test in 1963, with qualification of the engine during 1964.

The 200,000-pound-thrust hydrogen-oxygen engine was initiated in September 1960 and is being developed on a time schedule which will bring it to preliminary flight rating tests at approximately the same time as the 1,500,000-pound-thrust engine. The major emphasis in 1962 was devoted to development testing of the engine components. The major emphasis in 1963 will be in the engineering design, fabrication, and testing of engines leading to completion of the preliminary flight rating tests in the summer of 1963. Thereafter testing to full thrust and duration will be continued toward the objective of developing an upper-stage engine of very high reliability. The present development contract with Rocketdyne extends beyond the preliminary flight rating tests to include development and testing for the purpose of qualifying this engine for use in manned vehicle systems.

M-1 engine

The 1-million-pound-thrust class, liquid hydrogen-liquid oxygen engine will be developed primarily for the NOVA second stage. The M-1 engine will make it possible to accomplish manned lunar landing and return without refueling in the space environment. In the absence of such an engine, it would be necessary to resort to multiple clustering of smaller engines in the NOVA second stage, thus forcing a compromise between a smaller number of engines (with sacrifice in payload capability) and a larger number of engines (resulting in increased system complexity and jeopardy to system reliability). The contractor will perform engineering and design and development leading to early accomplishment of a preliminary flight rating test and qualification for use in manned missions. As in the case of the F-1 and J-2 engines, M-1 development and test effort will be under the technical direction of the Marshall Space Flight Center.

Since the M-1 engine is an entirely new development, it constitutes a critical leadtime element in the NOVA development schedule. Early initiation of the program effort will be needed to insure availability of a reliable engine to meet the NOVA program schedule requirements.

Present efforts are being used primarily to provide necessary fabrication and test equipment and to design and develop engine components. During fiscal year 1963 component work will be continued and testing of the full-scale engine will be initiated.

To insure that the required developmental capabilities will exist when needed, it is necessary to continue an aggressive analysis and experimental development program in anticipation of the requirements for booster and space propulsion. A second important benefit

is the minimization of costly "quick fixes" which are inevitable if the required engineering foundations have not been established before development programs are undertaken.

SOLID PROPULSION

The solid propulsion program is directed toward the application of the inherent virtues of solid rockets to the space missions. These desirable characteristics, already applied in weapons systems, are simplicity, reliability, relative ease of handling and use, and long storage life with continuous readiness for operation.

The program has two main categories: those tasks that support a possible solid propellant booster stage of a launch vehicle for the direct lunar ascent, and those that support space propulsion systems first used after long-term exposure to the space environment. In the first category, the special vehicle problems associated with the use of the very large solid propellant stage must be defined. Special systems, such as an abort warning system analogous to those available for liquid booster stages, must be defined and developed. Optimum component design and fabrication methods must be investigated. The satisfactory integration of solid propulsion elements into the complex lunar launch vehicle requires a vigorous attack on these and similar problems by the National Aeronautics and Space Administration. The Department of the Air Force has been assigned development responsibility for the large solid motor which may be used in a solid stage vehicle for manned space flight.

In the second category of space propulsion, the potential ability of solid propellant systems to withstand prolonged exposure to space environment must be verified, and high performance motors for possible lunar or planetary retro or takeoff use must be demonstrated in prototype form.

During 1962, effort was directed primarily to complete feasibility demonstration of a large solid propellant booster motor started in 1961, and to advance the technology by which greater performance and reliability of solid propulsion systems may be realized. Examples are propellant chemistry, nozzle design and fabrication, inspection techniques, case fabrication, and propellant-case bond.

In 1963, the technology effort will be continued with specific emphasis on the requirements of the manned lunar landing program. Particular attention will be given to the development of higher specific impulse propellants, thrust modulation techniques, and stop-start capabilities needed for spacecraft application.

NUCLEAR ENERGY SYSTEMS

In looking ahead to the vast areas of exploration that will ultimately be required in order to fully explore the space environment and space objects, it is clear that new energy sources not yet used extensively in the space program will have to be developed. The systems that will be required to permit such extensive exploration of space will undoubtedly rely upon the use of the energy contained in the nucleus of the uranium atom. No other energy source now appears competitive with the nuclear system. The work being conducted in this country on nuclear systems concentrates its attention

on the nuclear heat transfer rocket system and the nuclear electric generating systems to be used for auxiliary power and also for electrical propulsion. Another nuclear system also being considered is the Orion concept, which relies upon a succession of nuclear explosions to propel a vehicle. The performance potential of all of these systems is extremely high. It is important that the degree to which this performance potential can indeed be exploited and achieved be evaluated and demonstrated at an early time.

NUCLEAR HEAT TRANSFER ROCKET PROGRAM

The nuclear rocket holds a major place in this country's future plans for space travel and operations. The importance of the nuclear rocket derives from the potential for high specific impulse which is at least two or three times greater than for chemical rockets. Mission studies illustrate the benefits in mission capability that are afforded by the high specific impulse potential of nuclear rockets. For a manned mission to Mars or Venus, a nuclear rocket propelled spacecraft would be one-tenth the weight of an equivalent chemically propelled spacecraft. In addition, studies show that nuclear rockets can provide an efficient means for supplying freight and manned transportation to a lunar based. Other applications for nuclear rockets may be found in scientific space probes for very high velocity increment missions and in highly maneuverable spacecraft for operations in the vicinity of the earth. Generally speaking, nuclear rockets show their greatest advantage in the large-scale manned missions to the planets. However, the development of workable propulsion systems that use nuclear fission as a source of energy offer serious technical challenges. Success must be achieved; otherwise, man's ability to voyage in space will be seriously limited.

(a) The Kiwi reactor project.

(b) The development of the NERVA engine (NERVA—nuclear engine for rocket vehicle application),

(c) The RIFT (reactor-in-flight test) project for flight testing of the NERVA engine, and

(d) A broad program in advanced research and technology required for the development of future nuclear rocket engines.

These major activities, as well as the program's history and management, will be discussed in the following sections.

HISTORY

The nuclear rocket program (ROVER) was initiated by the Atomic Energy Commission and the U.S. Air Force in 1955 as a program to develop the feasibility of nuclear rocket propulsion. Initial studies were made by the Los Alamos Scientific Laboratory and the Livermore Radiation Laboratory until 1957 when the task of developing a reactor for this demonstration was assigned by the Atomic Energy Commission to the Los Alamos Scientific Laboratory, with turbopump and cryogenic flow systems support supplied by the U.S. Air Force. With the establishment of the National Aeronautics and Space Administration in 1958, the Air Force responsibilities in Project ROVER were assigned to the NASA. Since then, however, the Air Force has main-

tained a continuing interest in nuclear rockets as possible propulsion systems for future military missions in space.

Three proof-of-principle reactor tests known as the Kiwi-A series were conducted at the Nevada test site in July 1959 and July and October 1960. These tests provided important design information indicating the feasibility of the basic concept. In 1961, the program objective was extended to include flight demonstration.

In August of 1960 the joint AEC-NASA Space Nuclear Propulsion Office was established and given the responsibility by both agencies for developing nuclear rocket propulsion systems. In June 1961, the Aerojet-General Corp. was selected as the prime contractor to develop the first nuclear rocket engine (NERVA engine) with Westinghouse as principle subcontractor. The contract for this work was effective July 10, 1961.

The Kiwi-B series of reactor experiments, now underway, will evaluate several reactor design variations to determine the one best suited for use in the flight engine. This test series will also demonstrate our ability to operate the reactor with liquid hydrogen rather than gaseous hydrogen. The first test in this series was run on December 7, 1961. Although this test was cut short because of a hydrogen leak in the nozzle flange, the results were encouraging.

Preliminary studies of methods of flight testing the first nuclear stage were initiated in August of 1960, and followed by later studies to define the vehicle system necessary for nuclear flight testing. In May of this year the Lockheed Corp. was selected as the prime contractor for the development of the nuclear rocket test stage, known as the RIFT stage.

PROGRAM MANAGEMENT

As mentioned above, the overall management responsibility for the nuclear rocket propulsion program in the Atomic Energy Commission and the National Aeronautics and Space Administration resides with the Space Nuclear Propulsion Office, including its extensions in Albuquerque, Cleveland, and Nevada. The Albuquerque extension provides liaison with the AEC Albuquerque operations office and the Los Alamos Scientific Laboratory. The Cleveland extension (which is located at the NASA Lewis Research Center) is responsible for detailed technical direction and administration of the contract for the development of the NERVA nuclear rocket engine. The nuclear rocket development station, the location of nuclear test facilities for the nuclear rocket program, is administered by the Nevada extension of SNPO.

NASA, in undertaking the RIFT project for the flight testing of the NERVA engine, assigned management responsibility for the development of the nuclear stage and the flight test to the George C. Marshall Space Flight Center, Huntsville, Ala.

KIWI-NERVA-RIFT PROJECTS

The Kiwi, NERVA, and RIFT projects form the mainline effort leading to the first flight of a nuclear rocket engine. The objective of the Kiwi project is the establishment of a basic reactor core configuration which is suitable for application in a flight system. The NERVA project has the objective of development of a nuclear rocket

engine, based on the Kiwi reactor, that is reliable and suitable for flight in a rocket vehicle. The RIFT project, of course, is planned for the flight testing of the NERVA engine. Each of these is described in some detail in the following discussions:

Kiwi project.—The Kiwi reactors are experimental, ground-test reactors of the direct heat-exchanger type. They include both the Kiwi A and Kiwi-B series of reactors. The three reactors in the Kiwi-A series were operated successfully at the Nevada test site in 1959 and 1960 to demonstrate basic feasibility of the concept. The reactors in the Kiwi-B series of tests are intended to lead to a flight reactor.

The B-series includes several designs. The purpose of the Kiwi-B series is to test these designs under conditions representative of the performance desired for the NERVA engine operation so as to provide for selection of the design for incorporation into the NERVA engine. Tests on these reactors will include experiments designed to study startup and operation on liquid hydrogen. Tests will then be run on the NERVA reactors to prove their ability to withstand flight loads such as vibration and lateral stresses and to operate reliably under all NERVA operating conditions.

The first test in this series, the Kiwi-B1A, was operated on December 7, 1961, with results previously noted. The next test in this series is now scheduled for this summer. This will be the first test using liquid hydrogen. Several additional reactor tests in the Kiwi-B series are planned during fiscal year 1963. There have been several delays in the Kiwi test program during the last year primarily due to difficulties in construction of facilities and installation and checkout of equipment needed for liquid hydrogen operation at the nuclear rocket development station in Nevada.

At the conclusion of the Kiwi-B test series, the Los Alamos Scientific Laboratory responsibility for the research phase of the NERVA reactor development will be, for the most part, complete. The Kiwi reactor will then be turned over to the Aerojet-General-Westinghouse team which has the responsibility for developing and engineering this reactor into a flight-rated NERVA nuclear rocket reactor to be used in the NERVA engine.

NERVA project.—The development of the NERVA engine is being accomplished by the Aerojet-General Corp. with the Westinghouse Electric Co. as the principal subcontractor. Until an appropriate core design is experimentally verified using liquid hydrogen in the Kiwi project, the effort on the NERVA project is limited to design, planning activities, and long leadtime research and development on certain major components and subsystems, including the jet nozzle, turbopumps, valves and controls.

As soon as successful reactor operation with liquid hydrogen is indicated, the NERVA development will progress to extensive component development testing to provide highly reliable components prior to full-engine tests. To support component development, the contractors will employ the usual component test facilities and an engine simulator in which all components except the reactor can be tested to determine the effects of certain interactions encountered during the initial portion of engine startup.

Because of the nuclear radiation which is produced by the reactor, special determinations of the effect of this environment on the per-

formance of all components and flow systems must be made prior to engine testing.

Following these component development activities, many full engine-system tests will be run at the nuclear rocket development station (NRDS) which is located at the Nevada test site. It is estimated that from 30 to 40 engine assemblies will be needed to achieve the high reliability desired before a flight test is attempted.

Construction is being initiated on major facilities at the NRDS for the NERVA development. These facilities include engine test stands, a maintenance-assembly-and-disassembly building for engines, and other structures required for operation of an engine development program. Facilities for the RIFT project will also be constructed at NRDS. In addition to vehicle test stands, the RIFT project will require such items as a stage assembly building and a stage-engine demating facility.

RIFT project.—The NERVA engine will be flight tested in the RIFT stage which is planned to have the capability for development into an operational nuclear system as a follow-on program. A series of industrial studies of nuclear engine flight test methods were completed during 1961. It has been decided that the RIFT stage will be flight tested on the advanced Saturn booster vehicle. The RIFT stage will be the third stage of the launch vehicle. However, the initial flights will use a "live" first stage and a "dummy" second stage. In such a launch vehicle configuration, the nuclear stage will operate over a "lob-shot" flight from AMR with an impact in a controlled area of the Atlantic Ocean. A dummy second stage is used to stimulate the dynamics of the full launch vehicle in preparation for later development of the complete three stage chemical-nuclear system into an operational launch vehicle. The RIFT flight test program includes several flight tests, the first of which is presently scheduled for the 1966-67 time period.

ADVANCED RESEARCH AND TECHNOLOGY

The nuclear rocket program includes a variety of activities in the area of advanced research and technology:

(a) To provide for alternate reactor concepts should unforeseen and unanticipated but serious technical problems suddenly appear to block the Kiwi development.

(b) To supply an advanced engine technology for engines that will follow NERVA,

(c) To examine novel concepts to determine their feasibility and potentiality for greatly improved performance, and

(d) To raise the general level of nuclear rocket engine experience to that achieved with conventional chemical rocket engines.

Such far-reaching objectives require the efforts of many groups throughout the country and many different types of research and development activities are necessary. Some of the areas of work included in the advanced research and technology program are reactors, nozzles, hydrogen turbopumps and flow systems, controls and instrumentation, system studies and advanced concepts.

The Los Alamos Scientific Laboratory will concentrate its efforts on advanced reactor programs as the Kiwi project draws to its con-

clusion. Their efforts will include materials research, design studies, fuel-element experiments, and, ultimately, reactor tests. The LASL effort in advanced reactors has been named the Phoebus program.

For several years the NASA Lewis Research Center has been examining various reactor concepts and conducting research into the properties of certain appropriate materials as part of that Center's activities in advanced propulsion system research.

Recently, the SNPO began a study and research activity at the Argonne National Laboratory to provide a detailed engineering evaluation of various solid fuel element core reactor concepts for possible inclusion in the nuclear rocket program.

Advanced research and technology in the areas of nozzles, pumping systems, and controls and instrumentation is being conducted largely by the Lewis Research Center, although much of the work will be and has been done under contract to industry. The Rocketdyne Division of North American Aviation is developing feed systems and nozzles to support the Kiwi B tests and a feed system for the Phoebus program. Future reactor and engine projects will require additional development of nozzle and pump technology with the nozzle area posing the more difficult problems.

Reactor and system controls will require much work, because the high power engines of the future will create extreme radiation environments for the components of such control systems. In addition, the effects of startup coolant and after cooling must be carefully considered in trajectory controls.

Propulsion system studies are being done by the Lewis Research Center and by the Marshall Space Flight Center in support of mission analyses that include nuclear powered stages. The Air Force has also supported some contracts to study and define nuclear rocket characteristics for a range of thrust levels. System studies are essential for guiding the component research work and for providing propulsion system data for mission studies which help define the direction for the nuclear rocket program. Such mission studies are performed by "user-groups" such as the Marshall Space Flight Center and the Manned Spacecraft Center in NASA and the Air Force.

The advanced concept area provides for study and research on unconventional ideas for nuclear rockets which offer potentially high performance capabilities. An example is the cavity reactor. A solid core reactor is limited in operating temperature by the melting point of the materials. To avoid this limit, various concepts for cavity reactors which utilize the fuel in a liquid or gaseous state have been proposed as a means of providing rocket engines having specific impulses up to 2,500 seconds. The greatest problem in these concepts is the one of providing a means for retaining the gaseous or liquid nuclear fuel in the cavity. No solution to this problem is as yet available; however, there are many researchers seeking the answer. The Jet Propulsion Laboratory and the Lewis Research Center have been active in this area. In addition, the Air Force is sponsoring studies and research on certain cavity reactor concepts. The Los Alamos Scientific Laboratory and the Oak Ridge National Laboratory have also contributed in this area.

ELECTRIC PROPULSION SYSTEMS

The national nuclear electric space program is aimed at the acquisition of technology needed for the development and the demonstration in the space environment of nuclear electric power generating systems and electric engines for application in space electric propulsion or as auxiliary power sources in spacecraft or lunar and planetary missions, applications satellites, and orbiting space stations. This capability, when developed, will be of widespread and general utility in space to achieve many difficult and complex missions, some of which are only in the formative stages of planning at this time. Because of this, there are several agencies vitally interested in the success of this work. These include the National Aeronautics and Space Administration, the Department of Defense, and the Atomic Energy Commission. The program and objectives of these agencies in this area are briefly described below. The interests of other potential using agencies, such as the Federal Communications Commission, the Weather Bureau, the State Department, and the U.S. Information Agency will become clearer as success is achieved in the programs and as specific missions relating to global communications and meteorology are planned. Accordingly, this summary will be divided into discussions of (1) nuclear electric power sources, (2) electric propulsion engines, and; (3) nuclear electric power and propulsion system test flights.

NUCLEAR ELECTRIC POWER SOURCES

Presently under active development are three reactor systems: SNAP-2, SNAP-8, and SNAP-10A. The name "SNAP" stands for "systems for nuclear auxiliary power."

SNAP-2

This is a mercury vapor Rankine cycle turbogenerator system under development by the Atomic Energy Commission for the Air Force. In this system, the heat from a small nuclear reactor is transferred by a liquid sodium-potassium alloy to a heat exchanger in which liquid mercury is boiled. The mercury vapor drives a turbogenerator in a manner similar to that of a steam turbogenerator familiarly used in our cities by electric utilities. All waste heat must be radiated to space by a radiator which, for efficiency and light weight, must be operated at as high a temperature as materials and system conditions permit. SNAP-2 is designed to produce 3 kilowatts of electricity and is intended to operate for a lifetime of 1 year. The specific weight of SNAP-2 is about 200 pounds per electrical kilowatt, including some shielding. Prime contractor for the AEC is Atomics International with Thompson-Ramo-Wooldridge as the principal subcontractor for the turbogenerator. The Lockheed Missiles & Space Corp. is the Air Force contractor for the flight vehicle. The first flight test is planned by the Air Force in 1965. The elements of this flight program are coordinated through various Air Force—AEC steering and coordinating groups.

SNAP-8

This is a joint project of the National Aeronautics and Space Administration and the Atomic Energy Commission aimed at the development of a reliable, long-lived nuclear electric generating system

capable of providing 30 and 60 electrical kilowatts for large amounts of auxiliary onboard power and early electrical propulsion. The AEC is responsible for the nuclear reactor, reactor controls, and shield; and the NASA is responsible for the power conversion system and its integration with the reactor into an operable and reliable system. In addition, the NASA is responsible for the development of the spacecraft to flight test the complete system. The SNAP-8 system, like SNAP-2, uses a mercury vapor turbogenerator conversion system, but the design is different to provide for the higher power output. The sodium-potassium pump is on a separate shaft from the turbogenerator and the reactor outlet temperature has been increased by 100° F. With one conversion system, the SNAP-8 is designed to provide 30 kilowatts. With two conversion systems operating in parallel with a single SNAP-8 reactor, 60 kilowatts will be provided. It is intended to operate continuously for at least 10,000 hours. The specific weight of the 30-kilowatt version is about 67 pounds per kilowatt and at the 60-kilowatt level, the specific power is 50 pounds per kilowatt. Prime contractor for the AEC is Atomics International and Aerojet-General Corp. is prime contractor for NASA. The first flight test of the SNAP-8 system is planned for 1966. Formal coordination is through the SNAP-8 Coordination Committee with frequent informal working and program meetings between the contractors and the Government staffs involved in the program.

SNAP-10A

This system utilizes a SNAP-2 reactor with a thermoelectric converter instead of the mercury turbogenerator used in SNAP-2 and SNAP-8. The potential advantage of this system results from the fact that no rotating parts are used which may result in a more reliable system. SNAP-10A will provide 500 watts of power and is to be flight tested by the Air Force in 1963. In this program the thermoelectric elements will be provided by RCA, the reactor will be fabricated by Atomics International, and the flight test will be conducted by Lockheed Missiles & Space Co. In this system the heat from the nuclear reactor is transferred to the hot junction of the thermoelectric element. The cold junction is the system radiator. This difference in temperature provides the driving force for the creation of electricity as in an ordinary thermocouple. The specific weight of SNAP-10A is about 1,300 pounds per kilowatt or more.

In addition to the systems under development, there are several programs underway by the National Aeronautics and Space Administration, the Air Force, and the Atomic Energy Commission relating to the technology necessary for the development of high powered electric systems.

NASA advanced high powered systems program

The NASA early recognized the attractive mission potential of electrical propulsion systems if suitably lightweight and reliable electric power systems and electrical thrust devices could be developed. In addition, future missions indicated requirements for higher powered nuclear systems for onboard power purposes. Since 1958 an advanced energy conversion program aimed toward the eventual development of such nuclear power generating systems has been supported. The program objectives are system weights of 10 pounds for each electrical

kilowatt generated, power levels in the megawatt and multimegawatt range and unattended operating lifetimes of over a year. The program involves industrial and university contracting and extensive in-house support, the latter primarily at the NASA Lewis Research Center. In fiscal year 1963 a total of \$12.2 million is planned for contracting and in-house support covering both Rankine cycle mechanical systems and direct electrical conversion systems. The mechanical system program includes the development of refractory corrosion resistant materials, applied research on metal vapor turbines, boilers, pumps, bearings, phase separators and deployable waste heat radiators and the accumulation of basic alkali metal liquid and vapor property data which are unavailable at the temperatures of interest. The first of several major long leadtime test installations such as vapor turbine and boiling heat transfer test loops have recently been completed or are nearing completion. Important test data should be forthcoming during the coming year.

The direct conversion program support involves basic and applied research on thermionic converter types and their materials and on the components and basic principles governing magnetohydrodynamic power generation devices.

All nuclear electric systems at some time during their mission profile must operate successfully under weightless conditions. For auxiliary power applications the major part of the mission will be spent under such a flight condition. A program evaluating zero "g" system and component effects with ground facilities such as drop towers and in-flight experiments with both aircraft and rockets began in 1960 and is continuing.

A major uncertainty in the design of either the mechanical or direct conversion system types is the present lack of definition of the space meteoroid problem; that is, the meteoroid physical characteristics, density, energy, and population in space, and primarily the mechanics of meteoroid penetration of materials. A comprehensive program of flight experiments and ground testing is proceeding in the meteoroid area, and also in the more general space environmental effects area. The total NASA fiscal year 1963 budget request in meteoroid and zero-gravity flight investigations is approximately \$1.85 million. Although not all of this is directly applicable to advanced electric power systems, it will all contribute to the understanding of the phenomena.

Air Force SPUR program

The Air Force in 1959 initiated a design study of a 300- to 1,000-kilowatt nuclear electric space power system. Design objectives of the system were the same as the NASA requirements previously stated; that is, less than 10 pounds of weight per electrical kilowatt generated and over a year or more of operating life. AiResearch-Phoenix was awarded energy conversion equipment and system responsibility with Aerojet-General Nucleonics as the reactor subcontractor. The program was designated SPUR, an abbreviation of space power unit reactor.

The conceptual study phase of the program has recently been completed. A high temperature Rankine cycle turboelectric system using liquid lithium as the reactor coolant and potassium as the turbine working fluid has been selected as the reference design.

Phase II of the program now beginning is one in which component design problems will be experimentally investigated. The Air Force has funded \$2.5 million in fiscal year 1962 which will carry this program until June 1963. Four million dollars are budgeted for SPUR in fiscal year 1963.

AEC SNAP-50 program

As part of its space power program, the AEC in 1962 formally established the advanced space power program under the cognizance of the Division of Reactor Development, AEC headquarters. In April 1962 the decision was made to proceed with the development of an advanced space nuclear reactor not including the energy conversion equipment. This reactor program was designated SNAP-50. The reactor objective has been assigned to the Pratt & Whitney Aircraft Corp. lithium-cooled reactor program, which is located at the Middletown, Conn., facility. The Middletown facility was originally constructed in support of the indirect cycle phase of the nuclear powered aircraft program.

SNAP-50 is intended to supply the reactor thermal power for high temperature, compact turboelectric generating systems. The first phase of the program, which will take approximately 1 year, is concerned with system analysis of complete Rankine cycle systems, studies of reactor concepts, and the beginning of the detailed design of a prototype reactor. Some critical component and materials research and development will also be conducted. The program is funded for \$500,000 in fiscal year 1962 and \$3.5 million in fiscal year 1963.

An AEC program complementing SNAP-50 is the construction of the lithium-cooled reactor experiment (LCRE) at the Idaho National Reactor Test Station, also under Pratt & Whitney contract. The reactor experiment will supply general design information concerning the operation of a high temperature, fast spectrum, lithium-cooled reactor system. The preliminary reactor experiment reference design is at the 10-megawatt thermal power level.

In addition to the turboelectric space systems program the AEC is planning to fund in and out-of-pile investigations in the area of thermionic direct conversion reactor systems. The principal AEC work in this area has thus far been at the Los Alamos Scientific Laboratory. A broad experimental and analytical program aimed toward acquiring knowledge of thermionic system and component characteristics is being conducted at Los Alamos.

ELECTRIC ROCKET ENGINE PROGRAM

The electric rocket engine program objectives are to develop electric engine technology and hardware to propel space craft for orbital transfer and interplanetary space missions. At the present time, it is necessary to engage in applied research and advanced engineering investigations to provide needed information for the design, development, and testing of electric engines.

After a payload has been placed into space by utilizing high thrust-to-weight ratio engines, the electric engine could provide the main propulsive drive or perform the functions of attitude control and station keeping for the spacecraft.

The first generation of electric rocket engines are being developed to match small solar and nuclear power sources (500 watts) and the nuclear SNAP-8 (30 to 60 kilowatt) power source.

The 30- to 60-kilowatt electric power level will be the first plateau that will provide engine system technology for developing large engines to propel large payloads in space. The ultimate objective of the small electric engine program (500 watts—1 kilowatt) is to develop an electric engine system capable of maintaining three-axis attitude control and stationkeeping of a satellite.

The large payoff for spacecraft utilizing electric propulsion systems will be realized when power sources of the megawatt level become available for spacecraft integration. Thus, the NASA space engine development program is oriented toward—

1. High power level engines which are most useful for interplanetary missions.

2. Small power level engines which are most useful for attitude control, stationkeeping, and lifting of small satellites such as the 24-hour communication satellite and scientific satellites.

Electric rocket engines can be classified into three general categories:

1. Electrothermal rocket engine, in which a gaseous propellant is electrically heated then thermodynamically accelerated rearward to obtain forward thrust. Examples of this engine type are the arc jet and the resistance heater jet.

2. Electromagnetic (plasma) rocket engine, in which an ionized gas (plasma) containing a mixture of an equal number of ions and electrons is accelerated rearward through the exhaust by electromagnetic fields.

3. Electrostatic (ion) rocket engine, in which a beam of positive ions is accelerated by an electrostatic field. Electrons are injected into the ion beam near the exhaust to neutralize the gas, preventing the buildup of negative charge on the vehicle.

The technology inherent in the three basic propulsion concepts imposes specific impulse ranges on their respective devices for application purposes. The following specific impulse ranges are associated with the first generation electric rocket engines:

	<i>Specific impulse</i>
Arc jet engines.....	700 to 1,500 seconds.
Ion engines.....	3,500 to 10,000 seconds.
Plasma (MHD) engines.....	700 to 10,000 seconds.

Because electrothermal (arc jet) and ion devices are conceptually simpler than plasma accelerators, considerably more experience exists for engine development programs on ion and arc jet thrusters. For these reasons, the ion and arc jet concepts have reached an engine development stage whereas the plasma engine concepts are in the feasibility study and experimental research stages.

Small electric engine development

One-kilowatt arc engine.—NASA has been sponsoring work on a 1-kilowatt arc engine project with Plasmadyne Corp., Santa Ana, Calif., since 1960. The thruster developed 0.025 pound of thrust at a specific impulse above 1,200 seconds with an efficiency of more than 35 percent. Demonstrated life was over 25 hours; start-stop sequence in excess of 7,000 times was achieved. The engine is radiation cooled; it has been operated both with and without regenerative cooling pas-

sages, using hydrogen as propellant under supercritical cryogenic storage. A complete flight package that was designed to run from a battery and a solid-state power conversion supply was laboratory tested under high vacuum thermal and operational conditions at the NASA Lewis Research Center and the contractor's facilities.

Small ion engine project.—NASA has recently initiated a program to develop a small ion engine system (500 watts) for attitude control and station keeping of satellites.

Thirty-kilowatt arc engine development.—AVCO and General Electric were awarded 12-month contracts by NASA in 1960 to develop 30-kilowatt arc engines. The contracts were essentially parallel efforts, but General Electric proposed an engine operating on alternating current while AVCO advocated the direct current approach.

In May 1962 both arc engines demonstrated good engine performance operating on either hydrogen or ammonia propellants. The TVCO d.c. engine provided specific impulse of 1,000 seconds at 40 percent efficiency and 1,350 seconds specific impulse at 43 percent efficiency using hydrogen propellant. The General Electric three-phase a.c. engine demonstrated specific impulse of 1,000 seconds at an efficiency of 45 percent. Both 30-kilowatt engines provide 0.5 pound of thrust at specific impulse of 1,000 seconds and with engine radiation cooling.

AVCO and General Electric have continued their laboratory project efforts for NASA with the major emphasis being placed on engine system reliability and performance for 60 to 90 days of continuous engine operation.

Air Force 30-kilowatt arc engine project.—The Air Force (WADD) has been sponsoring a 30-kilowatt arc jet experimental program at Plasmadyne Corp. to determine thruster design requirements for a d.c. 30-kilowatt arc engine system. This project will continue until July 1963.

NASA 30-kilowatt ion engine development projects.—The Hughes Research Laboratory, Malibu, Calif., was awarded a NASA contract in September 1960 (NAS 5-517) to develop a laboratory model of a 30-kilowatt cesium surface contact ion engine producing one-tenth pound thrust. Shortly after the program started, it was decided to develop and flight test a small module of the 30-kilowatt ion engine at an early date primarily to determine whether ion engines can operate in true space environment. Consequently, a 0.002-pound thrust module (1 kilowatt) of this engine has been developed, successfully tested in an environmental chamber, and packaged for flight testing.

The NASA Lewis Research Center developed an ion engine-electron bombardment ion engine that utilizes a mercury ion beam to produce its thrust. A module of this engine (0.002-pound thrust) has been environmentally tested and packaged for a flight test on the same SCOUT vehicle that will carry the Hughes engine in early 1963.

Air Force 30-kilowatt ion engine development project.—Electro-Optical Systems, Inc., Pasadena, Calif., is developing a cesium surface contact ion engine under an Air Force (WADD) contract. A small 3-millipound (0.003) thrust engine model was developed and operated continuously in the laboratory for more than 200 hours. This engine will be flight tested by the Air Force. This development work is being continued to produce a 30-kilowatt engine.

NASA plasma (MHD) engine feasibility studies

NASA is sponsoring several investigations to determine the feasibility of various magnetohydrodynamic (MHD) techniques for producing propulsion.

A description of each MHD concept and the contractor engaged in determining its feasibility is given below:

The General Electric Laboratories investigated the development of a continuous microwave magnetic accelerator. The principles on which such an accelerator would be built are: (1) Electron cyclotron heating, and (2) plasma acceleration by a magnetic nozzle.

Convair investigated a coaxial plasma gun as a possible electric engine. Such an engine would heat a gas by an electrical discharge between concentric cylindrical electrodes and then accelerate the gas in the annulus (space between the cylinders) by the pressure of a magnetic field for propulsion.

Clauser Technology studied the moving magnetic field technique for an MHD electric engine. In this method, a gaseous plasma, formed by ionizing the propellant gas, is pushed by a pressure from moving magnetic fields. The moving magnetic fields are produced by properly timed currents flowing in coils mounted outside the cylinder that contains the gas. The timing may be obtained by correctly energizing a series of individual coils, or by designing the coils as part of a transmission line.

The Marquardt Corp.-MHD, Inc., investigated plasma propulsion by means of a continuous flow magnetohydrodynamic accelerator using multiple discharge points. This type of accelerator heats the gas by an electrical discharge and accelerates the gas in a channel by magnetic fields to develop power.

Air Force Plasma (MHD) engine feasibility studies

The Air Force electric engine program also includes several engine feasibility studies to determine the utility of MHD concepts for propulsion application.

The following MHD investigations are being sponsored by the Air Force:

Republic Aviation Corp. continued its investigation of the pinch engine, a pulse device which incorporates some characteristics of a conical gun with a straight radial pinch. When the discharge begins, a current sheet forms at the outer periphery of the device, moving toward the center. As this occurs, the initial radial motion of the plasma is changed to axial motion, by collisions with the curved electrode surfaces. A Republic Aviation Corp. pinch engine producing 0.01 pound thrust (1 kilowatt) will be flight tested by the Air Force and the Navy at an early date.

AVCO Corp., Everett, Mass., investigated the traveling-wave accelerator. The sodium propellant is vaporized, preionized, and injected into the main acceleration portion of the machine. Here, the basic field configuration consists of a magnetic field which is coaxial with a tapered circular container which in turn is surrounded by coils. The d.c. component of this magnetic field constrains the conducting plasma to motion which is primarily parallel to the axis of the container. The current in the a.c. polyphase coils serves to increase the magnetic field strength at several local points whose positions move continuously with time. These points of increased magnetic field

strength serve as constrictions, thereby defining the axial motion of the plasma in accordance with the well-known magnetic mirror principle. The polyphase characteristic of the a.c. magnetic field serves to accelerate the plasma which is trapped between the points of increased field strength. This acceleration mechanism is analogous to that which occurs in the squeezing of a toothpaste tube.

High power level electric engine studies

NASA and the Air Force are initiating feasibility studies that will provide data for conducting laboratory experiments on electric engine models for power levels of 100 kilowatts to 15 megawatts or larger.

ELECTRIC PROPULSION FLIGHT TEST PROGRAM

The program of flight testing is considered an integral part of the nuclear electric power generation and electric rocket engine ground development programs discussed in the preceding sections.

Nuclear electric power generation system flight tests

Flight testing of these systems is required to advance the general technology, such as by discovering unforeseen problems in the space environment, and also for verifying the particular design for mission applications.

At the present time, the flight test programs for the SNAP-2, SNAP-8, and SNAP-10A are in various stages of planning and development. Flights are planned in the next several years with the actual flight dates dependent on the progress of the systems in their ground development programs.

Chemical rockets will be utilized to boost the systems into a high orbit (500 miles or greater) after which startup will be initiated.

Electric rocket engine flight tests

The electric rocket engine flight test program has two general objectives:

1. To obtain basic engine data in space which cannot be obtained in ground-based vacuum facilities and to correlate these data with results obtained in ground-based vacuum facilities.
2. To qualify specific engines in the space environment to either discover unforeseen problems, or to bring them to a mission-ready status.

With regard to the first objective, it is well recognized that the ion engine beam neutralization information obtained in ground-based vacuum facilities cannot be considered conclusive. For this reason, both NASA and the Air Force have presently undertaken flight test programs for obtaining this information but using different test techniques. These flights are described below:

1. The first NASA flight test is now scheduled for early calendar year 1963. This flight involves a capsule containing two ion engines launched by a Scout vehicle on approximately a 1-hour ballistic path using batteries as the power supply. The engines are a Hughes cesium surface contact ion engine and the NASA Lewis Research Center mercury electron bombardment ion engine. Each engine will employ a different method of neutralization. Measurement of thrust (which indicates whether the ion beam is neutralized) is determined by measuring the rate of change of spin rate of the capsule.

2. The first Air Force flight will carry an Electro-Optical Systems, Inc., cesium ion engine on a ballistic path using a Blue Scout, Jr., vehicle and batteries as the power supply. In this case, the capsule will be a stabilized platform in flight and thrust will be measured against a torque balancing system rather than by measuring spin rate as in the NASA test.

3. Further flights planned by the Air Force include an orbital flight for long life testing involving the above Electro-Optical Systems, Inc., ion engine.

In addition to the ion engine flight tests discussed above, both the Air Force and the Navy have plans for flight testing a plasma pinch engine under development by the Republic Aviation Corp.

With regard to the second objective, the NASA is planning to conduct a flight test on a 3-kilowatt ion engine. These 3-kilowatt ion engines would be clustered for use with the 30-kilowatt SNAP-8 nuclear electric power generating system. Ballistic flights of the 3-kilowatt ion engine module are tentatively scheduled for the calendar year 1964-65 period. Also tentatively scheduled in the calendar year 1964-65 period is flight testing of small ion and/or arc jet engines (1 kw. or less) designed to meet requirements for stationkeeping systems. These tests will utilize Scout vehicles on a ballistic trajectory.

III. RADIO ASTRONOMY

(NOTES ON RADIOFREQUENCY ALLOCATIONS FOR SCIENTIFIC RESEARCH IN THE UNITED STATES)

The term in the subtitle, *scientific research*, is to be construed as primarily meaning fundamental research in the natural sciences. The terms of reference naturally touch on areas of applied science, for it is hard to draw a sharp line, even if that were necessary. For example, in the fields of meteorology, radio propagation, and oceanography, which are of great theoretical interest in understanding our physical environment, there are nevertheless results that have large practical applications.

Management of the radio spectrum, including the allocation of radio-frequencies, exemplifies an area of policy and rulemaking that is carried out by the Government and international and intergovernmental organizations, but in which scientists have a good deal at stake. The principal uses for which the allocation of radiofrequencies are required by scientific research activities fall into three categories:

(1) *Ordinary communications*, for example, between ships, boats, airplanes, shore stations, mobile ground parties, or any combination of these. Such requirements naturally arise in those fields of activity where exploratory or survey parties have to keep in touch with each other or with a base of operations. Oceanography and large-scale terrestrial surveys are obvious examples.

(2) *The telemetry of data from a remote measuring device*, located on an unmanned vehicle such as a buoy, balloon, sounding rocket, or artificial satellite; the monitoring of the condition of the devices or the vehicle; radio control of the device or vehicle; and tracking. Again, examples of such uses in oceanography (buoys), meteorology (balloons and rockets), or the atmospheric and space sciences (balloons, rockets, satellites, and space probes) will have already occurred to the reader. The present situation with regard to this type of use varies considerably with the user and type of research. Meteorological uses of telemetry have for some time been recognized as a separate "radio communications service" in the formal sense of "a recognized service" by the International Telecommunication Union (ITU) regulations. Space communications for scientific research achieved this status in the ITU Geneva Regulations in 1959, and at that time some steps were made toward meeting its requirements.

(3) *Transmissions in which the characteristics of the radiofrequency radiation are themselves of primary interest*.—For example, the power, modulation, and polarization of emissions of natural origin are studied by the radio astronomers and atmospheric physicists; and the reflection, refraction, attenuation, and polarization of manmade signals of known characteristics by the atmosphere, circumterrestrial medium, or extraterrestrial objects,

are of interest to radar astronomers and ionospheric propagation experts. In this category, allocations exist for certain types of fixed-frequency beacons for the study of ionospheric and tropospheric scatter, but special temporary experimental licenses are ordinarily required for studies outside these allocations or for sweep-frequency studies covering a large range of frequencies. At present, radar studies of all sorts are classed under the "radio-location service," and assignments are made on that basis. This situation can be described as fairly satisfactory for the time being, because most such studies that are made today are carried out under Government contract, and allocations can usually be obtained from the contracting agency. The situation of radar astronomy is, however, worsening with respect to protection from interference. This is due to the fact that many of the radars used in astronomy were designed with frequencies already designated for radar use and hence can be interfered with by similar radars in other services. Radio astronomy was recognized in the 1959 ITU as a separate radio service, and has on that basis been allocated a single band at 1400-1427 megacycles as the exclusive user on a worldwide basis, and a number of other bands as the secondary user. Radio astronomers, although heartened by the fact that their research field is now recognized in principle, do not regard this situation as satisfactory. This question will be treated in greater detail below.

GENERAL REMARKS

Two generalizations can be made about the present status of allocations and assignments of radiofrequencies for scientific purposes. The first is that Government agencies doing scientific research and private institutions working under contract with Government agencies are still able, for the most part, to acquire assignments in the very crowded radio spectrum for the frequencies that they find necessary to use. This statement is true of those Government agencies that already have legal access to portions of the spectrum. But if the requirement for frequencies is an unusual one, requiring, for instance, a large bandwidth to accommodate a high information rate, this arrangement has upon occasion turned out to be inadequate. Furthermore, institutions financed by private funds do not have recourse to any such arrangement.

The second generalization is that, in the large number of applicants for the use of parts of the radio spectrum, scientists on the whole are rather late arrivals. Their difficulties have, furthermore, been aggravated by factors other than simply finding the radio spectrum already very crowded. Scientists on the whole have not until recently gathered together to present a coherent picture of the needs of science and research. Each individual has tended to act all by himself, perhaps not even aware that there are others like himself with identical problems. Individual petitions for a frequency already assigned to another service are difficult for the Federal Communications Commission (FCC) to grant. Assignments are governed by what is best "in the public interest." Furthermore, the individual efforts by scientists to obtain allocations and assignments have sometimes worked at cross-purposes with one another. Moreover, scientists have often not realized what the established procedures are, or what steps might be

taken to remedy the situation when they find established procedures inadequate for their purposes. Considering the virtually complete allocation of the radio spectrum up to those frequencies where techniques are largely experimental (the spectrum below 40 Gc/s is allocated by the 1959 ITU regulations, now in force), and considering that the reallocations of the spectrum involves powerful and strongly entrenched interests as well as the international and national procedures for arriving at allocations, both in the drafting of international treaties by the International Telecommunication Union (ITU) conferences, and in the detailed allocations and assignments in each adhering nation, most frequently it is the position of the communications engineer that prevails. The preamble to the Federal Communications Act of 1934, as amended, sets the tone for this rationale, but the omission of any statement that the use of the radio spectrum for the advancement of science is also a legitimate aim, and "in the public interest," is nevertheless significant.

It should be remarked that, from the standpoint of the scientists, matters have been improving over the last several years. The accelerated pace of large-scale scientific efforts, involving as it has many more research workers and very large sums of money, has not only made the frequency requirements of scientists more pressing, but has served to awaken many of them to the fact that they have common problems for which common solutions are to be sought wherever possible.

In the experience of the Academy's Committee on Radio Frequency Allocations for Scientific Research it has appeared that the chief bars to effective action by a Government agency are either that the agency is not aware that a problem exists, or that it does not understand the nature of the problem. However, in frequency allocations as in other areas, the Academy's Frequency Committee has tried to channel the information and energies of scientists to reach these common solutions. Recently the Government agencies responsible for frequency allocations—the Federal Communications Commission (FCC), and the Interdepartment Radio Advisory Committee (IRAC), now operating under the Director of Telecommunications Management, Office of Emergency Planning, Executive Office of the President—are becoming aware of the problems of science and, wherever these have become known, the responsible agencies have responded with sympathetic appreciation and assistance.

In the field of frequency allocations some disagreement remains, as one might expect, in what constitutes the best use of a frequency from the standpoint of "the public interest," which is the criterion derived from the preamble to the Federal Communications Act of 1934, as amended. The interpretation of this phrase is more difficult than interpretations bound on matters of demonstrable fact, such as the existence and seriousness of a given type of interference. The holders of commercial television licenses, the developers and users of navigation devices for aviation, those responsible for the defense of the Nation, and those who are attempting to make the measurements necessary for a better understanding of the world we live in, all have a rather different idea of the "public interest." Scientists, of course, hold to the last mentioned view, and believe that, as the most fundamental of all, that view should have some claim to parts of the radio

spectrum. But the genuine needs of science and research have not until recently been presented to the world at large.

A case in point may be mentioned. Until the International Telecommunications Conference of 1947 in Atlantic City, frequencies above 25 megacycles were not allocated internationally. Now, radio frequency radiations from extraterrestrial sources had not been systematically exploited in any very thorough way before 1947, nevertheless enough work had been done to establish the claim that the science of radio astronomy was by then well on its way. But no radio astronomers were sufficiently alert to realize that the Atlantic City conference presented an opportunity to explain their case for reserving a few frequency bands for the future which they must have already been able to foresee. Hindsight makes it seem likely that they might well have been successful in staking out a few bands in 1947, but foresight is what is required.

ALLOCATIONS FOR SCIENTIFIC RESEARCH

In the rest of this section, allocations for space research and radio astronomy will be discussed in slightly greater detail. Since the general background, many of the technical questions, and a chronological account of events involving the regulatory agencies and the scientific community are well described in the report entitled "Radio Frequency Control in Space Telecommunications," March 1960 (prepared by Edward Wenk, Jr., for the Senate Committee on Aeronautical and Space Sciences), this report will deal principally with the role played by the National Academy of Sciences and some of its special committees and with developments since 1959.

Space research

The launching of satellites by the U.S.S.R. and the U.S.A. during the International Geophysical Year (July 1957–December 1958) ushered in the space age as an actuality. As noted above, satellites for scientific research require radio communications for tracking; for telemetering to earth stations, not only data on satellite performance and condition, but more especially the numerical information being recorded by the various devices designed to measure characteristics of the physical environment; and for various command functions. Radio communication with the first satellites launched during the IGY was planned and carried out in frequency bands assigned on a temporary basis—in particular those at 20, 40, and 108 megacycles—with the understanding that more permanent arrangements would be made at a later date. For instance, the allocation at 108 megacycles was in a guard band between the highest FM channel and a band allocated to aeronautical navigation aids. The temporary authorization for its use expired on January 1, 1959, and the band was then officially reclaimed by the aeronautical navigation service, although its use was continued with satellites launched before that date. Frequencies allocated to various experimental developmental work were also "borrowed" for space use in the early days.

The requirements for communications with satellites were first considered internationally by the Ordinary Administrative Radio Conference of the ITU at Geneva in 1959. In anticipation of that con-

ference, discussions among representatives of interested U.S. agencies took place in IRAC (then operating under the Office of Civil and Defense Mobilization and led to issuance by the FCC of a notice (No. 67973, January 8, 1959, docket 12263) which invited comment on a draft U.S. position intended, in final form, to represent the formal position of the U.S. delegation to the ITU. The paper contained proposed definitions for two new services:

(1) The Earth/space service for radio communication between Earth and objects in space, both natural (like the Moon and planets) and artificial satellites and space vehicles. The definition specifically excluded conventional aircraft, balloons, missiles, or rockets which are limited to flight between points of the Earth's surface and which already had allocations for various purposes;

(2) The space service, for radiocommunication between objects in space.

These two new services were recognized by the Ordinary Administrative Radio Conference. The draft U.S. position also provided for seven frequency bands ranging from 25.60–25.65 to 31,500–31,800 megacycles, to be allocated to these new services on a primary basis, worldwide, with secondary allocations to the fixed and mobile services. In the opinions of scientists and engineers working with satellites, the draft position for proposed allocations for space science was very good as far as it went, but made no provision for frequencies in the band from 25.65 to 1,700 megacycles. Technical problems arising from this rather long gap were discussed by space scientists, with each other and with the Academy. Some of the discussion was brought to a head at a meeting of the International Radio Consultative Committee (CCIR) of the ITU which took place in Los Angeles in April 1959. Meanwhile the Committee for Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) had met in March 1959 at The Hague, and its Working Group on Tracking and Telemetry had come up with a set of proposals compatible with those desired by U.S. space scientists. Besides setting up a system for the registration and publication of satellite and space probe frequencies, these proposals advocated the allocation of a band for space research in frequency range 30–100 megacycles, 100–300 megacycles, etc., on up to 10,000–30,000 megacycles, for telemetry and tracking, and three narrow bands in the interval 5 to 20 megacycles for ionospheric research. COSPAR formally adopted the proposals of its working group and circulated them to the national organizations adhering to COSPAR. In the USA this is the Space Science Board of the National Academy of Sciences. COSPAR further urged that the national organizations bring the proposals to the attention of their own national delegates to the CCIR and to the ITU, and request their support.

The Space Science Board of the NAS, besides serving as the U.S. national committee for COSPAR, also serves as the body in which U.S. scientific view on space research can be focussed and brought to the attention of Government agencies concerned, and through which Government viewpoints and plans in space research can be disseminated to the scientific world. Space scientists at NASA and elsewhere requested the Board to look into the question of allocations in the interval 25–1,700 megacycles and make appropriate recommendations.

The Board advocated the exclusive allocation to space research of three bands, one at 135–136 megacycles, one at 400–401 megacycles, and one near 900 megacycles.

The rationale behind these choices was as follows:

135–136 megacycles: The spectral region 100–150 megacycles had been picked originally as the region for which to design and build satellite tracking stations, because it represented a compromise between tolerable ionospheric distortions and the technical limitation of building lightweight equipment for the satellites. Below 100 megacycles, the frequency is near enough to the ionospheric critical frequency that ray-paths can be severely bent as they pass through the ionosphere. Higher frequencies would require the use of instrumentation in satellites that was, at the state of development then prevailing, impossibly heavy. Any shift from 108 megacycles (the frequency on which the whole existing Minitrack net of radio-interferometers had been designed and built during the IGY) to anything much over 150 megacycles would entail drastic changes and redesign which the United States could ill afford because of the delays it would entail. The decision to remain in the frequency range 100–150 megacycles was regarded as the best expedient for the time being, and in this range the spot at 135–136 megacycles looked as if it could most easily be spared for the next few years.

400–401 megacycles: At this frequency ionospheric refraction is an order of magnitude smaller than in the neighborhood of 135 megacycles. It was envisaged that technological developments would in the next several years make possible the use of this higher frequency for tracking purposes and the exploitation of the greater accuracy it would provide.

900 megacycles or nearby: It appeared necessary to go to a frequency of this order to obtain a bandwidth as wide as needed, for two important purposes, (i) to transmit the television pictures that are an important part of the space science program in meteorology, lunar surveys, and so forth; (ii) to communicate with deep space probes, whose large relative velocities would lead to large Doppler shifts in the nominal frequency. On the other hand, the feasibility of going to still higher frequencies was extremely limited, because this step would require massive equipment then in a highly experimental stage.

Representatives to IRAC were not able to agree unanimously on instructing the U.S. delegation to the ITU Ordinary Administrative Radio Conference regarding these recommendations. The allocation at 400–401 megacycles was approved; the allocation at 135–136 megacycles was approved with some dissent, and was referred to OCDM for decision; the matter of an allocation near 900 megacycles was left to the U.S. delegation to work out as best they could with their foreign counterparts, without instructing them very specifically as to what exact frequency should be chosen.

The Ordinary Administrative Radio Conference (Geneva, 1959), besides formally recognizing space communications and Earth-space communications (in the sense defined above) as distinct radiocommunications services, finally adopted the allocations for these services shown in table I.

Radio astronomy

The science of radio astronomy consists in the measurement of the power flux and polarization of radiofrequency radiation from extraterrestrial sources as a function of direction, frequency, and time, and makes deductions from these data about the nature, state, and distribution of matter not available in any other way. For this purpose, radio astronomy must have access to a few particular frequencies typical of the matter which emits or absorbs those frequencies and which are fixed by the nature of the matter—e.g., the 1420.4 megacycles (21.1 centimeters) lines of neutral atomic hydrogen. Radio astronomy must also have access to the continuous spectrum emitted by discrete radio sources (the sun, planets, distant galaxies, and other “radio stars,” many as yet unidentified optically), and by the general cosmic background. To understand the continuous spectrum—for instance, to separate its thermal and nonthermal components, and to fix the frequency of any interesting features in the spectrum, especially any features which might serve as a marker to measure the red-shift of objects more distant than any accessible to the largest optical telescopes—the radio astronomers need to be able to sample the r-f flux at frequencies about one octave apart, although the exact frequency of these samples is not very important. They would like to do this for that part of the radio spectrum which penetrates our atmosphere and ionosphere, that is, from about 10 megacycles to 100,000 megacycles.

Radio astronomy is uniquely different from the other activities that make use of the radio spectrum, in several respects. The equipment does not emit any radiation, but only receives it. Other services thus have no way of telling whether a radio observatory is “on the air.” It obviously follows also that radio-astronomical facilities can in no way be a source of harmful interference to any other service. Finally, radio-astronomical receiving equipment (commonly called “radio telescopes”, but actually very sensitive radiometers with highly directional antennas) are designed to operate at radiation flux levels far below most other radio equipment. By using highly directional antennas of large area, very sensitive receivers of most recent design, long integration times, autocorrelation techniques, etc., they can detect fluxes of the order 10^{-25} or 10^{-26} watt/m² per c/s in some parts of the spectrum. It has been estimated that all the information about the physical world that has been obtained through analysis of the radio spectrum from extraterrestrial sources—and it is considerable—has been carried by radiation with an integrated energy of one erg, or about that required to blow out a match. (1 watt-second is equal to 10 million ergs.) It is therefore apparent that emissions which other radio services would regard as mild interference would be orders of magnitude larger than the weakest signal detectable with a large radio telescope and would be intolerable to radio astronomy. The presence of an interfering signal large enough to be noticeable simply results in the rejection of that observation. This procedure might be a great nuisance, but it would not lead to spurious measurements. On the other hand, the presence of interfering signals of the same order of magnitude as that being measured, or somewhat smaller, can easily go undetected. If that happens, erroneous conclusions are drawn from the data.

Radio astronomers have tried to protect themselves in many instances by locating their establishments in remote unpopulated localities, as far as possible from all the radio transmitters of our technologically developed society; but even in such quiet sites, during a comparatively large fraction of the time they pick up emissions from great distances, propagated or scattered by the atmosphere, ionosphere, and terrain features, or reflected off high-flying aircraft and satellites. Radio astronomers are therefore convinced that any frequency bands allocated for their use must be cleared of all other transmissions, all over the world.

Meanwhile, they scan the spectrum accessible to their instruments, looking for relatively quiet frequency bands, as uncluttered as possible by other transmissions. Even this procedure is of no use when the frequencies of the radiation of interest are fixed by nature; for example, the line emission of hydrogen, or the dynamic spectra of solar bursts.

The course of developments concerning allocations for radio astronomy before and during the first part of the Ordinary Administrative Radio Conference in Geneva, 1959, is another example of the difficulties arising from the inadequate communications then prevailing between the scientific community and the Government agencies charged with managing the radio spectrum.

In preparation of the U.S. position for the 1959 Geneva Conference, the FCC issued notices requesting information from U.S. radio astronomers concerning their needs for frequency allocations. This action followed earlier deliberations by IRAC, which in turn had been in touch with an ad hoc group of radio astronomers at the Naval Research Laboratory. Responses to the FCC from individual radio astronomers were somewhat random and inconsistent in detail chiefly because there then existed no efficient machinery by which they could themselves reach agreement among themselves and thus present to the FCC a set of requirements satisfactory to all of them. As it was, the only single item on which all responses agreed was that a band near the frequency of the neutral hydrogen line (1420.4 megacycles) should be exclusively reserved for radio astronomy. Observations of the hydrogen emission are the only available source of very important information about the nature, state, and distribution of much of the matter in the universe. To some extent, radio astronomers responding to the FCC also agreed that frequencies should be cleared near other naturally occurring frequencies, which had at that time been predicted but not positively observed; namely, the deuterium line at 327.4 megacycles and the hydroxyl line at 1667 megacycles. They also desired clear frequency bands spaced about one octave apart, in order to observe the continuous radio spectrum of extraterrestrial sources as described above, but differed in detail as to the exact choice. This range of recommendations is natural, considering that the exact choice of frequencies is in fact unimportant, and the final choice would depend on what could be obtained in the face of needs of a nonscientific kind (e.g., commercial). In connection with the Administrative Radio Conference, it is also possible that radio astronomers were lulled into a false sense of security, in view of the fact that both the International Astronomical Union and the CCIR had each strongly advocated a set of proposals that were quite acceptable to most radio astronomers, which they perhaps assumed would be accepted by the Conference.

As a consequence of the lack of agreement in detail among the individual responses on almost everything except the necessity for clearing a band around the hydrogen line, the U.S. Preparatory Committee felt that it should not require the U.S. delegation to recommend any specific frequency allocations to radio astronomy except the 1400- to 1427-megacycle band. The 1959 Geneva Conference had been in session for several weeks when U.S. radio astronomers, alerted by their colleagues abroad who had expected a different and stronger U.S. position on this subject, came to life. After being in touch with the U.S. delegation to the ITU and with the President's Science Advisory Committee, the National Academy of Sciences called together an ad hoc group of 20 able and active U.S. radio astronomers and representatives of scientific bodies. This group met in October 1959 and reached a unanimous position, which was discussed later that same day with representatives of the FCC, OCDM, DOD, and the Department of State. During the first part of the joint meeting, the Government representatives explained to the assembled radio astronomers exactly what function each Government office performs in the management of the radio spectrum, the reaching of international agreements, the domestic allocations of frequencies to users, and so on. It is believed that these briefings marked the first time that some of the radio astronomers present learned how complex the management of the radio spectrum is from the practical standpoint, and what methods already exist by which problems can be dealt with (though perhaps not solved) in this area.

Slightly modified, the recommendations of this group were transmitted to the U.S. delegation in Geneva. The eventual outcome included these features: (1) The recognition of radio astronomy as a distinct service, with right of access to the radio spectrum; (2) the incorporation of only one exclusive allocation to radio astronomy; namely, the 1400- to 1427-megacycle band straddling the hydrogen line; (3) the granting of a footnote status to many of the other recommended frequency bands, sometimes with slight shift in frequency, e.g., in the guard bands of standard frequencies (2.5 megacycles, etc.) or in bands occupied by relatively low power ground-based services. (While not as strong as a secondary allocation, a footnote recognized the rights of the service to freedom from interference from all other spectrum users except those to which the band is specifically allocated.) Although the granting of footnote status is certainly a step forward, it would be more nearly correct to describe it as simply an official recognition of the problems of radio astronomy than as a very great practical help. The reason for saying this is that many of the footnotes are qualified by such statements as: "The radio astronomy service shall be protected from harmful interference from services operating in other bands in accordance with the provisions of these regulations only to the extent that these services are protected from each other" (footnote 204 to the standard frequency guard bands); or "administrations assigning frequencies to stations of services to which this band [73 to 74.6 megacycles] is allocated, should take all practicable measures to avoid harmful interference to radio astronomy observations" (footnote 253). The practical effect of such footnotes is rather vague, but, as has been stated elsewhere, they constitute a first step. As the entire spectrum is adjusted to a more rational match between the requirements of the various services and the part of the spec-

trum they occupy, they should serve as a basis for further development into full-fledged allocations. The allocations to radio astronomy agreed on at that Conference are shown in table 1.

The 1959 Ordinary Administrative Radio Conference also recommended that radio astronomy facilities file with the International Frequency Registration Board a list of the frequencies they observe or intend to observe, simply to make it a matter of record for future discussions, and as a measure of protection in those bands where radio astronomy has footnote status. This mechanism provides the only means by which other services can tell whether the bands in question are actually being used.

The convening of the group of radio astronomers in October 1959 to draft an agreed position and the subsequent discussion with representatives of the appropriate Government agencies constituted the first known occasion in which views of all concerned could be presented and exchanged, and difficulties explored directly with those in a position to influence the outcome, all at a single time and place. The success of this meeting made it plain to both the radio astronomers and the Government that continuing arrangements for the exchange of ideas were essential. Accordingly, in October 1960, a new working group of six radio astronomers, under the chairmanship of Dr. Edward Lilley of Harvard University, was convened by the Academy. It assumed the task of reviewing in greater detail and under less pressure the recommendations made to the 1959 Ordinary Administrative Radio Conference of preparing an updated statement of the needs of radio astronomy for protection against interference, and of recommending steps that might be taken to meet these needs. After writing a final report, in the preparation of which many radio astronomers in the United States were consulted by correspondence, the Lilley group went out of existence (June 1961). Its report was forwarded by the Academy to the appropriate Government offices, in particular to IRAC and the FCC, and to the USA committees of CCIR Study Group IV (Space Communications) and its Subgroup 6 (now Subgroup D) on Radio Astronomy.

The Committee on Radio Frequency Allocations for Scientific Research

In the meanwhile, it had become apparent to certain segments of the scientific community that the need for radio frequency allocations for scientific research was not limited to radio astronomy, or even those other branches of research that have been mentioned so far—radar astronomy, space research, meteorology, oceanography. It was obvious that these needs would become greater and more demanding as the use of radio techniques proliferated among wider and wider groups of scientific investigators. Furthermore, it seemed entirely possible that, although one group (say, radio astronomers) might agree among themselves and another group (say, space scientists) might also agree among themselves, the two groups might easily conflict in presenting their respective cases for attention before the regulating agencies. Moreover, ICSU had in the meantime already established the Inter-Union Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF) with representatives from the three ICSU-connected bodies principally concerned; namely the IAU, URSI, and Cospar. It seemed desirable for the U.S. National Acad-

emy of Sciences to set up a national body which would be in part a counterpart of that international committee.

With these thoughts in mind, in the spring of 1961 the Academy established a permanent Committee on Radio Frequency Allocations for Scientific Research. Its present membership is given in appendix E. From that list it will be apparent that the principal scientific organizations and activities having a present interest in the subject are well represented. Liaison with Government regulatory bodies, like the FCC and IRAC, is provided on an ad hoc basis, depending on the questions being discussed. In this connection, it will be noted that one of the members is also a member of IRAC.

The first order of business of the Committee was to define its task and its sphere of operations. At an early meeting, the Committee adopted the "Statement of Functions and Activities," an updated version of which appears as appendix F. Since its inception, the Committee's attention has been directed for the most part to the needs of radio astronomy, and to a lesser degree to radar astronomy, space research, and (most recently) oceanography. With the discharge of the Lilley working group, most of the members of that group had been appointed to the permanent Academy Committee. The six members of the Committee who are working radio astronomers, together with two additional members, were constituted a Subcommittee on Radio Astronomy.

This action was taken in response to two stimuli: (1) The general fact that much of the activity of the main Committee was, and still is, connected with the problems of radio astronomy; and (2) a communication from the American Astronomical Society (AAS) reporting that radio astronomer members of the society, worried about the future of radio astronomy, had approached the society with the view of establishing a committee of its own to advance the cause of frequency allocations for radio astronomy. This spontaneous movement resulted partly from the fact that some radio astronomers were not current with discussions and negotiations already being conducted through established channels. Radio astronomers, while welcoming the advances incorporated into the Geneva regulations, 1959, regarded these developments as only a beginning, because many serious problems remain unsolved. In any case, the need for a continuing body working solely on their problems was evident. It appeared to both the Astronomical Society and the Academy that the proposed body should work within the Academy Committee, which itself was already well acquainted with the problems and the procedures for getting them solved in the most expeditious and practical way. The membership and statement of functions of the Subcommittee on Radio Astronomy are given in appendix E and G. A review of frequency requirements by the Subcommittee is given in appendix H.

Prior to the appointment of the Subcommittee, the Committee of Radio Frequency Allocations for Scientific Research had considered in detail the stated requirements of American radio astronomers and had rendered assistance to the Government agencies preparing for a future international conference. During the summer of 1961, IRAC was looking ahead to the possibility of getting radio astronomy requirements on the agenda of the Extraordinary Administrative Radio Conference of the ITU meeting in October 1963. IRAC, in consulta-

tion with the FCC, drafted a paper which was to form the nucleus of a future U.S. position paper for that Conference. The paper represented a compromise between the stated needs of the radio astronomers and the realities of practical spectrum management over the next few years. In the fall of 1961, when the draft was finished, IRAC invited the Academy Committee to send some radio and radar astronomers to a joint meeting, at which they were requested to discuss the draft point by point. With a few modifications this paper, together with companion documents indicating how the new set of recommendations (if incorporated into the next set of ITU Regulations and Table of Allocations) might be implemented in regions under U.S. jurisdiction, was released in January 1962 by the FCC under docket Nos. 14475 to 14477, inviting comment from all interested parties. To radio astronomers and the Academy Committee this process was a welcome one; it was, so far as the Academy records show, an unprecedented but eminently sensible move by which many criticisms of the draft position were anticipated and partially met, all in advance of publication.

Among other questions examined by the Academy Committee have been: (i) What constitutes "harmful interference" to radio astronomers, which as noted above operates at levels of sensitivity much higher than most other services; (ii) whether or not there is any possibility of sharing the spectrum with other services; (iii) what regions or line frequencies in the spectrum look as if they will be important in the future in the light of present experimental developments, especially in the extremely high frequency regions of the order of 100,000 megacycles, which are not yet allocated to anyone; (iv) a number of specific detailed questions referred to it by CCIR Study Group IV (space systems). The results of these studies have been communicated to the appropriate offices.

The Academy Committee has compiled a list of radio astronomy facilities, and the frequencies that they actually use or intend to try to use in the next several years. The Committee has communicated this information to the International Frequency Registration Board via the FCC and the Telecommunications Division of the Department of State.

The Committee has more recently taken cognizance of problems in the fields of radar astronomy and oceanography. Oceanographic activities are now beginning to undergo a considerable expansion. Oceanography, besides being of great interest from the standpoint of pure science, is also of great practical importance from standpoint of mineral and food resources and of waterborne transportation. Furthermore, since the oceans act as vast reservoirs of heat and moisture, a study of their interaction with the atmosphere is necessary for a proper understanding of meteorology and climatology. Plans are underway for better observational coverage of the oceans, with ships, aircraft, boats, and networks and chains of buoys which automatically record and telemeter physical data. The communications requirements of operations of these types are currently being studied under committee auspices by ad hoc groups of oceanographers and radio propagation experts, maintaining liaison with Government regulatory agencies.

The Academy Committee has kept itself up to date on the requirements for communications with scientific satellites and space probes, principally through its NASA representatives.

The Committee has maintained close but informal liaison with its international counterpart, the IUCAF, through the two members common to both committees, and has thus been able to coordinate planning in the United States with that in other countries, particularly in the fields of radio astronomy and space research.

The Committee and its small staff, which is part of the secretariat of the National Academy of Sciences, have worked out effective formal and informal working relationships with the Government offices concerned with management of the radio spectrum, in particular the FCC, IRAC (OEP), and the Telecommunications Division of the Department of State.

Although the Academy Committee is a relatively new one, there are hopeful signs that it will be an effective means by which the U.S. Government regulatory agencies, international scientific advisory groups, and treaty-making organizations can effectively exchange views with the scientific community in the United States, affording a means for the presentation of the needs of science and research.

IV. SCIENTIFIC MANPOWER AND EDUCATION

During the first meeting of the Panel on Science and Technology before this committee on March 25, 1960, Dr. James A. Van Allen first expressed the concern of our Nation's colleges and universities for financial assistance if they were to meet the requirements of this Nation during the coming era. At subsequent meetings of the Panel, various aspects and possible solutions of this problem were ably discussed, and at each meeting the problem was viewed with increasing significance.

The condition of our educational institutions however, was not discussed so much in terms of our immediate needs—since it is felt that the United States has sufficient manpower resources for its immediate objectives—but rather it was viewed as one of the underlying problems determining the future course of this country.

It is evident that the United States is in a battle of survival with the Russians. If the democratic way of life is to prosper, the United States must be strong both militarily and economically. As Philip H. Coombs, Assistant Secretary of State for Educational and Cultural Affairs, has stated:

Military strength buys valuable time for the free world * * * but in the long run the peace of the world and preservation of the free societies will depend upon the development of human capacities and upon the development of a vast "common market" of ideas, knowledge, and cultural interchange.¹

In addition, there is the economic factor to consider. It has been stated that the world population will double in the next 40 years. The United States has both an opportunity and an obligation to develop the resources of our planet in order to assist the underdeveloped countries of the world to obtain a way of life capable of sustaining the growing population. Such action is not to be viewed as a form of charity. By raising the standard of living of the underdeveloped countries, the United States thereby provides another possible market for this country's industrial goods and services and at the same time places a valuable bulwark against the inroads of communism.

In order to supply the requisite technological proficiency for such a broad program, it is necessary for the United States to present a balanced program that will make the best use of our existing technological capabilities. Such a program must assure (1) that science advances on a broad front and provides a current pool of ready information for the use of government, industry, and universities in order to avoid the needless duplication of effort, (2) that Americans have the opportunity to develop their individual capabilities through proper educational training, and (3) that universities are equipped to provide an increasing number of informed scientists and engineers.

The National Science Foundation estimates that the demand for scientists and engineers during the next 10 years will almost double,

¹ The G.E. Forum, vol. IV, No. 3, October-December 1961.

They state that in 1959 the United States had 1,096,000 scientists and engineers, but by 1970 the United States will need 2,032,000. Dr. Richard E. Bolt, Associate Director of Planning, National Science Foundation, testified earlier this year before the committee that this demand will exceed the supply by about 17,000 per year during this period. The universities are already filled to capacity; if they are to train more students, it will first require that universities' facilities be expanded. Dr. Bolt further testified that unless this expansion takes place, the result will be overloaded teachers and classrooms and a general lowering of the quality of education. Those students who have the highest competence, ingenuity, and creativity will not be developed in accordance with their capabilities.

In view of this required expansion, the Panel saw the need for greater financial support as the greatest problem confronting the universities. Unless this problem is resolved, this deficit will manifest itself in the universities' lack of adequate research facilities and the inability to compete with industry and government for qualified personnel. In analyzing this problem, the Panel concerned itself with primarily the support of higher education in the fields of science and engineering. It should not be overlooked however, that the United States must have a thoroughly balanced program from elementary to graduate education in order to provide a continual supply of competently trained students without bottlenecks anywhere along the line. Each level of education is equally important in that each lays the foundation upon which each succeeding level must build. Therefore, each level of education must be closely coordinated and assimilated to meet our national needs.

It is estimated that in the graduate schools alone during the next 10 years, the cost to build the required research laboratories will be \$3 billion. In these times, education has become big business and this money can come from only three possible sources: (1) industry, (2) State governments, or (3) the Federal Government. The Panel limited their discussion primarily to the Federal Government, indicating that this seemed to be the only practical solution; however, they did touch upon the difficulties confronting industry and State governments as possible sources of financial support.

INDUSTRY

The business world should be made aware of the general need for improving the Nation's educational standards. The support of higher education should not be regarded as a type of philanthropy to be indulged in by a handful of industrial giants, but rather must be viewed as an investment by the American business community regardless of its individual corporate size. Investment in research will develop an industry that will grow with the Nation; noninvestment in research will cause an industry to stagnate and be priced out of the competitive market. A good illustration of what can happen is the obsolescence prevalent in today's railroad industry.

If business does recognize the need to invest in research and education, there still may be some hesitancy to undertake such a program because the rewards seem too distant. As pointed out during the panel discussion, the basis of our free enterprise system is obviously the profit motive. Stockholders are looking for an immediate return

on their investments and there is a natural caution to invest large sums of money in basic research which may or may not, pay off 10 or 15 years hence.

It should also be considered that the Federal Government is spending a vast amount of money on industrial contracts. Of the \$12.4 billion that the Federal Government will expend in fiscal year 1963 for research and development, 80 percent of this amount will be expended through non-Federal institutions. There is a trend for organizations to seek Government contracts where they are assured of a profit instead of investing their own money on fundamental research where profits are speculative and distant. This is especially true when a company's competitors are already operating under Government contracts and developing the "expertise" to be the logical candidate for additional future Government contracts.

STATE GOVERNMENTS

The traditional view has been that the States individually support their respective educational institutions. This system has functioned well in the past since it allows the States to determine their own goals, methods, and priorities. However, unlike as it was in the past, over 20 percent of the population is now attending college and the proportion is expected to increase. With this increasing college enrollment, and the corresponding increase in operating costs and facilities, it is becoming exceedingly more difficult for the States to bear this financial burden.

What has been said of the corporate hesitancy to undertake basic research may also be said in some degree of the State governments. The Panel mentioned that an essential characteristic of basic research is its uncertainty. No one knows what benefits may be derived from a certain research project; in fact, frequently no benefits accrue at all. It may be stated that only 10 percent of the basic research carried out results in a benefit to some need of society; however, this 10 percent, and there is no way of knowing what 10 percent it will be, pays for all of the expenditures on basic research many times over. Since that portion of basic research which is beneficial may benefit the industry of some other State, or perhaps the national space or defense effort, there is a tendency for the States to spend money on applied research or development. In this way, the State sees immediate returns for its money that will accrue directly to the people of that State.

It would seem proper and logical therefore, that the Federal Government be the principal tax-receiving agency which supports the field of basic research since it is only the Federal Government that has the broad interest in every field of human activity which can justify spending this money for an adventure into the unknown.

FEDERAL GOVERNMENT

As stated earlier, it is believed to be in the national interest that the Federal Government take an active part in stimulating the growth of our educational system at all levels in order to provide a balanced and well coordinated program. At present there are programs in existence such as the National Defense Education Act of 1958 and the

Veterans' Readjustment Assistance Act of 1952 (Korean GI bill) which provide loans or grants to individuals for the purpose of stimulating educational and vocational training. There is also the proposed College Academic Facilities Act which would provide a 5-year program of grants and loans for building classrooms, libraries, and related academic and service facilities. Similar related proposals for providing financial assistance to elementary and secondary schools have been introduced in Congress and acted upon in committee. In addition, there have been various proposals introduced to amend the Internal Revenue Code of 1954 to provide funds for educational purposes (1) by providing direct aid to States and territories, (2) by providing a tax credit for charitable contributions to institutions of higher education, and (3) by providing a deduction for amounts paid for tuition, fees, and books at an institute of higher education. As yet however, hearings have not been scheduled on these proposed amendments to the Internal Revenue Code.

It is felt that this indicates that serious thought has been given to the educational problems of the United States and that measures are being undertaken to correct possible deficiencies. Therefore, rather than to discuss what has been already accomplished, this report will address itself to those matters immediately concerned with, and under the legislative cognizance of this committee.

In this new era of science and technology, the United States must set national goals and direct its research effort toward attaining those goals. This does not mean that one area should be stressed to the detriment of another; rather, it is essential that there be a balanced program. Basic research should be carried out which has a possibility of benefiting many areas, but nevertheless the immediate stress may be laid on those areas which best conform to our national objectives. To accomplish such a national program, it is necessary that the country (1) expand its university facilities, (2) integrate the teaching aspect directly with the research, and (3) identify those areas of vital interest to our security and economic well-being and establish a system of setting priorities of work.

EXPANSION OF UNIVERSITY FACILITIES

In the report to the President on research and development contracts prepared by the Bureau of the Budget, it is shown that 65 percent of the total national expenditure for research and development if financed by the Federal Government and that this share is increasing. In 1960, universities and other not-for-profit organizations performed 85 percent of the basic research undertaken that year, whereas industry concerned itself primarily with the development aspect. It should be recognized, as these figures illustrate, that one of the primary functions of our universities is to carry out basic research. If the requirement of basic research is to be expanded, facilities must likewise be expanded.

INTEGRATING TEACHING WITH RESEARCH

The notion that teaching is the main function of a university, and that research is something a professor should do as a hobby should be dispelled. In this modern world where knowledge is changing so

fast, there is nothing that an individual learns in college that does him any good 10 years later except how to learn, and the best way to learn is through research. Therefore, research from a teaching standpoint alone is a primary function of the university, and in addition, the knowledge gained from research provides the nucleus for the great advances and achievements that can take place in society. The United States cannot continue to produce new knowledge without also producing new talent, and it is only the universities which can produce both knowledge and talent.

One of the primary causes of alarm to the Panel on this question of integrating teaching and research was the difficulty in planning ahead. Contracts or grants are normally awarded to universities on a year-to-year basis, and the departments are therefore experiencing difficulty in making firm commitments for the requisite manpower and facilities for succeeding years. It was felt that if the universities knew that they would have an extended contract, they could more efficiently plan their time and resources. Allied to this point, is the increasing amount of administrative time spent by the professor in preparing proposals to submit to Government agencies to obtain contracts for his students to work on. Frequently the college professor is in strong competition with industry for these same research funds, and more often than not, it is a losing battle for the college professor since industrial organizations normally have a staff experienced in proposal writing and are geared to followup proposals. The result is that the universities and industry are forced into being competitors when they should have mutual interests in each other's welfare.

Since universities and industry are in a sense competitors for the research dollar, it is frequently this fund raising consideration which forces a professor to channel his research into what may be called applied research where he has a greater certainty of obtaining funds. Although he may feel that research of a more speculative nature would stimulate the creative ability of his students to a greater degree and provide more ultimate benefit, he tends not to follow such an approach because of the difficulty of selling that which does not lead to positive results.

Another problem facing the scientific community as a whole, and one intimately related to the teaching and research ability of the universities, is the present competition for scientific personnel. Both the Federal Government and the universities are losing men to industry because industry can pay a higher wage. The danger in tolerating such a course of action is evident when we examine the fact that two-thirds of the research and development work performed in this country is under a cost-plus-fixed-fee contract. This type of contract provides little or no incentive for industry to reduce costs and the Federal Government is the ultimate one who bears the burden of paying these increased salaries in the form of overhead charges. Therefore, the Federal Government is fostering a system where it is paying industry to entice scientists and engineers from the universities and from the Federal Government itself. Perhaps the sole solution to this question is not to be found by raising the salaries of Government employees—since industry could then raise their salaries and continue the inflationary spiral—but rather raise the Government salaries:

comparable to industry and then limit the amount which the Federal Government will reimburse industry for salaries in the form of overhead charges.

IDENTIFYING AREAS OF INTEREST AND ESTABLISHING PRIORITIES OF WORK

Studies should be undertaken by those agencies of the Federal Government concerned with research and development to determine in which of their respective areas the greatest emphasis should be placed to insure the national good. Obviously, equal emphasis cannot be placed on all projects from which some benefit may possibly be derived since such a program would be enormously costly and spread our existing facilities and manpower resources so thin that it may endanger the forward momentum of the country's scientific and technical movement. Programs which are undertaken by the agencies should be coordinated through the new Office of Science and Technology whenever possible to insure maximum utilization of facilities and to avoid the unnecessary duplication of effort.

Those universities which have demonstrated the ability to conduct basic research and at the same time graduate students of superior quality, should be given the first opportunity to participate in any program of expansion. Once such a program is functioning, it could then be expanded to include other universities by developing their capability to conduct research. In this way, the program will be given the quickest initial impetus and, by bringing in other universities at a later time, it will result in widening the base of the country's research and teaching resources, thereby increasing the ultimate quality of the country's scientific and technical knowledge.

Once a program of university assistance is initiated, undoubtedly there will be many competing requests from universities to augment existing facilities. In order to avoid "shooting in the dark," it is essential that such a system of priorities be adhered to. It is recognized however, that there will be some difficulty in administering such a program since there will not be unanimous agreement as to which universities are the more capable.

In considering the type of program to be instituted, it was suggested that a program similar to the Hill-Burton Act of 1946 may be feasible. The Hill-Burton Act was designed to provide assistance for the construction of facilities in the medical and biological areas on a matching fund recipe of roughly \$2 of local money to every \$1 of Federal money. The advantage of the matching fund idea is the powerful stimulus it provides at the local level while at the same time providing an automatic assurance of the soundness of the request. It was recommended that such a program be investigated to stimulate the construction of facilities in the physical sciences such as physics, chemistry, biology, geology, astronomy, mathematics, and the engineering sciences.

CONCLUSION

It was concluded from the discussion which transpired during the four meetings of the Panel that financial support of educational institutions, particularly of basic research in the physical sciences at the graduate level, must be encouraged on the part of State govern-

ments and industry, but that much of the ultimate financial burden must be borne by the Federal Government. The reason that the Federal Government should bear this cost is due to the fact that only the Federal Government has the wide sweeping interest in the country's military and economic security which could justify the expenditures required in the utilization and development of any breakthrough made in basic research, which is of its very essence, uncertain and unpredictable.

V. THE METRIC SYSTEM

On June 28, 29, 1961, Subcommittee No. 1 under the chairmanship of Congressman Miller, held hearings on H.R. 2049, a bill providing for a survey to determine the practicability of adopting the metric system of weights and measures. On July 21, 1961, the full committee met and unanimously agreed to report H.R. 2049 to the House. The bill was placed on the Consent Calendar and subsequently was passed over without prejudice. On April 16, 1962, the bill was objected to on the Consent Calendar, and on May 7, 1962, it was again objected to and stricken from the Consent Calendar. No further action has been taken on the bill at this time.

PURPOSE OF THE BILL

The purpose of H.R. 2049 is to provide that the National Bureau of Standards shall conduct a study to determine (1) the advantages or disadvantages that would result from the conversion to the metric system in the scientific, engineering, manufacturing, and commercial areas, and in the educational institutions, (2) the advantages that would accrue in international trade and commerce as well as in the military and other areas of international relations, and (3) the possible practical difficulties that might result to the various Federal or State departments or agencies in accomplishing the conversion to the metric system.

BACKGROUND

Numerous bills for the adoption of the metric system have been before the Congress dating back to the time of George Washington. Although the metric system was legalized for use in the United States in 1886 by an act of Congress, it still has not been widely used by industry, the scientific community, or by the public.

WHY HASN'T THE METRIC SYSTEM BEEN ADOPTED?

No definite theory has been advanced as to why the metric system was never officially adopted as the standard of weights and measures in the United States. One possible theory as to why the various bills have failed is simply that in each case the proposed effective date of the change followed too soon after the passage of the bill. It was submitted that an early effective date would undoubtedly work a severe hardship on the adult population not familiar with the metric system, and it would make obsolete a prohibitive number of everyday items pertaining to weights and measures. Perhaps it is this reason coupled with the fact that our forefathers originally started with the English system and there has subsequently been simply a reluctance to change. The benefits realized by the adoption of the metric system, if benefits there be, will be primarily realized in the business, scientific, and engineering community. Of course these benefits will

ultimately accrue to the population as a whole, but perhaps in the everyday domestic life of the people there has just not been sufficient interest in either system to petition the Congress for a change. It is submitted that it is not that the people do not want the metric system, but simply that the people have not been shown any valid illustrative reasons why a change should be made.

WORLDWIDE USE OF THE METRIC SYSTEM

At present some 76 countries comprising 90 percent of the world population have laws which require use of the metric system. The three primary countries which have not adopted the metric system yet are the United States, England, and Canada.

In our own country, the pharmaceutical industry has already converted to the metric system and others, notably the chemical industry, are looking forward to conversion in the immediate future. In addition, U.S. Army is converting their weapons and associated fire control equipment to the metric system and this conversion is expected to be completed by January 1, 1966. The reason given why the Army converted to the metric system was an effort to simplify procedures and develop a better capability of working with the armies of friendly nations.

Technically speaking, the metric system is more simple to use than the system of English units for the reason that it is a decimal and therefore requires little or no translation. There is considerable thinking that commercially the metric system is essential in order that the United States may compete with countries which are able to supply drawings, specifications, plans, and goods to the metric standards.

Studies have already been completed by various groups to determine the feasibility of converting to the metric system. The reports have been favorable, and the time required for such a transition has been estimated to take as long as a generation (33 years). It is proposed that this period of time would allow the gradual transition to the metric system by introducing the system in our schools in order that the younger generation would grow up accustomed to using this system. In addition, a generation would allow a sufficient period of time for most items of equipment to be replaced following the normal depreciation rate for obsolescence.

CONCLUSION

While these studies have been helpful, an official study by the Government as proposed by H.R. 2049 could be used by the Congress as a clear, factual, and realistic basis for determining the magnitude and the desirability of converting our present measuring system to the metric system of weights and measures. It should be stressed that it is not the purpose of H.R. 2049 to introduce the metric system in the United States. Rather, it provides that the National Bureau of Standards should study the feasibility of converting to the metric system, and if it is feasible, then to determine when would be the most advantageous time to convert to the system, and how the conversion could be accomplished.

The panel enthusiastically recommended that this study be conducted at the earliest possible date.

APPENDIX A

PROGRAM

MARCH 21, 1962

Wednesday, 10:30 a.m.

Opening remarks:

Chairman George P. Miller.

Ranking minority member Joseph W. Martin, Jr.

Panel moderator:

Dr. George B. Kistiakowsky.

Papers:

Mapping and geodetic satellite program.

Dr. Fred L. Whipple.

Discussion period.

Wednesday, 2 p.m.

Advanced propulsion for space.

Dr. Maurice J. Zucrow.

Discussion period.

Wednesday, 5 p.m.

Reception

MARCH 22, 1962

Thursday, 10 a.m.

Panel moderator:

Dr. Harrison S. Brown.

Discussion period:

The panel meeting will be open to discussion topics selected by the panel members which they feel will be of interest to the committee and to the panel.

Guest participant:

Sir Bernard Lovell, O.B.E., F.R.S., director, Jodrell Bank experimental station, England.

Closing remarks:

Chairman George P. Miller.

APPENDIX B

BIOGRAPHIES OF THE PANELISTS

BALDES, EDWARD J (AMES)

[From Who's Who in America, 1958-59, vol. 30, supplemented from American Men of Science, vol. 1, ninth edition and amended by committee staff]

Biophysicist; b. Fairfield, Neb., July 5, 1898; s. Joseph James and Margaret (Lenzen) B.; B.A., U. of Saskatchewan, Can., 1918, LL.D., 1955; M.A., Harvard, 1920, Whiting Fellow, 1922, Ph. D., (physics), 1924; Ph. D., (physiology), University Coll., London U., London, Eng., 1936 m. Mary Cooney, June 27, 1934; children—Joseph, James, Mary Margaret, Honora, Elizabeth Louise. Asst. in physics U. of Saskatchewan, 1918-19; Radcliffe Coll., Cambridge, Mass., 1921-24; instr. in physics Harvard, 1923-24; asso., Section of Biophysics, Mayo Clinic, since 1924, dir., 1948-58, senior consultant since 1958; vice chmn. Mayo Aero Med. Unit since 1942; prof. biophysics Mayo Foundn. Grad. Sch., U. of Minn., since 1943; Cons. to Council on Phys. Med. and Rehabiltn., A.M.A., 1946-56; mem. Council Am. Electroencephalographic Soc., 1947-51; chmn. panel on aviation medicine Research and Development Bd., Nat. Mil. Establishment, 1948-53; mem. panel on aero. medicine Sci. Advisory Board to Chief of Staff USAF, 1948-54; member editorial board International Journal of Electroencephalography and Clin. Neurophysiology 1947-54; mem. subcom. on acceleration Nat. Research Council, 1942-46, com. on aviation medicine 1946-49. Spl. cons. Aero Med. Lab. Wright-Patterson Air Force Base, 1942-49; mem. adv. panel on physiology Office of Naval Research 1947-51. Alternate mem. Aerospace Medical Panel, Adv. Group for Aero. R. & D. of NATO, 1960—; mem. Panel on Science and Techn., Com. on Science and Astronautics, House of Representatives, 1960—; Chevalier Legion of Honor (France), Knight St. Gregory the Great. Fellow Aerospace Med. Assn. (member executive council 1953-56) mem. Am. Phys. Soc., Institute Am. Phys., Inst. Am. Physics, American Physiol. Society, A.A.A.S., Institute Aerospace Science, Minn. Academy Science (president 1956-57). Biophysical Soc., Am. Heart Assn., Sigma Xi (honorary). Awarded War Dept. Commendation and Medal for Exceptional Civilian Service in aviation medicine to U.S.A.F., 1945; presdl. Certif. Merit for work in aviation medicine, 1948. Author of over 100 sci. papers in field of biophysics, physiology, aviation medicine. Mem. editorial bd. Jour. Physiology, Jour. Applied Physiology, 1956—; mem. adv. editorial bd. Aerospace Medicine, Aerospace Medical Assn., 1957—. Home: 427 Fifth Ave. S.W. Office: Mayo Clinic, Rochester, Minn. Fields: Blood flow, osmotic pressure, electrophysiology, aviation medicine.

BROWN, HARRISON (SCOTT), SEPT. 26, 1917—GEOCHEMIST; UNIVERSITY PROFESSOR; AUTHOR

"To what extent can man subjugate selfishness to generosity, ignorance to wisdom, and hate to love?" asks Geochemist Harrison Brown in his book, "The Challenge of Man's Future" (Viking, 1954). A scientist who is "thoroughly at home in the tangle of sciences that bear on man's future on earth," Professor Brown is "also at home in history and sociology and * * * is a good writer" (Time, Mar. 22, 1954). In his books, articles, and lectures he has frequently pointed out the position of "overwhelming responsibility" held by citizens of the United States "in this time of grave decision when our survival depends upon the victory of wisdom and knowledge over stupidity and dogma."

While studying at the University of California in Berkeley, Brown helped to support himself by playing the piano in taverns, an experience he terms "an eye-opening extension of my education." Prof. R. D. Fowler aroused the youth's interest in nuclear chemistry and after Brown's graduation with a B.S. degree in 1938, he followed Professor Fowler to the Johns Hopkins University at Baltimore, Md., to do graduate work in that field. Brown's research was supported in 1940 and 1941 by a Du Pont fellowship. His doctoral dissertation was in two parts: "Thermal Diffusion Coefficient of Argon" and "Construction of a Mass Spectrometer for Isotope Analysis."

After receiving his Ph. D. degree in 1941, Brown remained at Johns Hopkins as an instructor in chemistry. He planned to devote his research time to investigating the chemical composition of the universe, but following the Japanese attack on Pearl Harbor, he went to Chicago as a research associate and during 1942 and 1943, worked on the atomic bomb at the plutonium project at the University of Chicago.

In addition to his scientific papers, Harrison Brown has written the book, "The Next 100 Years," and reviews and articles for the Saturday Review, Nation, and the American Scholar. He was a coauthor of "Years of the Modern" (Longmans, 1949). Brown spoke on "The Social Responsibility of Science" on Mar. 6, 1949, at the New York Herald Tribune Forum and urged his fellow scientists to "develop, wherever possible, constructive solutions to the technical problems that confront mankind: the production of food, clothing, and shelter."

He belongs to the American Association for the Advancement of Science, the American Chemical Society, the American Physical Society, and the Geological Society of America, and is a member of Sigma Xi and Phi Beta Kappa. He is chairman of the committee on oceanography and member of the Space Science Board of the National Academy of Sciences.

DUBRIDGE, LEE A (LVIN)

[From Who's Who in America, 1958-59, vol. 30, supplemented from American Men of Science, vol. I, ninth edition and amended by committee staff]

Physicist; born Terre Haute, Ind., Sept. 21, 1901; s. Frederick Alvin and Elizabeth Rebecca (Browne) DuB.; A.B. Cornell Coll., Ia. 1922, Sc. D., 1940; A.M., U. of Wis., 1924, Ph. D., 1926; Sc. D., Wesleyan Univ., 1946, Brooklyn Poly., 1946; U. British Columbia, 1947; Wash-

ington U., 1948; Occidental Coll., 1952; U. Md., 1955; Columbia, 1957; Ind. U., 1957; U. Wis., 1957; LL.D., U. Cal., 1948; U. Rochester, 1953; U. So. Cal., 1957; U. of Redlands, L.H.D., 1958; U. of Judaism, L.H.D., 1958; Northwestern U., LL.D., 1958; m. Doris May Koht, Sept. 1, 1925; children—Barbara Lee (Mrs. David MacLeod), Richard Alvin. Assistant in physics, U. of Wis., 1922–25, instr., 1925–26; fellow Nat. Research Council at Calif. Inst. Tech., 1926–28; asst. prof. of physics, Washington U., St. Louis, 1928–33, asso. prof., 1933–34; prof. of physics of U. of Rochester, 1934–46, dean faculty arts and science, 1938–42; investigator, Nat. Defense Research Com. dir. radiation lab., Mass. Inst. Tech., 1940–45; pres. Calif. Inst. Tech., since 1946. Bd. Trustees, Rand Corp., Santa Monica, Calif., since 1948. Mem. gen. adv. com. A.E.C., 1946–52. Naval Research Adv. Com., 1945–51; Air Force Sci. Adv. Bd., 1945–49; mem. President's Communications Policy Bd., 1950–51; mem. Nat. Sci. Bd., 1950–54, 1958—; chmn. sci adv. committee Office Defense Mobilizn.; 1952–56; mem. Nat. Manpower Council, 1951—; trustee Mellon Inst., Pitts., 1958—. Trustee Rockefeller Found., 1956—, Nutrition Found., 1952—, Carnegie Endowment for Internat. Peace, 1951–57. Received Research Corp. Award, 1947. Medal for Merit (U.S.), 1948; King's Medal for Service (Brit.), 1948. Fellow Am. Phys. Soc. (v.p., 1946, pres., 1947); mem. Nat. Acad. Sci., American Philosophical Soc., A.A.A.S., American Assn. of University Professors, Phi Beta Kappa, Sigma Xi, Tau Kappa Alpha, Tau Beta Pi. Presbyn. Author: Photoelectric Phenomena (with A. L. Hughes), 1932; New Theories of Photoelectric Effect, 1935. Contbr. numerous articles to scientific and other jous. Home: 415 S. Hill Av., Pasadena, Calif.

Fields: Biophysics, nuclear disintegration, photoelectric and thermionic emission, direct current amplification, energy distribution of photoelectrons, theory of photoelectric effect, radar.

FURNAS, CLIFFORD C(OOK)

[From Who's Who in America, 1958–59, vol. 30, supplemented from American Men of Science, vol. I, ninth edition and amended by committee staff]

Chemical engineer and univ. pres., author; b. Sheridan, Ind., Oct. 24, 1900; s. Thomas Chalmers and Clara Evana (Spray) F.; B.S., Purdue U., 1922, D. Eng. (hon.), 1946; graduate work Carleton College, 1923–24; Ph. D., University of Michigan, 1926, D. Eng. (hon.), 1957; LL.D. (hon.), Alfred U., 1958; Sc. D. (hon.), Thiel College, 1960; married Sparkle Moore, April 12, 1925; 1 daughter, Beatrice Louise. Teacher of mathematics, Shattuck School, 1922–24; research chemist with U.S. Steel Corp., 1924–25; phys. chemist with U.S. Bur. of Mines, 1926–31; asso. prof. of chem. engring., Yale U., 1931–42; tech. aide, Nat. Defense Research Com., 1941–43; director research, Curtiss-Wright Airplane Div., 1943–46; exec. v.p., dir. Cornell Aeronautical Lab., 1946–54; industrial consultant; chancellor U. Buffalo, 1954—; research asso. Bureau of Ednl. Research in Science, summer, 1938; lectr. Bur. of Ednl. Research in Science for Tchrs. Coll., Columbia, summer, 1939. Research chem. engring., and metallurgy; chmn. guided missile com., Research and Development Bd., 1952–53; N.A.C.A. 1955–57; chmn. Air Navigation Development Bd. 1956–57;

chmn. advisory panel on aeronautics Dept. of Defense, 1954-55; asst. sec. of defense for research and development, 1955-57; chmn. Army Scientific Adv. Panel, 1960—; mem. Naval Adv. Panel 1958—; mem. Bd. Trustees Aerospace Corp., 1960—. Awarded Big 10 Conf. medal for best combined scholastic and athletic record, 1922; mem. 1920 Am. Olympic Team; recipient Vincent Bendix award Am. Soc. Engring. Edn.; western N.Y. honor scroll Am. Inst. Chemists; gold medal Buffalo Club. Fellow A.A.A.S., Inst. Aero. Scis. (vice pres., 1959-60); mem. Am. Inst. Chem. Engrs., Am. Chem. Soc., Newcomen Soc., Sigma Xi, Phi Beta Kappa, Tau Beta Pi, Phi Lambda Upsilon, Theta Chi. Clubs: Chemists (N.Y.); Buffalo, Buffalo Country, Saturn (Buffalo); Cosmos (Washington). Author: *America's Tomorrow*, 1932; *The Next Hundred Years*, 1936; *Man, Bread and Destiny*, 1937; section on metallurgy in *Technological Trends and National Policy*, 1937; *The Storehouse of Civilization*, 1939; also author sects. on sci. in various publs. Editor: *Roger's Manual of Industrial Chemistry*, 1941; *Industrial Research: Organization and Management*, 1948. Contbr. sects. on sci. and technology *Modern World Politics*, 1953. Home: 651 Le Brun Rd. Office: U. of Buffalo, Buffalo 14, N.Y.

Fields: Reduction of iron oxides, chemical and physical reactions in blast furnaces, heat transfer, gas flow, distillation equilibria, combustion of carbon, ionic base exchange, fluid flow distillation, gas absorption, reaction kinetics, base exchange, world natural resources.

GOLAND, MARTIN

[From *American Men of Science*, vol. I, ninth edition; revised by committee staff]

Applied Mechanics. b. New York, N.Y., July 12, 1919; m. 1948, c.3. M. E. Cornell, 1940. Instr. eng. mech., Cornell 1940-42; sect. head applied mechanics, research lab, Curtiss-Wright Co., N.Y. 1942-46; Chairman Eng. Div. Midwest Research Insti. 1946-53; Director Eng. Sciences, 1953-55. Staff, Southwest Research Inst; 1955—, President, 1959—.

Awards: Spirit of St. Louis Junior Award, Am. Soc. of Mech. Eng., 1944; Junior Award, Am. Soc. of Mech. Eng., 1946; Alfred Noble Award, Am. Soc. of Civil Eng., 1947; Prof. of Research, *honoris causa*, St. Mary's Univ. Member: Am. Soc. of Mech. Eng.; Tech. Develop. Com. and Publications Com. of ASME; Am. Rocket Soc.; Institute of Aerospace Scis.; Soc. for Experimental Stress Analysis; Chmn., Research Adv. Com. on Aircraft Structures of the National Aeronautics and Space Adm.; mem., Sci. Adv. Com., Diamond Ordnance Fuze Labs.; Panel on Sci. and Techn. Com. on Science and Astronautics, House of Representatives, Washington, D.C.; Brittle Fracture Com., National Research Council; mem. Board of Governors, St. Mary's Univ. and Graduate Council, Trinity Univ., San Antonio, Tex. Editorial Advisor, *Applied Mechanics Reviews*. Address: Southwest Research Institute, 8500 Culebra Road, San Antonio 6, Tex.

Fields: applied mechanics, applied mathematics, and engineering analysis. Diversified experience in structures, aerodynamics and fluid

flow, aircraft dynamics, vibration and impact problems, and other engineering analysis fields. Experience in operations research and industrial economics techniques.

KISTIAKOWSKY, GEORGE B., HARVARD UNIVERSITY, ABBOTT AND JAMES LAWRENCE PROFESSOR OF CHEMISTRY (BIOGRAPHY TO JANUARY 15, 1962)

Prof. George B. Kistiakowsky of Harvard is known for his experiments over a wide range of chemical problems. In recent years, his interest has centered on finding out exactly what happens in a chemical change, whether it is a relatively slow enzyme reaction or a very quick detonation.

A key member of the team that made the atomic bomb in World War II, he was one of the original members of the President's Scientific Advisory Committee, and has served on that body since 1957. He was a member of the U.S. delegation at technical talks with the Soviets in Geneva during 1958, on ways of reducing the danger of surprise nuclear attack. From 1953 to 1958, he was on the ballistic missiles advisory committee of the Air Force and Defense Department.

At Harvard, where he is Abbott and James Lawrence Professor of Chemistry, Dr. Kistiakowsky was chairman of the department from 1947 to 1950. For several years, he has been on the Admissions Committee for Harvard College. As a member of the faculty committee on athletics, he regularly attends home football games and other sports events. His own favorite sport is skiing.

As a scientist, Professor Kistiakowsky is an experimentalist rather than a theorist. Colleagues praise his wise choice of key problems to investigate, his skill in devising the means for carrying out a laboratory test, and his shrewd interpretation of experimental results.

He is a shirt-sleeve chemist, who prefers to work in the laboratory himself in investigating a problem. There, his craftsmanship in forming laboratory tools is a help. He is a skilled glassblower. Needing a special pressure gage for one experiment, he designed and made it in the laboratory. Before governmental demands on his time grew heavy, he would spend 2 or 3 days working in the laboratory beside an advanced student, to help find the kinks in an experiment that was not working right.

One of his chemical interests is the kinetics of free radicals—unstable pieces separated off from molecules, which then recombine into stable molecules in the space of one-millionth of a second. In various chemical changes, he has studied the detailed mechanism by which molecules break and reform into other substances. He has studied many chemical changes by use of a gaseous detonation chamber, which is a long metal tube. He used this device to provide one of the first solutions to the question: How much energy does it take to tear apart the tightly bound nitrogen molecule?

Earlier, he did pioneer work in spectroscopy, in the precise measurement of heat in chemical reactions, and in photochemistry.

His knowledge of the chemical chain of events in explosions was put to work on defense problems during World War II. He became chief of the explosives division of the National Defense Research Committee. He established and ran the Explosives Research Committee.

He established and ran the Explosives Research Laboratory at Bruce-ton, Pa., and helped establish a second laboratory, for underwater explosives research, at Woods Hole, Mass.

In 1944, he became chief of the explosives division of the Los Alamos Laboratory of the Manhattan district, and there he designed the arrangement of conventional explosives necessary to detonate the atomic bomb.

For his service, he received the President's Medal for Merit. This he later had to show to officers of the town of Lincoln, who has questioned his qualifications for dynamiting stumps on his property.

Professor Kistiakowsky also holds the King's Medal of the United Kingdom for services in the cause of freedom, the Exceptional Service Award of the U.S. Air Force, and the Medal of Freedom in 1961, among others. His scientific honors include the Nichols Medal, the Joseph Priestley Award, membership in the National Academy of Sciences, honorary fellowship in the Chemical Society (London), the American Chemical Society's Charles Lathrop Parsons Award for outstanding public service in 1961, the George Ledlie Prize (Harvard's top faculty award) for 1961, and honorary degrees from Harvard, and from Williams College.

Professor Kistiakowsky was born in Kiev, Russia, on November 18, 1900. His father was a professor of international law there, and he attended private schools in Moscow and Kiev. During the Russian revolution of 1918-20, he was a tank soldier in the White (anti-Communist) Russian Army. After defeat, he spent most of a year in concentration camps in Turkey and the Balkans, and then entered the University of Berlin. In 4 years, studying under the great chemist. Max Bodenstein, he achieved the doctor of philosophy degree. He worked as Professor Bodenstein's assistant for a year, and then came to the United States as an International Education Board fellow at Princeton University, working under Prof. H. S. Taylor. He became as assistant professor at Princeton, and taught there for 2 years. In 1930, he joined the Harvard faculty, where he has held office since. He became professor of chemistry in 1938. From May 1959 to January 1961, he was special assistant to President Eisenhower for science and technology.

LOVELL (ALFRED CHARLES) BERNARD, AUG. 31, 1913—SCIENTIST;
UNIVERSITY PROFESSOR; AUTHOR

The first holder of a chair in radio astronomy at the University of Manchester and director of the Jodrell Bank Experimental Station, Dr. Bernard Lovell is recognized as one of the foremost authorities in his field. At Jodrell Bank he supervises the world's largest radio-telescope, which owes its existence to his foresight and zeal. Dr. Lovell has used this unique instrument to track the Russian and American Earth satellites to chart radio signals giving data on the existence of cosmic explosions, to observe the activity of the mysterious aurora, and to obtain climatic and topographical information about the planets.

He took a bachelor of science degree in 1933 and a Ph. D. degree 3 years later. In 1936 Lovell was appointed an assistant lecturer in physics at the University of Manchester, and the following year he

was named an assistant to Prof. Patrick Maynard Stuart Blackett, with whom he worked on cosmic ray research.

Books that Dr. Lovell has written are "Science and Civilization" (Nelson, 1939), "Radio Astronomy" (Chapman, 1951), "Meteor Astronomy" (Oxford, 1954), and "The Exploration of Space by Radio" (Chapman, 1957), and "The Individual and the Universe" (Reith Lectures of 1958).

MALONE, THOMAS FRANCIS

[From American Men of Science, vol. I, ninth edition; revised by committee staff]

Meteorology. b. Sioux City, Iowa, May 3, 1917; m. 1942; c. 5. B.S., S. Dak. Sch. Mines & Tech, 1940; Sc. D., Mass. Inst. Tech, 1946. Asst. Mass. Inst. Tech. 1941-42, asst. prof. Meteorol. 1943-51, assoc. prof. 1951—; Director of Research, The Travelers Insurance Companies. Ed. "Compendium of Meteorol." Civilian with U.S.A.; Office Naval Research, 1944. Am. Meteorol. Soc. (now pres.). Address: The Travelers Insurance Companies, 700 Main Street Hartford, Conn.

Fields: Applied meteorology; synoptic climatology; climate in relation to architecture.

NOYES, W(ILLIAM) ALBERT, JR.

[From Who's Who in America, 1958-59, vol. 30, supplemented from American Men of Science, vol. I, ninth edition and amended by committee staff]

Chemist and univ. prof.; b. Terre Haute, Ind., Apr. 18, 1898; s. William Albert and Flora (Collier) N.; student U. of Ill., 1916-17; A.B., Grinnell (Ia.) Coll., 1919; D.Sc., 1946; D.-es-Sc., U. of Paris, France, 1920, also hon. doctorate, 1957; D.Sc. U. Rhode Island, 1952; D.Sc., Indiana U., 1958; D.Sc., U. of Ottawa, 1960; student U. of Geneva, Switzerland, 1920; U. of Calif., 1920-21; m. Sabine Onillon, June 10, 1921; 1 son, Claude Charles. Instr., U. of Calif., 1921-22, U. of Chicago, 1922-23; asst. prof., U. of Chicago, 1923-29; asso. prof., Brown U., 1929-35, prof., 1935-38; prof., U. of Rochester since 1938, chmn. chemistry department since 1939, dean graduate school, 1952-56; acting dean College Arts and Sciences, 1956-58; chairman division Chemistry and Chemical Technology, Nat. Research Council, 1947-53; chmn. com. on chem. warfare, Research and Development Bd., 1948-50; vice pres. Internat. Union of Chemistry, 1947-51; treas. Internat. Council Sci. Unions, 1952-55; exec. committee, Internat. Union Pure and Applied Chemistry, 1955-59 (pres., 1959-63). Montgomery lectr., U. Neb., 1956; Westman Memorial lectr., Chem. Inst. Can., 1955; Harkins lectr., University of Chicago, 1956. Served as pvt., corpl., sergt., 2d lt., Signal Corps, U.S. Army, 1917-19; Officer Legion of Honor, France. Sect. chmn., National Defense Research Com., 1940-42; div. chmn., 1942-46. On staff of chief Tech. Div., Chem. Warfare Service, U.S. Army, 1942-46; adviser U.S. delegation 1st conf. UNESCO, 1946, alt. del., 3rd conf., 1948; Naval Research Advisory Committee, 1947-52; mem. bd. of trustees Sloan-Kettering Inst. for Cancer Research since 1950. Received Kings Medal for Service in Cause of Freedom, Medal for Merit, Am. Phil.

Soc.; Priestley Medal, American Chemical Society, 1954, Willard Gibbs Medal, 1957. Member Nat. Acad. Sciences (mem. council, 1947-50), American Chemical Society (chairman com. on professional training of chemists, pres. 1947), Am. Acad. Arts and Sciences, Am. Phys. Soc., N.Y. Acad. Sciences, Ill. Acad. Sciences, member COSPAR; Sigma Alpha Epsilon, Alpha Chi Sigma, Phi Lambda Upsilon, Sigma Xi, Phi Beta Kappa, Conglist. Author: *Modern Alchemy* (with W. A. Noyes, Sr.), 1932; *Photo-chemistry of Gases* (with P. A. Leighton), 1941; *Traite de Chimie Physique* (with H. Weiss) (translation into French of text by E. W. Washburn), 1925; *Spectroscopie et les Réactions Initiées par la lumière*, 1938. Editor, *Chem. Revs.*, *Jour. Am. Chem. Soc.*, *Jour. Phys. Chemistry*. Home: 7 Summit Dr., Rochester 20, N.Y.

Fields: Electrochemistry, photochemistry, vapor pressures, reaction kinetics, fluorescence, spectroscopy.

OLIVER, CLARENCE P(AUL)

[From *Who's Who in America*, 1958-59, vol. 30, supplemented from *American Men of Science*, vol. II, ninth edition and amended by committee staff]

Zoologist, geneticist and educator; b. Obion Co., Tenn., Nov. 8, 1898; s. Benjamin Wesley and Mary Eunellie (Massey) O.; A.B., U. Tex. 1925, M.A.; 1930, Ph. D., 1931; m. Cecile Worley, July 29, 1931; children—Peter Lee, George Benjamin, Asst. prof. zoology Washington U., St. Louis, 1930-32; successively asst. prof., asso. prof., prof. zoology U. Minn., 1932-46, dir. Dight, Inst. Human Genetics, 1941-46; prof. zoology U. Tex. since 1946, chmn. dept. zoology 1947-59, Mem. A.A.A.S., Am. Assn. Cancer Research, Soc. Exptl. Biology and Medicine, Am. Soc. Human Genetics, (pres. 1953). Am. Genetics Assn., Am. Soc. Zoologists, Am. Soc. Naturalists, Genetics Soc. Am. (sect. 1953-55; pres. 1958). Author articles profl. journ. Co-managing editor *Genetics*, 1957—. Home: 305 E. 32d St., Austin 5, Tex.

Fields: Human genetics, genetics of human cancer, gene action in *Drosophila* alleles, mutation process, radiation effects on *Drosophila*.

PETTERSEN, SVERRE

[From *Who's Who in America*, 1958-59, vol. 30, supplemented from *American Men of Science*, vol. I, ninth edition, amended by committee staff]

Meteorologist; b. Hadsel, Norway, Feb. 19, 1898; s. Edward Hildor and Petronella (Petersen) P.; B.S., Oslo U., 1924, M.S., 1926, Ph. D., 1933; m. Daisy Bonner, Aug. 16, 1925; 1 dau. Eileen (Mrs. Anton Oerbeck); m. 2d Lillian Bye Sept. 30, 1941; 1 son, Bernt; m. 3d Grace Beverly, Mar. 29, 1946. Came to U.S., 1948. Naturalized, 1955. Meteorologist Norwegian Weather Service, 1924-31, regional dir., 1931-39; vis. prof. Cal. Inst. Tech., 1935; prof., chmn. meteorol. dept. Mass. Inst. Tech., 1939-42; advisor Meteorol. Office Brit. Air Ministry, 1942-45; chief Norwegian Forecasting Service, 1945-48; advisor Dir. Gen. Observatories, India, 1948; dir. sci. services U.S.A.F.

Weather Service, Washington, 1948-52; prof. meteorology U. Chicago, since 1952; chmn. Dept. of Meteor. since 1960. Decorated Comdr. Order Brit. Empire; Comdr. Order St. Olaf; Liberation Cross (Norway); The Buys Ballot's gold medal (Netherland Acad. Sci.), 1948; Letter commendation Gen. Dwight Eisenhower, 1944; letter of commendation British Air Council, 1944; Distinguished Service Award, U.S. Air Force, 1953; Distinguished Service Award, Chicago Council of Technical Societies, 1957; New York Board of Trade Gold Award, 1958. Pres. Internat. Commn. for Maritime Meteorology, 1939-46; pres. Internat. Comm. for Aerology, 1946-51. Mem. Norwegian Acad. Sci., hon. mem., Royal Meteorological Soc.; hon. mem., Peruvian Meteorological Soc.; foreign mem., Societas Scientiarum Fennica; Am. meteorol. soc. (past pres.); Amer Geophys. Union; A.A.A.S. Author: *Weather Analysis and Forecasting*, 1940, sec. ed. 1957, *Introduction to Meteorology*, 1941, sec. ed. 1958; Co-author: *The Meteorology of the Arctic*, 1956. Home: 5737 S. Blackstone Av., Chgo. 37.

Fields: Synoptic and dynamic meteorology.

REVELLE, ROGER (RANDALL DOUGAN)

[From *Who's Who in America*, 1958-59, vol. 30, and supplemented from *American Men of Science*, vol. I, ninth edition]

Geophysicist, oceanographer and educator; b. Seattle, Mar. 7, 1909; s. William Roger and Ella Robena (Dougan) R.; A.B., Pomona Coll., Claremont, Cal., 1929; student Claremont Coll., 1929-30; Ph. D.; U. Cal., 1936; m. Ellen Virginia Clark, June 22, 1931; children—Anne (Mrs. Shumway), Mary Ellen, Carolyn, William Roger. Teaching asst. Pomona Coll., 1929-30; teaching asst. U. Cal., 1930-31, research asst. Scripps Instn. Oceanography, 1931-36, instr., 1936-41, asst. prof., 1941-46, asso. dir. 1948-50, prof. oceanography, since 1948, acting dir., 1950-51, dir. since 1951; civilian cons. Office Naval Research, 1948; mem. internat. joint commn. sci. oceanography Internat. Council Sci. Unions, since 1951. Adv. bd. Mus. Arts Soc., La Jolla, since 1947; trustee La Jolla Town Council since 1949. Served with U.S.N., 1941-47, naval officer Radio and Sound Lab., San Diego, Cal. 1941-42 with Bur. Ships, Navy Dept., 1942-46, staff Joint Task Force No. 1, 1946, Office Naval Research 1946-47. Fellow San Diego Soc. Natural History, Geol. Soc. Am.; mem. Am. Assn. Petroleum Geologists, Am. Geophys. Union (v.p. oceanography sect. 1950-53). A.A.A.S., Nat. Research Council, Am. Meteorol. Soc., Soc. Limnology and Oceanography Geol. Soc. Washington, Western Soc. Naturalists, Sigma Xi. Clubs: Cosmos (Washington), Men's Faculty (Berkeley, Cal.). Contbr. articles profl. publs. Home: 7348 Vista del Mar, La Jolla, Cal.

Fields: Physical oceanography and geology of the sea floor.

RUSSELL, RICHARD JOEL

[From *Who's Who in America*, 1958-59, vol. 30, supplemented from *American Men of Science*, vol. I, ninth edition and amended by committee staff]

Physical geographer and univ. prof.; b. Hayward, Calif., Nov. 16, 1895; s. Frederick James and Nellie Potter (Morrill) R.; A.B., U. of Calif., 1919, Ph. D., 1926; m. Dorothy King, 1924 (died 1936); 1 son,

Benjamin James; m. 2d Josephine Burke, 1940; 4 sons, Robert Burke, Charles Douglas, John Walter, Thomas William. Teaching fellow, U. of Calif., 1920-22, asso. in geography, 1923-25; asso. prof. geol. Tex. Tech. Coll., 1926-27; asso. prof. of geography, La. State U., 1928-29, prof. phys. geog. since 1930, head dept., 1936-49, asst. dir. Sch. of Geology, 1944-49, dean grad. sch. since 1949; lectr. in geography, summers, University of California, Harvard, Clark U.; collaborator Soil Conservation Service since 1935; geologist La. Geol. Survey 1935-40. Ensign U.S.N.R.F., 1918-19. Received first W. W. Atwood award for studies in phys. geography from Assn. Am. Geographers, 1937. U.S. del. Internat. Geog. Congress, Amsterdam, 1938; U. of Calif. and La. State U. del. to Internat. Geog. Congress, Paris, 1931; La. Stat. U. del. to Internat. Geol. Congress, Moscow, 1937; La. State U. del., Internat. Geol. Congress, London, 1948, Algiers, 1952. Rio de Janeiro, 1956, Stockholm, 1960. Internat. Assoc. of Sedimentologists (Council, 1952-60). Mem. U.S. Mil. Establishment Research and Development Bd., Com. Geophys. and Geog., 1948-54. (Since 1954 General Sciences panel). Fellow A.A.A.S. (vice pres., chmn., Sect. E, 1961), Am. Geog. Soc., Geol. Society of Am. (pres. 1957) mem. Assn. Am. Geog. (council 1937-39, pres. 1948), Nat. Research Council (representative 1941-44; mem. exec. com. Div. Geol. and Geog., 1942-44, com. on Fellowships, 1946, vice chmn., division of geology and geography, 1952-54, chmn, 1954-55), American Association Petroleum Geologists (distinguished lecturer, 1943), American Geophysical Union, Assn. Am. Univ. Profs., La. Hist. Soc., Geol. and Mineral Soc. Am. Univs., (hon.) Soc. Belge Geol. Paleo. et Hydrol. ogie, 1948; Royal Geography Society of Netherlands (honorary); Phi Sigma Kappa, Theta Tau (nat. pres. 1928-32); Gamma Alpha, Phi Sigma, Phi Kappa Phi, Sigma Xi (national lecturer, 1959), Vega gold medal, Royal Swedish Society of Anthropology and Geography, 1961, pres. Council of Deans of Southern Graduate Schools, 1953, hon. mem., Academy of Sciences, Göttingen (Germany), mem. National Academy of Sciences. Democrat. Mason. Clubs: Faculty (Berkeley, Calif.); Faculty (La. State U.) (pres. 1946); Cosmos (Washington). Asso. editor of *Geologie der Meere und Binnengewasser* (Berlin), 1939-41, *Zeitschrift für Geomorphologie*, since 1957, *Monograph Series*, Assn. Am. Geographers, 1957-61. Contbr. numerous articles to sci. jous. Home: 4575 Highland Rd., Baton Rouge 8, La.

Fields: Geomorphology and Structure of Great Basin, climatic map of California, dry climates of the United States, climatic years, cheniers, deltas of the Mississippi River, stream patterns, geomorphology, climatology, coastal geomorphology.

STEVER, H(ORTON) GUYFORD

[From *Who's Who in America*, 1958-59, vol. 30, supplemented from *American Men of Science*, vol. I, ninth edition and amended by committee staff]

Aeronautical engineer and educator; b. Corning, N.Y., Oct. 24, 1916; s. Ralph Raymond and Alma (Mott) S.; A.B. Colgate U., 1938, D.Sc. (hon) 1958; Ph.D., Cal. Inst. Tech., 1941; m. Louise Risley Floyd, June 29, 1946; children—Horton Guyford, Sara Newell, Margarette Risley, Roy Risley. Staff mem. radiation lab. Mass. Inst.

Tech. and instr. officers radar sch., 1941-42, asst. prof., 1946-51, asso. prof. aero. engring., 1951-55, prof. of aero. engineering, 1955—; exec. officer guided missiles program, 1946-48; on leave as chief scientist USAF, 1955-56; cons. aero. industry. Mem. secretariat guided missiles com. Joint Chiefs of Staff, 1945; sci. liaison officer London Mission, ORSD, 1942-45; mem. guided missiles tech. evaluation group Research and Development Bd., 1946-48; mem. sci. adv. bd. to chief of staff USAF, 47—, vice chairman 56—; mem. steering com. of tech. adv. panel on ordnance to Asst. Sec. of Def.; mem. Defense Science Board. Recipient President's Certificate of Merit, 1948. Exceptional Civilian Service Award USAF, 1956, Scott Gold Medal, American Ordnance Assoc. 1960. Episcopalian. Fellow Inst. Aero. Scis. (Pres. 1961), Am. Acad. Arts and Scis., Am. Phys. Soc.; mem. Phi Beta Kappa, Sigma Xi, Sigma Gamma Tau. Contbr. profl. publs. Home: 36 Fairmont St., Belmont 78, Mass.

Field: Gas discharge geiger counters, cosmic rays, radar guided missiles, hypersonic dynamics, shocktubes transonic aircraft nuclear propulsion for aircraft, condensation in high speed flow.

VAN ALLEN, JAMES ALFRED

[From Who's Who in America, 1958-59, vol 30, and supplemented from American Men of Science, vol. I, ninth edition]

Physicist, educator; b. Mt. Pleasant, Ia., Sept. 7, 1914; s. Alfred Morris and Alma E. (Olney) Van A.; B.S., Ia. Wesleyan Coll., 1935, Sc.D., 1951; M.S., State U. Ia., 1936, Ph. D., 1939; m. Abigail Fithian Halsey, Oct. 13, 1945; children—Cynthia Olney, Margo Isham, Sarah Halsey, Thomas Halsey. Research fellow, physicist dept. terrestrial magnetism Carnegie Instn. of Washington, 1939-42; physicist, group and unit supervisor, applied physics lab. Johns Hopkins, 1942, 1946-50; organizer, leader sci. expdns. study cosmic radiation, Peru, 1949, Gulf of Alaska, 1950, Greenland, 1952; prof. physics, head dept. State U. Ia. since 1951; research asso. Princeton, 1953-54. Development radio proximity fuze Nat. Def. Research Council, OSRD; pioneer high altitude research with rockets; mem. subcom. on upper atmosphere Nat. Adv. Com. Aeros., 1948-52, mem. upper atmosphere rocket research panel since 1946, chmn. since 1947. Mem. panel on cosmic rays, rocketry and earth satellite program, International Geophysical Year. Served as lt. comdr. U.S.N., 1942-46, ordnance and gunnery specialist, combat observer. Received C. N. Hickman medal for development Aerobee rocket, Am. Rocket Soc., 1949; physics award Wash. Acad. Sci., 1949; research fellow Guggenheim Meml. Found., 1951. Fellow Am. Phys. Soc.; mem. Am. Geophys. Union, Ia. Acad. Sci., Sigma Xi, Gamma Alpha. Presbyn. Contbg. author: Physics and Medicine of the Upper Atmosphere, 1952; Rocket Exploration of the Upper Atmosphere. Editor, Scientific Uses of Earth Satellites, 1956. Contbr. articles sci. journals. Home: 130 Ferson Av., Iowa City, Ia.

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WHIPPLE, FRED L(AWRENCE)

[From Who's Who in America, 1958-59, vol. 30, supplemented from American Men of Science, vol. I, ninth edition, and amended by committee staff]

Astronomer; b. Red Oak, Ia., Nov. 5, 1906; s. Harry Lawrence and Celestia (McFarland) W.; student Occidental Coll., 1923-24; A.B., U. of Calif. at Los Angeles, 1927, Ph. D., U. of Calif. at Berkeley, 1931; A.M. (hon.), Harvard, 1945; D. Sc. (hon.), American International Coll., 1958; m. Dorothy Woods, 1928 (div. 1935); 1 son, Earle Raymond; m. 2d., Babette F. Samelson, Aug. 20, 1946; children—Dorothy Sandra, Laura. Teaching fellow U. of Calif. at Berkeley, 1927-29; Lick Observatory fellow, 1930-31; instr. Stanford summer 1929, U. of Calif. summer 1931; staff mem. Harvard Coll. Obs. since 1931, instr. Harvard, 1932-38, lectr., 1938-45, assoc. prof. astronomy, 1945-50, prof. astronomy since 1950, chmn. dept. astron., 1949-56; director Smithsonian Astrophysical Observatory, 1955—. Research assoc. Radio Research Lab., O.S.R.D., 1942-45. Mem. Rocket and Satellite Panel, U.S., since 1946; mem. U.S. Nat. Adv. Com. on Aeronautics subcom., 1946-52; mem. U.S. Research and Development Bd. panel, 1947-52; mem. U.S. National Com. of the IGY (chmn. Tech. Panel on Rocketry, 1955-59, mem. Tech. Panel on Earth Satellite Program, 1955-59, mem. Working Group on Satellite Tracking and Computation, 1955-58); mem. Nat. Acad. of Sciences, 1959—; mem. Scientific Advisory Bd. to U.S.A.F., 1953—; mem. Adv. Panel on Astronomy to the Nat. Sci. Found., 1952-55, chmn, 1954-55; mem. of Com. on Meteorology of Nat. Acad. of Scis., Nat. Research Council, 1958—; delegate to Inter-American Astrophysical Congress, Mexico, 1942. Mem. of Commn. 22, Meteors, Zodiacal Light and Analogous Problems, of International Astronomical Union, 1946—; pres. of Commn. 22, 1946-52; pres. of Subcommn. on Meteorites, 1955—; mem. of Commn. 15, Physical Study of the Comets, 1952—; mem. of Commn. 34, Interstellar Material and Galactic Nebulae, 1950-55; mem. of Commn. 36, Spectrophotometry, 1935-52; and mem. of Commn. 44, Astronomical Observations from Outside the Terrestrial Atmosphere, 1959—; voting repres. of U.S.A. in International Astronomical Union, 1952 and 1955; mem. of Bio-Astronautics Com. of the Armed Forces and National Research Council, 1959-61; mem. of Com. on Standardization in the Field of Photography, Amer. Standards Assoc., 1938-50; mem. U.S. Nat. Com. of International Scientific Radio Union Commn. 3, 1949—; mem. of Upper Atmosphere Com. in the Meteorology Sec. of the Amer. Geophysical Union, 1957—; mem. of Com. on Cosmic and Terrestrial Relationships of the Amer. Geophysical Union, 1957—; mem. of Space Sciences Working Group on Orbiting Astronomical Observatories, NASA, 1959—; mem. of Aerospace Technology Panel for Space Physics, Inst. of the Aerospace Scis., 1960—; and mem. of Physics of the Atmosphere Com., Amer. Rocket Soc., 1959—. Assoc. ed. of the Astrophysical Journal 1952-54, and Astronomical Journal, 1954-56; ed. of Harvard Announcement Cards, 1952-60, Smithsonian Contributions to Astrophysics, 1956—, and Planetary and Space Science, 1958—. Active leader of project on Upper-Atmospheric Research via Meteor Photography sponsored by the Bureau of Ordnance, U.S. Navy, 1946-51; and sponsored by the Air Research and Development Command, U.S. Air Force, 1948—, by

the Office of Naval Research, 1951-57, and by U.S. Army Office Ordnance Research, 1953-57. Chief investigator of project, Optical Tracking of Artificial Earth Satellites sponsored by the Nat. Sci. Found. for the Nat. Acad. of Sci. in the IGY Program; project director, Harvard Radio Meteor Project, 1958—; Lowell Lecturer, Lowell Institute, Boston, 1947; vice-pres., Amer. Astronomical Soc., 1948-50. Recipient of Donohue Medals for the independent discovery of six new comets; recipient of Presidential Certif. of Merit for scientific work during World War II; recipient of J. Lawrence Smith Medal of the Nat. Acad. of Scis. for research on meteors, 1949; recipient of Exceptional Service Award by U.S. Air Force for scientific service in conjunction with A.F. Scientific Advisory Board, 1960; recipient of Medal from the University of Liege, Belgium for Astronomical Research, 1960. Mem. Pi Mu Epsilon, Phi Beta Kappa, Sigma Xi, Amer. Acad. of Arts and Scis., Amer. Philosophical Soc., Amer. Assoc. for the Advancement of Science, Amer. Astronomical Soc., Amer. Meteoritical Soc., Amer. Geophysical Union, Amer. Meteorological Soc., Fellow of the Amer. Astronomical Soc., Fellow of the Amer. Rocket Soc., Astronomical Soc. of the Pacific, Cosmos Club, and Examiner Club of Boston. Author: *Earth, Moon and Planets*, Blakiston Company, 1942; scientific papers on Orbits of Comets, Asteroids and Meteors; Spectrophotometry of Cepheid Variable Stars, Novae and Supernovae; Colors of External Galaxies; Planetary Nebulae; Earth's Upper Atmosphere and Nature of Meteors by two-camera photographic method; Interstellar Medium; Stellar and Solar-System Evolution; Theory of Comets; Optical Tracking of Artificial Earth Satellites; Astronomy from Space Stations; various subjects in the Encyclopedia Britannica; various popular articles on astronomical subject. Office: Harvard College Observatory or Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge 38, Massachusetts. Home: 12 Randolph Ave., Belmont 78, Mass.

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ZUCROW, MAURICE J (OSEPH)

[From Who's Who in America, 1958-59, vol. 30 and amended by committee staff]

Jet propulsion expert and mech. engr; born near Kiev, Russia, Dec. 5, 1899; s. Solomon and Dora (Smarskin) Z.; came to England, 1900, U.S., 1914, naturalized, 1921; B.S. in M.E. magna cum laude, Harvard, 1922, M.S., 1923; Ph. D., Purdue, 1928; m. Lilian Feinstein, Aug. 1, 1925; 1 dau., Barbara (Mrs. Louise A. Cohen). Prof. gas turbines and jet propulsion, Purdue U., 1946-59; Atkins Prof. of Eng'g, 1959—; research assoc. and instr. Purdue, 1923; vice pres. in charge engring., Paragon Vaporizer Corp., Chicago, 1929-34; partner Hubbard Engring. Co., cons., 1937-40; vice pres. and gen. mgr. Ring Balance Instrument Co., Chicago, 1940-41; research and development engr. Elliot Co., Jeannette, Pa., 1941-42; tech asst. to exec. v.p. Aerojet Engring. Corp., Azusa, Calif., 1942-46; cons. engr. since 1946. Com. on Guided Missiles, Research and Development Bd., National Military Estab. (Chmn., Panel on Propulsion and Fuels,

1947-52, mem. Technical Consulting Group, 1951-53, and consultant, Aeronautics Panel, Office of Asst. Secy. of Def. for R. & D., 1953-57); mem. Ordnance Sci. Adv. Com., Dept. of Army, 1959—; National Adv. Com. for Aeronautics (mem. Subcom. on Propulsion Systems Analyses, 1947-50, chmn., Subcom. on Rocket Engines, 1950-53, and mem. Subcom. on Rocket Engines, 1953-58); National Aero. and Space Adm. (mem. Adv. Com. on Chemical Energy Systems, 1960—); mem. Science and Engineering Com. Soc. of Automotive Engineers, 1959—; mem., Panel on Sci. and Techn., Com. on Science and Astronautics, House of Representatives, 1960—; and mem., Bd. of Directors, Amer. Rocket Soc., 1951-55, 1957-61. Fellow, Amer. Soc. of Mech. Engineers; Fellow Amer. Rocket Soc. (ARS Pendray Award in 1952), Assoc. Fellow, Inst. of the Aerospace Scis.; mem., Amer. Soc. of Engineering Education (Vincent Bendix award, 1960); mem. Amer. Ordnance Assoc., Sigma Xi (award, Purdue U., 1956), Tau Beta Pi, Pi Tau Sigma, Gamma Alpha Rho, Sigma Alpha Mu. Registered Professional Engineer, Indiana. Jewish. Author: Principles of Jet Propulsion and Gas Turbines, 1948, Aircraft and Missile Propulsion, vol. I and vol. II, 1958; coauthor: Principles of Guided Missile Design, vol. II. Contbr. over 40 articles to tech. pubs.; holder several patents. Home: 801 Carrolton Blvd., West Lafayette, Ind.

Fields: Jet propulsion, gas turbines, industrial instruments and control apparatus, rocketry, fuels, guidance systems.

APPENDIX C

MAPPING AND GEODETIC SATELLITE PROGRAM

(By Dr. Fred L. Whipple, Smithsonian Astrophysical Observatory
and Harvard College Observatory)

REPORT TO THE COMMITTEE ON SCIENCE AND ASTRONAUTICS, HOUSE OF
REPRESENTATIVES, MARCH 21, 1962

Mapping is concerned with the relative positions of features on the actual Earth. Geodesy is concerned with the size and shape of an idealized earth, or geoid, described mathematically and numerically. The two subjects are intimately related, geodesy being the broader and including not only the geometrical features but also the physical characteristics of the Earth's surface and interior. Hence I shall talk here only of geodesy, including mapping as an important, related subject.

The basic geometrical measurements in geodesy have been made by the techniques of surveying, including triangulation, leveling and traversing, while fundamental position and directional measurements on the Earth have been determined by observations of astronomical bodies and related to the plumb line. Radar techniques have recently added immensely to the triangulation methods, which were limited in the past to optical observations.

Astronomical determinations of position are always limited by the unknown or poorly determined deviations in the direction of the plumb line from the ideal geoid, induced by irregularities in the density and distribution of matter in the Earth. Over large continental areas these deviations can be averaged out to a fairly high degree of accuracy; thus triangulation has been extended over these areas with great precision. Theoretically, a complete knowledge of gravity at all points on the surface of the Earth, coupled with surveying methods, would lead to a complete knowledge of the shape and size of the Earth, both for direct mapping purposes and for establishing the idealized geoid. In recent years, direct measures of gravity have been made with great precision over an increasing area of the Earth. The development of sea-surface and airborne gravimeters has aided greatly in this effort.

In practice, however, it will be a long time before the measures of gravity are adequate to give a satisfactory knowledge of the relative positions of the various continents and their geodetic systems, at least as compared to the internal accuracy of these systems. The problem is much greater for isolated land masses, such as small islands separated at great distances from the continents. Astronomical observations of Moon positions with respect to stars occulted (eclipsed) by the Moon are, however, aiding in the solution of this problem.

At the present time, positions on the surface of the Earth located in the geodetic systems of the various continents are known on a worldwide basis to an accuracy of perhaps 500 feet; the internal accuracy of the systems on individual continents is of the order of 50 feet or less. Positions of isolated islands are more poorly determined on this system; in some cases, the errors are a mile or more. The gross shape and size of the Earth were known to a comparable accuracy; that is, 500 feet, until the advent of artificial satellites.

Artificial Earth satellites have added immensely to our knowledge of the shape of the Earth. The irregular shape of the Earth and the related irregularities in the distribution of matter in the Earth produce irregularities in the motions of close-Earth satellites. Satellite-tracking techniques, which measure these motions very accurately, provide information concerning the distribution of matter in the Earth and hence provide improved knowledge of the Earth's shape.

The bulging of the Earth at the equator (due to its rotation) has been corrected in this way by approximately a third of a percent from the classical value. The motions of artificial Earth satellites have also shown that the Earth is slightly pear-shaped, with the stem directed toward the Earth's North Pole. These are popular descriptions of the theoretical geoid, which is mathematically represented by a power series of trigonometric functions. Before the use of artificial Earth satellites, we know only the second-order term, or second harmonic, meaning that in a section through the poles of the Earth, we found two maxima, on opposite sides of the Equator. The pear-shaped Earth represents the third harmonic with three maxima in a section through the poles. Now accurate measurements are available of the fifth harmonic, while higher order harmonics are roughly determined. It is difficult to foresee a limit to the number that will eventually be determined as more and more satellites are accurately observed. Furthermore, we have evidence that the Earth is not symmetrical even around the Equator, but has an elongation of several hundred feet along an axis off the east coast of Brazil and northeast of New Guinea.

Artificial Earth satellites have thus already demonstrated their merit in determining the gravitational behavior of the Earth, which is intimately related to the geometric shape, but is not a direct measurement of it. Were the mass in the Earth symmetrically distributed, the gravitational harmonics, such as the pear shape, would lead directly to the geometrical shape. It is of extreme importance to measure the geometrical shape directly, both to learn about the distribution of mass and density in the Earth and to tie together the geodetic nets for mapping purposes.

Precision observations of satellites are capable of providing a much improved knowledge of the geometrical shape of the Earth and in interrelating the geodetic networks on the various continents to an accuracy of the order of 30 to 50 feet. For this purpose, the satellite can be considered as an extension of ordinary triangulation, in which one point is placed at a very great height above the Earth's surface where it can be observed from many points on the surface. We are just beginning to apply satellite observations for this purpose at the Smithsonian Astrophysical Observatory. The 12 worldwide stations of photographic cameras and precision clocks, set up under the Inter-

national Geophysical Year and now supported by the National Aeronautics and Space Administration, measures the directions of satellites referred to the stellar background. Astronomers have determined the positions (or directions) accurately for several hundred thousand stars. The directions of satellite measurements are accurate demonstrably to about 3 seconds of arc and probably to about 2 seconds of arc. At a distance of 500 miles the observed accuracy corresponds to about 20 feet, and the expected accuracy to about 12 feet. A satellite near the Earth moves about 25,000 feet per second, so that a timing accuracy of one-thousandth of a second will determine a position to about 25 feet. We believe, therefore, that the accuracy of this method for geodetic purposes can reach about 25 feet, or perhaps better, an improvement of more than an order of magnitude over past methods of position determination on an absolute worldwide basis.

As mentioned above, a satellite can be used as a triangulation point to be observed simultaneously from several stations on the Earth. Suppose that some are on one continent tied to that geodetic net, while other stations are on another continent tied to its geodetic net. Where actual directions in space are measured with respect to the stars, the resulting triangles can be solved completely and the relative positions over a large distance on the Earth's surface determined by this purely geometric method. This triangulation method is limited at the present time by the relatively low heights of satellites, by the need for simultaneously clear skies at many stations, and particularly by the fact that our present photographic methods depend upon sunlight for satellite illumination, so that observations can be made only in twilight. Preliminary applications of the method, however, indicate its great value, within these limitations.

Since the triangulation method demands simultaneous or nearly simultaneous observations from a number of stations, a more general method is one that we call the dynamic method. Here the observations from the satellites are made whenever possible. With adequate theory for the motions of satellites, we can effectively determine the orbit of a given satellite to the accuracy with which the observations are made; hence we can determine the relative positions of the stations to this same accuracy. We have not yet been able to attain as high a precision with this method as we expect, because the gravitational shape of the Earth is not yet well enough determined for us to calculate the position of a satellite to the necessary precision at all times over several revolutions. Thus, this method will develop in precision with time. Mutual improvement is continuing in both the geometry of our stations and the gravitational potential of the Earth.

To date, no satellite has been especially designed and launched to make possible the greatest use of artificial earth satellites for geodetic purposes. A satellite with a flashing light would enable precision observations to be made throughout the night at each station, and consequently increase markedly the usefulness of such observations for geodetic purposes. The direct triangulation method could be utilized over greater distances, while the dynamical method could be improved immensely because observations could be made along the entire orbit instead of being limited to those portions visible in twilight.

A geodetic satellite could utilize other than optical methods of observation for geodetic purposes. Radar ranges on the surface of the Earth are now extremely accurate and can be used at satellite distances. A radar can operate by means of direct reflection from the surface of a satellite, by reflection from corner reflectors built into a satellite, and by means of electronic responders that hear and retransmit a received pulse back to Earth. These latter methods can increase immensely the range and precision of radars for geodetic purposes.

The Minitrack system developed during the IGY by the Naval Research Laboratory and now utilized in the National Aeronautics and Space Administration tracking system can be developed to much greater precision in determining directions by radio. Here, however, extremely large antenna systems are required to match the accuracy of optical observations.

Satellites with radio transmitters, in which extremely stable oscillators are used, can have their ranges measured with surprising precision by the "Doppler method." Here the frequency or pitch of the radio changes as the satellite approaches and recedes from the observing antenna on the ground. The rate at which these distance changes occur depends upon the distance of the satellite and its speed with respect to the ground. This method has been utilized with excellent results in the Transit satellites and, indeed, has led to a determination of the gravitational ellipticity around the Equator in agreement with that obtained by optical means. Other variants of the radar direction-finding and velocity-measuring techniques with electronics are possible, and can be developed for geodetic satellites.

Two points should be made about the use of geodetic satellites for worldwide calibration of geodetic networks and for precision geodesy. First, a large number of stations located on land and possibly even on the high seas are required for an optimum solution. Second, all of the methods so far mentioned involve a precision determination of time at each station, to about one one-thousandth of a second. Although such accuracy is quite obtainable, it is nevertheless very expensive, particularly for remote stations. Considerable bulky equipment is required to maintain the clock and provide radio reception to our excellent WWV time service or a few other such time services now available.

If the time keeping is transferred to the satellite by means of a precision clock in the satellite or by control signals from the ground, the timekeeping equipment at the stations can be very simple, costing only a few hundred dollars.

In a flashing-light satellite, where the light flashes are controlled from the ground or by a precision clock in the satellite, the optical equipment can also become extremely simple. Small telescopes of aperture 3 to 6 inches are quite adequate, while their focal lengths can fall in the convenient range of 20 to 40 inches. Telescopes of longer focal length are not required because the instantaneous deflection by atmospheric seeing amounts to the order of a second of arc or more. The complete station equipment could be moved readily, so that observations of a single satellite might be made at several sites in the course of a year.

Hence a flashing-light satellite having flashes predetermined and coupled with a small extension of our present communication system, could make possible precision geodetic measurements by literally hundreds or even thousands of observers supported in their own countries throughout the world. Analysis would probably be confined to a few of the larger centers, but it could be carried out by any country in the program. The observational material would be made easily available on a worldwide basis, as was done in the IGY program. Such a satellite, operated by the National Aeronautics and Space Administration and coordinated through the COSPAR, would be welcomed internationally and would focus attention on our prime role as scientific leader in the use of space for the good of mankind.

The requirement for a geodetic satellite is not now active in the National Aeronautics and Space Administration, although they did make a serious start on it. We have had knowledge of the requirement, and we have had the capability for at least 3 years.

My colleagues in the scientific community join me in recommending such a satellite. I hope that you of the Committee on Science and Astronautics in the House of Representatives can add your weight to this proposal.

APPENDIX D

ADVANCED PROPULSION FOR SPACE

(By Dr. Maurice J. Zucrow, Purdue University)

REPORT TO THE COMMITTEE ON SCIENCE AND ASTRONAUTICS, HOUSE OF REPRESENTATIVES, MARCH 21, 1962

1. INTRODUCTION

In the past decade the field of propulsion has become so broad that it is not feasible to make even a cursory examination of the entire field at this meeting. An appreciation of the scope of the field of propulsion can be derived from an examination of table 1. In that table I have attempted to classify all of the different types of engines that are of interest in considering the propulsion of aircraft, missiles, and space vehicles, for either peaceful or military purposes.

TABLE I.—*Classification of propulsion engines*

- A. Air-consuming chemical engines :
 - (1) Piston engines.
 - (2) Normal turbojet engines.
 - (3) Turbofan (turbojet) engines.
 - (4) Ramjet engines.
 - (5) Turboprop engines.
 - (6) Turbo-ramjet engines.
- B. Air-consuming nuclear engines :
 - (1) Nuclear turbojet and turboprop engines.
 - (2) Nuclear ramjet engines.
- C. Rocket engines (non-air-consuming engines) :
 - (1) Chemical rocket engines.
 - (2) Nuclear (heat-transfer) rocket engines.
 - (3) Electric rocket engines.
- D. Hybrid engines: Combination of air-consuming and rocket engines.

Since the committee, Mr. Chairman, is directly concerned with legislative matters pertinent to developing in this country an unchallenged leadership in space exploration, particularly for peaceful purposes, my discussions today will, therefore, be limited to the propulsion engines which must be considered in developing such space exploration programs.

The technical problems of space exploration lie in many fields. To name a few there are problems in the fields of aeromedicine (including protection against radiation), communications, vehicle guidance, biology, bacteriology, astronomy, environmental control of space vehicles and space stations, electric power supply, and propulsion. It is generally acknowledged that "propulsion is the key to space exploration" (1)¹ and it is not exaggeration to state that the advances made in propulsion will exert the rate-controlling influence upon the

¹ The numbers in parentheses contained throughout this paper refer to the references listed at the end of the paper.

specific programs of space exploration that can be undertaken. We as a nation, therefore, will not achieve the goal of unchallenged leadership in space unless we exert the effort, but with a spirit of urgency, to become the unchallenged leaders in the field of propulsion, and its associated technologies.

Current conceptions for achieving distant flights into outer space are based, in general, on conducting the space mission in two or more phases. First, there will be a "boost" phase during which a "booster" vehicle will carry a separable payload from the surface of the earth, and place it in an "assembly" orbit from 300 to 1000 miles from Earth's surface; the booster vehicle would then return to Earth and be discarded, or could possibly be re-employed for transporting other payloads to the "assembly" orbit. The actual journey into space would start from the orbit or from an artificial satellite "space station" after the spaceship had been assembled and equipped for its mission by rendezvous techniques (1) (3). Less ambitious programs are based on boosting a payload, the last stage of multistage vehicle, to the required flight velocity.

There is a wide variety of conceivable space missions with tremendous differences in their propulsion requirements. Table 2 presents some of the functions to be provided by the propulsion system.

Items 5 and 6, in table 2, are not truly propulsion functions. They are included for two reasons: (1) The successful exploration of space requires that electric power be available in space; and (2) the problems associated with developing electric powerplants for space are similar to those encountered in developing some of the space propulsion engines.

Table 2.—Some functions to be provided by propulsion system

- (1) Acceleration or boost thrust.
- (2) Deceleration thrust.
- (3) Satellite orientation thrust.
- (4) Efficient transfer of a payload to a given destination.
- (5) Electric power for operating the space vehicle or the space station.
- (6) Control of internal atmosphere of the space vehicle or the space station.

Mission analyses indicate that the thrust requirements for a complete space mission will range from extremely large values, of the order of millions of pounds, to extremely low values, fractions of a pound. High-thrust propulsion engines are needed for the "boost" phase; for Earth-orbital missions a velocity of the order of 25,000 feet per second (18,000 miles per hour) must be imparted to the payload, for interplanetary missions its velocity must exceed 36,000 feet per second (25,000 miles per hour), and for a lunar mission the payload must attain a velocity in between those two values (3) (4). Low-thrust propulsion engines appear advantageous for operations conducted in or from satellite orbits. Table 3 presents some typical applications for low-thrust engines (5) (6) (7).

TABLE 3.—Some applications for low-thrust engines

- (1) Adjustment of the orbit of a low altitude satellite to increase its lifetime.
- (2) Lowering or raising a satellite orbit.
- (3) Changing the orientation of a satellite orbit.
- (4) Propulsion of instrumented probes to distant planets (Mars and Venus).
- (5) Propulsion of manned space ships:
 - (a) From one Earth orbit to another; and
 - (b) Between interplanetary orbits.

Experience has demonstrated that, from a propulsion standpoint, all of the space missions so far conceived can be achieved by the proper application of the rocket jet propulsion principle, hereafter termed rocket propulsion. Accordingly, the discussions which follow will be limited to rocket engines; that is, to engines utilizing the rocket jet propulsion principle.

Figure 1 illustrates the essential components of a rocket engine and their coaction for producing thrust by rocket propulsion. Three main components are required:

- (1) A supply of propellant, carried inside the propelled vehicle;
- (2) A propellant feed and metering system; and
- (3) A thrust chamber, also called either a rocket motor, thruster, or accelerator.

In addition there must be a means for adding energy to the propellant as it flows through the thrust chamber.

Propellant material from the supply is metered and fed to the thrust chamber wherein energy is added to the propellant. As a consequence of the energy addition the propellant is ejected from the thrust chamber as a high velocity jet of material, the speed of the exhaust jet is called the (exhaust) jet velocity, and is denoted by V_j . A propulsive force, termed the thrust, denoted by F , is thereby produced acting in the direction opposite to that for the exhaust jet; that is, the thrust acts in the same direction as the propelled vehicle moves, and the vehicle velocity is denoted by V .

In the abstract, as least, there is no restriction upon the kind of matter that can be used as the propellant material comprising the exhaust jet. It may be solid particles, a liquid, a gas, a plasma, ions, electrons, and combinations thereof. The different types of rocket engines differ primarily in the means employed for producing the high velocity exhaust jet.

Rocket engines are characterized by the facts that they do not consume atmospheric air in their functioning, and the thrusts they develop are substantially independent of the surroundings.

2. BASIC OPERATING PRINCIPLES OF THE DIFFERENT TYPES OF ROCKET ENGINES

It was shown in table 1 that rocket engines may be classified into three main categories:

- (a) Chemical rocket engines;
- (b) Nuclear heat-transfer rocket engines; and
- (c) Electric rocket engines.

For convenience of discussion brief descriptions of the more important engines in each category will be presented at this point. The descriptions are for identification purposes only. More detailed discussions of the different engines will be presented later.

(a) *Chemical rocket engines.*—All chemical rocket engines have two common characteristics (9).

(1) They utilize chemical reactions in the thrust chamber as the means for producing a high temperature propellant gas at the entrance plane of a converging-diverging exhaust nozzle; the latter is the propulsive element of the rocket engine.

(2) The high temperature propellant gas expands as it flows through the converging-diverging nozzle and is ejected to the sur-

roundings as a high velocity gaseous exhaust jet. The expansion in the nozzle is a thermodynamic process which converts a portion of the thermal energy (enthalpy of reaction) released by the combustion of one or more propellants into the kinetic energy associated with the high velocity gaseous exhaust jet.

All of the components of a chemical rocket engine, except the exhaust nozzle of the thrust chamber, form essentially a gas generator for supplying a gas, at a high temperature and pressure, to a suitable exhaust nozzle.

Chemical rocket engines may be grouped into four main categories.

- (i) Liquid bipropellant rocket engines;
- (ii) Liquid monopropellant rocket engines;
- (iii) Solid propellant rocket engines; and
- (iv) Hybrid chemical rocket engines.

(i) *Liquid bipropellant engine*: Figure 2 illustrates the essential features of a liquid bipropellant rocket engine employing a turbo-pump for feeding two propellants (an oxidizer and a fuel) to a rocket motor.

(ii) *Liquid monopropellant engine*: Figure 2 also illustrates the essential features of a monopropellant engine of the oxidizer tank, oxidizer pump, oxidizer lines, etc., are removed; a monopropellant since it contains the oxygen it needs for combustion in its chemical or physical structure, does not require an oxygen supply system.

(iii) *Solid propellant engine*: Figure 3 is a schematic illustration of a solid propellant rocket motor which utilizes an internal-burning case-bonded grain. A solid propellant which incorporates the oxygen for combustion in its molecular structure is termed a double-base propellant. A solid propellant which is an intimate physical mixture of a finely powdered solid oxidizer and a fuel binder is termed a composite or heterogeneous propellant. The combustion of a solid propellant is initiated by the energy supplied to it by some form of electrically fired igniter.

(iv) *Hybrid chemical rocket engine*: Figure 4 illustrates diagrammatically the essential features of a hybrid chemical rocket engine.

(b) *Nuclear heat-transfer rocket*—Figure 5 illustrates schematically the basic features of a nuclear heat-transfer rocket engine employing a solid-core nuclear reactor. The heat liberated by the fission of uranium is utilized for heating a gaseous propellant, usually hydrogen. Since the exhaust nozzle is the propulsive element, the remaining components constitute the gas generator. The basic difference between the operating principles of the nuclear and the chemical rocket engines is that the energy for heating the propellant gas is supplied by the fission of uranium instead of a chemical reaction.

(c) *Electric rocket engines*.—These engines use electric power for either heating or accelerating a propellant.

Figure 6 illustrates schematically the general features of an electric rocket engine. It comprises, in addition to the requisite control devices, the following principal components:

- (1) A nuclear power source;
- (2) An energy conversion unit for converting the energy supplied by the nuclear power source into the desired form of electrical energy;
- (3) A propellant feed and metering system; and
- (4) An electrically operated thruster or accelerator.

The combination of the nuclear power source and the energy conversion equipment will be termed hereafter a nuclear electric powerplant.

Electric rocket engines may be segregated into three principal groups:

- (i) Electro thermal rocket engines;
- (ii) Electromagnetic, plasma, or magnetofluid mechanic (MFM) rocket engines; and
- (iii) Electrostatic, or ion, rocket engines.

(i) *The electrothermal rocket engine.*—In general, an electrothermal rocket engine uses electric power for heating a gaseous propellant to a high temperature by the time it reaches the entrance plane of an exhaust nozzle.

Figure 7a illustrates a form of electrothermal rocket engine known as a thermal arc-jet engine. It uses an electric arc for heating a propellant gas. It should be noted that the chemical, nuclear heat-transfer, and electrothermal rocket engines possess the common feature of being thermodynamic engines; that is, they produce a hot gas in some form of gas generator and then expand it in a converging-diverging exhaust nozzle to produce a high velocity gaseous jet.

(ii) *Electromagnetic engine.*—Figure 7b illustrates schematically the essential features of an electromagnetic or MFM rocket engine. There are a wide variety of such engines (14) but all of them utilize the same operating principle. A plasma (a neutral ionized conducting gas) is accelerated by means of its interaction with either a stationary or varying electric and magnetic fields.

(iii) *Electrostatic engine.*—Figure 7c illustrates schematically the essential features of an electrostatic or ion rocket engine. It comprises the following principal assemblies:

- (1) A nuclear electric powerplant;
- (2) A propellant supply;
- (3) Ionization apparatus;
- (4) An ion accelerator; and
- (5) An electron emitter for neutralizing the ion beam ejected from the accelerator.

Its operating principle is based on utilizing electrostatic fields for accelerating and ejecting electrically charged particles, from an accelerator, with extremely large velocities. The overall objective is to transform thermal (nuclear) energy into the kinetic energy associated with an extremely high velocity stream of electrically neutral particles ejected from a thruster.

3. ENERGY LIMITED AND POWER LIMITED ENGINES

In a chemical rocket engine the energy for propulsion as well as the mass ejected through the exhaust nozzle are provided by the propellants. Furthermore, the energy which can be added to a unit mass of the propellant gas is a fixed amount which is limited by the chemical bonds of the reacting materials (15). For that reason chemical rocket engines are said to be energy-limited rocket engines. It should be noted that a nuclear heat-transfer rocket engine is also energy-limited, the limitation, in that case, being imposed by the amount of energy which can be added per unit mass of propellant without exceeding the

maximum allowable temperature for the materials used in fabricating the solid-core reactor.

Electric rocket engines, on the other hand, are termed power-limited or separately powered rocket engines. The power which can be used for propulsive purposes is limited by the maximum power output of its nuclear electric powerplant. The latter contributes most of the weight to an electric rocket engine.

4. ROCKET PERFORMANCE PARAMETERS

There are several parameters which must be considered in selecting a rocket engine to a specific mission. The more important ones will be defined and discussed briefly.

(a) Thrust (F): The thrust developed by a rocket engine, irrespective of type, is given by

$$F = \dot{M}_{pr} V_j = \frac{\dot{W}_{pr}}{g_o} V_j \quad (1)$$

where

$\dot{M}_{pr}$ = rate at which mass is expelled from the exhaust nozzle in unit time.

V_j = effective velocity of exhaust jet, fps.

$\dot{W}_{pr} = g_o \dot{M}_{pr}$ = weight rate of flow of propellant gas, (lb/sec).

$g_o = 32.173 \text{ ft/sec}^2$.

Equation 1 demonstrates the fundamental characteristic of rocket propulsion; that is, to develop thrust a mass of propellant $\dot{M}_{pr}$ must be carried in the propelled vehicle, and ejected to the surroundings at the rate $\dot{M}_{pr}$; the latter depends on the operating time.

(b) Specific impulse (I): By definition:

$$I = \frac{F}{g_o \dot{M}_{pr}} = \frac{V_j}{32.174} \quad (2)$$

The specific impulse, I , is a measure of the effectiveness with which a rocket engine converts the energy available for propulsive purposes into the kinetic energy associated with an exhaust jet. Equation 2 shows that the larger the jet velocity the larger the specific impulse, indicating that either parameter may be employed as a criterion of performance.

(c) Jet power (P_j): The power associated with the propulsive jet ejected from a rocket engine, is termed the jet power, P_j . Thus

$$P_j = \frac{1}{2} \dot{M}_{pr} V_j^2 \text{ (ft-lb/sec)} \quad (3)$$

or

$$P_j = \frac{FI}{45.8} \text{ (kw)} \quad (3a)$$

Equation 3a shows that for a given value of the jet power, P_j , an increase in the specific impulse, I , is obtained only at the expense of a decrease in thrust, F .

(*d*) Power required (P): It has been pointed out that the major component of an electric rocket engine is its nuclear electric powerplant. It is reasonable to assume that the take-off weight of the powerplant will be a function of the peak power it must furnish; that is, the maximum power it will be required to deliver during the space mission. Because of the inefficiencies which unavoidably occur in the transformation of electric energy into jet kinetic energy, the power output capacity of the nuclear electric powerplant, called the required power (P), must be larger than the jet power, P_j . The required power, P , is given by

$$P = \frac{FI}{45.8\eta} \quad (4)$$

where η (less than 1) is the power-conversion efficiency.

Equation 4 shows that for fixed values of thrust, F , and conversion efficiency, η , the required capacity for the nuclear electric powerplant, in kilowatts, increases directly with the specific impulse, and inversely with the energy-conversion efficiency.

(*e*) Specific powerplant weight (α): By definition, the specific powerplant weight, denoted by α , is given by

$$\alpha = W_{PP}/P_j (\text{lb/kw})^2 \quad (5)$$

where W_{PP} is the weight of the powerplant.

The parameter, α , is applicable to all types of rocket engines, but is particularly convenient in the study of electric rocket engines.

(*f*) Powerplant weight (W_{PP}): It is desirable to express the powerplant weight, W_{PP} , in terms of the thrust, F , the specific impulse, I , and the specific powerplant weight, α . Thus.

$$W_{PP} = \alpha P_j = \alpha \frac{FI}{45.8} \quad (1b) \quad (6)$$

(*g*) Propulsion system weight (W_{PS}): The total weight of a propulsion system, denoted by W_{PS} , is given by

$$W_{PS} = W_{pr} + W_{PP}$$

or

$$W_{PS} = F \left(\frac{I\alpha}{45.8} + \frac{t_p}{I} \right) \quad (7)$$

Figure 8 presents the propellant, powerplant, and propulsion system weights as functions of the specific impulse, I , for fixed values of the thrust, F , powered-flight time, t_p , and specific powerplant weight, α . It is seen that the powerplant weight, W_{PP} , increases directly with the specific impulse, I , while the propellant weight, W_{pr} , decreases as I increases.

Figure 8 demonstrates that there is an optimum value of the specific impulse, I_{opt} , that minimizes the weight of the propulsion system W_{PS} ,

² Ordinarily the specific weight of a rocket engine is defined by the ratio W_{PP}/F .

If it is assumed, for convenience, that the specific powerplant weight, α , and the powered flight time, t_p , do not depend upon the specific impulse, which is not strictly correct, then

$$I_{opt} = 1990 \sqrt{\frac{t_p \text{ days}}{\alpha (1b/kw)}} \quad (8)$$

5. PAYLOAD RATIO

It is essential for a space propulsion system that the ratio of the payload, W_{pay} , to the total initial weight of the vehicle, W_o , be large. If W_o denotes the initial gross weight of the vehicle, W_{str} its structural weight, and W_{pay} , the payload weight, then

$$W_o = W_{str} + W_{pay} + W_{PP} + W_{pr} = W_{str} + W_{pay} + W_{PS} \quad (9)$$

Hence

$$\frac{W_{pay}}{W_o} = 1 - \frac{W_{str}}{W_o} - \frac{F}{W_o} \left(\frac{\alpha I}{45.8} + \frac{t_p}{I} \right) \quad (10)$$

Let $W_{str}/W_o \approx 0.05$, then Equation 10 becomes

$$\frac{W_{pay}}{W_o} = 0.95 - \frac{F}{W_o} \left(\frac{\alpha I}{45.8} + \frac{t_p}{I} \right) \quad (11)$$

The problem of matching a propulsion system to a mission is ultimately the problem of maximizing the payload ratio W_{pay}/W_o , or that of minimizing the weight of the propulsion system, W_{PS} .

The powerplant of an electric rocket engine weighs considerably more than the structure of the vehicle, so that the exact value of the structural ratio, W_{str}/W_o , is not as important for electric rocket engines as it is for chemical and nuclear rocket engines, because, as pointed out earlier, the electric-rocket engine must be operated for the entire space mission, it cannot be discarded.

The payload which can be transported by the vehicle propelled by an electric-rocket engine will be a maximum, provided the engine is operated at its optimum specific impulse throughout the journey. In that case the payload ratio is given by

$$\left(\frac{W_{pay}}{W_o} \right)_{\max} = 0.95 - 87 \frac{F}{W_o} \sqrt{\alpha t_p \text{ (days)}} \quad (12)$$

If an electric rocket engine is to be operated with the optimum specific impulse, then the weight of its propellant load at take-off (from an Earth orbit) must be approximately equal to the weight of the nuclear electric powerplant. Hence, the minimum weight that must be boosted into an Earth orbit is larger than twice the weight of the nuclear electric powerplant.

The specific weight of the nuclear electric powerplant, therefore, exerts a predominant influence upon the maximum value of the payload ratio and the range of useful values of specific impulse. For

space exploration to become practical, high specific impulse with small values of specific powerplant weight are essential. The need for reliable nuclear electric powerplants having low specific weights cannot be overemphasized; without them electric rocket engines cannot be applied effectively to deep space explorations (Mars, Venus, etc.).

I am assuming that our national space program is to be oriented so that landing a man on the Moon and returning him safely to Earth is not our ultimate goal.

6. SOME GENERAL CHARACTERISTICS OF POWERPLANTS FOR ELECTRIC ROCKET ENGINES

An electric rocket engine, because it is a separately powered rocket engine, must incorporate means for achieving and coupling the following two functions:

- (1) supplying electrical energy to the propellant and its feed system; and
- (2) furnishing electric power at the correct voltages for accelerating and ejecting the propellant from the thrust chamber (accelerator).

The major component of an electric rocket engine, irrespective of type, is its nuclear electric powerplant. It is worth examining briefly, therefore, the state of the art and the problems to be solved in developing a nuclear electric powerplant which will be satisfactory for either an electric rocket engine or electric power production in space, or both.

As indicated earlier, unless an adequate supply of electrical power is made available in space for communications, control, instrumentation, and furnishing an environment which will support human life in space, it is extremely doubtful that manned exploration of space will be achievable.

The electric power requirements, and hence the weight of the nuclear electric powerplant, will depend, of course, upon the mission (16). For missions such as satellite sustaining, satellite orientation, or for furnishing the electric power for communications, instruments, and the like, the electric power demands will be relatively small; ranging from a few watts to possibly 30 kilowatts. Estimates indicate that for unmanned lunar and Mars missions the power requirements will range from 30 to 300 kilowatts, and that for manned missions the power requirements may reach 20,000 to 30,000 kilowatts. For electric power demands exceeding approximately 300 kilowatts the nuclear electric powerplant and its appurtenances are by far the heaviest component of an electric rocket engine. The weight of the accelerator of thruster is such a small fraction of the total weight of the complete engine that no significant error is introduced by assuming that the weight of an electric rocket engine is equal to the weight of its nuclear electric powerplant.

(a) *Essential features of a nuclear electric powerplant.*—Nuclear electric powerplants for space power have been under active development since 1956. Figure 9 illustrates diagrammatically the essential features and the cycle conditions for the SNAP³ VIII which is currently under development (17). It is expected that SNAP VIII powerplant will enter its space-testing phase in 1965 (22).

³ SNAP—Systems for Nuclear Auxiliary Power.

Reference to figure 9 shows that a nuclear electric powerplant for space application comprises three major components, in addition to its control system.

1. A nuclear reactor which, by atomic fission, serves as a high temperature source of thermal energy.

2. An energy conversion unit wherein a portion of the thermal energy supplied by the high temperature source (the nuclear reactor) is converted into the desired type of electric power.

3. A low temperature sink, or radiator, which dissipates the nonuseful thermal energy rejected to it by the energy conversion unit.

The energy conversion unit may be a direct conversion device (thermionic or thermoelectric) or a dynamic conversion device (turboelectric generator). Studies for determining the best method of energy conversion for the nuclear electric powerplants which will be required for electric rocket engines indicate that for power levels exceeding a few hundred kilowatts the dynamic conversion unit is the logical choice (18).

In a dynamic energy conversion unit, thermal energy from the high temperature source is first converted into mechanical energy in some form of turbine which drives an electric generator. Since only a portion of the thermal energy supplied the turbine can be converted into useful work, the balance is rejected to the radiator. Because of the absence of an atmosphere in space, the radiator must dissipate the energy rejected to it by means of thermal radiation. Since the rate at which heat can be rejected from the radiator is directly proportional to the fourth power of the absolute radiation temperature, heat transfer by radiation is an effective process for dissipating heat only if the absolute radiation temperature is relatively high.

(b) *Importance of high cycle temperatures.*—The temperatures at different points of the thermodynamic cycle for the SNAP VIII powerplant are presented in figure 9. The technology for the SNAP VIII is based on utilizing materials in the reactor coolant circuit that will maintain their structural integrity at a peak temperature of 1,300° F., in the power circuit, at 1,250° F., and in the radiator circuit, at 700° F. The required radiator area, assuming a flat plate configuration for a radiator temperature of 700° F. is 520 square feet. If the SNAP VIII technology were to be "scaled-up" unchanged from 30 kilowatts to 1,000 kilowatts, the computations give a required radiator area of 20,000 square feet, and the specific weight of the powerplant would be approximately 55 pounds/kilowatts, which, of course, is an impractical powerplant.

The radiator of a nuclear electric powerplant for space application is in any case a large piece of apparatus, and it becomes a dominant factor in the designs of powerplants for power outputs exceeding a few hundred kilowatts. The dimensions of the radiator are important for the following reasons:

- (a) It introduces problems of packaging the powerplant in the launch vehicle;

- (b) Its size affects the dimensions and the weight of the radiation shield; and

- (c) It must be protected from damaging collisions with micrometeorites.

To achieve the minimum powerplant weight and size for a given high temperature source, the radiation temperature should be selected so that the radiator size will be a minimum. In the Rankine cycle a fairly accurate rule is that the area of radiator will be a minimum if the absolute radiation (rejection) temperature is approximately three-fourths the absolute temperature of the working fluid at the inlet to the turbine; this is known as the $\frac{3}{4} T$ rule.

Figure 10 presents the radiator area in square feet per kilowatt as a function of the radiator (rejection) temperature, for different values of cycle efficiency (39).⁴

Large reductions in radiator area can be achieved with radiation temperatures ranging from 1,200° F. to 1,500° F., the corresponding turbine inlet temperatures range from 1,800° F. to 2,200° F. (22). If the radiator temperature is raised to 1,500° F., the radiator area for a 1,000 kilowatt plant is reduced to approximately 2,100 square feet, and the specific weight of the powerplant to 10 pounds/kilowatt.

Figure 11 illustrates the physical significance of raising the cycle temperatures of a nuclear electric powerplant; the figure compares the sizes of the radiators of two 1,000-kilowatt powerplant with the Saturn C-1 vehicle (17).

To achieve successful operation with higher radiation and turbine inlet temperatures, construction materials with higher temperature capabilities must be employed. Figure 12 illustrates the relative effects of different refractory materials on the weight of fin and tube radiators (39).

To advance nuclear powerplant technology in the direction of higher cycle temperatures, the SPUR program was initiated early in 1960. Figure 13 presents estimates of the specific weights as a function of power level for SPUR system powerplants (18); it is seen that the estimated specific weight for a 1,000-kilowatt powerplant is approximately 9 pounds/kilowatt.

(a) *Powerplant specific weight.*—Figure 14 presents estimated values of specific weight for nuclear turboelectric powerplants as a function of power output; the figure also indicates the estimated electric power requirements for several different space missions (5).

Studies by NASA, in 1959, indicated that it should be possible to build a 20,000-kilowatt, sodium vapor cycle nuclear turboelectric powerplant, assuming a low voltage alternating current, for a specific weight of 6 pounds per kilowatt and an overall efficiency of 22.7 percent (20). This is considerably lighter than the current state of the art of nuclear turboelectric powerplants as represented by the 30-kilowatt SNAP VIII (75 pounds per kilowatt) but may be approached with extension of the SPUR system. Even if one accepts optimistic estimates that nuclear electric powerplants in the 10- to 20-megawatt capacity can be developed, by say 1972, having specific weights of 2 pounds per kilowatt, the accelerations which will be obtainable with electric rocket engine propulsion will be less than 10^{-2} g. For that reason one may conclude (1) that an electric rocket engine is incapable of propelling a vehicle from the surface of Earth, (2) that they are inherently engines for accomplishing low-acceleration missions in space, (3) that they must operate continuously for long periods of time to achieve large vehicle velocities, and (4) they are single-stage

⁴ I am indebted to S. Lieblein, NASA, Lewis Research Laboratory, for figs. 10 and 12.

vehicles. On the other hand, they have the advantage that the specific impulse can be varied over a wide range by varying the amount of electric power used for accelerating the propellant.

It is not unreasonable to state that the availability of electric rocket engines for space propulsion will be paced almost entirely by the progress made in developing highly reliable, lightweight, nuclear electric powerplants. The successful development of such a powerplant will require solving a large number of extremely difficult engineering problems. There are materials problems associated with using liquid metals such as, lithium, rubidium potassium, and the like, at the high temperatures involved ($2,000^{\circ}\text{F}$. or more). The development of a turbine which will operate efficiently and reliably for long periods of time, without attention, in an atmosphere of high temperature wet liquid-metal vapor is a most challenging problem.

Other difficult problems to be solved in the course of developing the required nuclear electric powerplant are those relating to bearings, seals, separation of metal vapor, condensation of liquid metals in zero or near zero gravity conditions, cavitation phenomena in the inlets to liquid metal pumps, the operation of the electrical generator in a high temperature and probably corrosive environment, etc. It cannot be overemphasized that the most important requirement which must be satisfied for equipment to be of value to space exploration is that it be thoroughly reliable. It is in that area, the development of reliable nuclear powerplants in the 10- to 20-megawatt range that a vigorous effect is required, and in that connection there must be made available the large specialized facilities for the thorough testing of large nuclear electric powerplants for electric rocket engines and space power production.

7. GENERAL CHARACTERISTICS OF ROCKET ENGINES

Since an electric rocket engine must be operated during the entire flight mission, a vehicle propelled by an electric rocket engine is, as mentioned earlier, essentially a single-stage vehicle. The relatively recent interest in electric rocket engines stems from the fact that chemical rocket technology has advanced to the stage where it is becoming feasible so that heavy payloads, such as a vehicle equipped with an electric rocket engine can be placed into an Earth orbit. Consequently, a propulsion system which is virtually inoperable terrestrially, can be placed in an environment in which it can operate effectively; that is, one free from aerodynamic drag and strong gravitational fields. The first artificial Earth satellite demonstrated that engines for propelling vehicles in space need not be required to operate in the environment of the Earth's gravitational field or large aerodynamic resistance. For space exploration, therefore, the low-thrust electric rocket engines can serve a useful purpose. Under the conditions in space such an engine delivering an exceedingly small thrust can accelerate a vehicle to very large velocities if the correspondingly long-powered flight times are acceptable. Mission studies indicate that for vehicles starting from low-altitude orbits around Earth, power-limited (electric) rocket engines should have a superior payload capability than energy-limited (chemical and nuclear) rocket engines.

Table 4 presents some of the general characteristics of the different types of rocket engines.

TABLE 4.—General characteristics of different rocket engine types

Type of engine	I_{sp} (sec) ¹	Thrust to weight ratio	Typical duration of powered flight
Chemical.....	200-420	10^{-2} - 10^2	Minutes (high thrust) hours (low thrust).
Nuclear.....	500-1, 100	10^{-2} -10	Do.
Electric:			
Electrostatic (ion).....	7, 500-60, 000	10^{-5} - 10^{-3}	Months.
Electrothermal (arc-jet).....	700-2, 500	10^{-4} - 10^{-2}	Days.
Electromagnetic (MFM).....	2, 500-10, 000	10^{-5} - 10^{-3}	Weeks.

¹ Vacuum expansion.

Based on G. P. Sutton, "Rocket Propulsion Systems for Interplanetary Flight," Journal of Aero/Space Science, October 1959.

Of the rocket engines listed on table 4 only the chemical types have attained practical realization. To date no electric rocket engine has been operated in space so that the practicable feasibility of electric rocket engines is an unknown quantity. It appears that it will be a few years before electric rocket engines will be flight tested in space. Undoubtedly, it will be more than a decade before manned flights in electric rocket-propelled spacecraft will become feasible.

All of the electric rocket engines have propellant storage and handling problems to be solved, and metering systems, which must be capable of the accurate delivery of controlled flow rates of propellant over a flow range of less than 1 milligram to several grams per second, depending on the thrust level and the desired specific impulse. Probably the most challenging problems are those pertinent to the development of a complete propulsion system that will operate reliably and continuously without attention for a long period of time, a year or more.

8. DEVELOPMENT STATUS OF NONCHEMICAL ROCKET ENGINES

Before discussing the chemical rocket engines, the general characteristics, development status, and some of the technical problems of the specific nonchemical rocket engines will be discussed briefly.

(a) *The nuclear rocket engine.*—The attractiveness of the nuclear rocket engine stems from the enormous energy per unit mass obtainable from the fission of uranium. A nuclear rocket engine equipped with a solid-core reactor which can heat hydrogen gas to approximately 4,000 R. at the entrance to the exhaust nozzle will have a specific impulse of approximately 750 seconds; that is, almost twice the best value obtainable from a chemical rocket engine. During 1959 a successful test was made of the Kiwi A reactor, as part of the Rover project for demonstrating the feasibility of nuclear rocket engine propulsion. The information obtained from that test has been incorporated in the design of subsequent reactors for checking design concepts, materials, and operating characteristics, as a part of the NERVA program.

The maximum operating temperature of a nuclear rocket engine is limited by the structural integrity, at high temperatures, of the solid materials containing the fissioning uranium. Currently, the

operating temperature of a solid-core reactor appears to be limited to approximately 5,000 R. If it were possible, with future development, to raise the operating temperature to 7,000 or 8,000 R., the hydrogen gas could be heated to approximately 6,000 R., and the specific impulse would be raised to approximately 900 seconds.

There are several materials such as tungsten, graphite, the carbides of hafnium and tantalum that appear promising for use at temperatures above the present limiting value of 5,000 R. Their application to a reliable, flyable, propulsion reactor, however, requires solving several difficult scientific, engineering, and manufacturing problems. The development of a reliable, solid-core reactor involves solving problems concerned with reducing reactor weight, speeding up the startup period, control, shielding during powered flight, decreasing the size and weight of the heat exchanger, safety techniques, and achieving the extremely high degree of reliability so essential for space propulsion engines. It should be realized, however, that to achieve the desired high degree of reliability there must be an adequate background of testing. Consequently, the availability and adequacy of the facilities for testing the nuclear heat-transfer rocket, must be matched in time and capacity to the time scale of the development program.

(b) *Electric rocket engines.*—All of the electric rocket engines are in their infancy and most of the research and development has been concerned with demonstrating the conceptual feasibility of the different types of thrusters. As pointed out earlier in this presentation, the application of those thrusters to space exploration will be governed by two important considerations.

(1) The availability of nuclear electric powerplants of large power output capacity, having a low specific powerplant weight, and capable of reliable continuous operation, without attendance, for long time periods, possibly a year or two.

(2) The availability of large booster engines, developing 5 to 20 millions of pounds of thrust, for placing the heavy payloads represented by electric-rocket-propelled vehicles into an Earth orbit.

(i) The electrothermal rocket engine: The thermal arc-jet engine is a most promising form of electrothermal rocket engine. Hydrogen or ammonia is heated in an electric arc to temperatures ranging from 5,400 to 21,000 R. Some experiments are also being conducted with mixtures of hydrogen and lithium (22). The merit of a propellant for a thermal arc-jet engine is determined not only by its available energy (enthalpy) at the design temperature for the thrust chamber, but also by its storability and heat absorbing capacity when used for regeneratively cooling the exhaust nozzle and the electrodes.

It is anticipated that a specific impulse of $I=1,500$ seconds may be achievable within a few years, and it appears that the upper limit for the specific impulse obtainable from the thermal-arc-jet rocket engine will be approximately $I=2,000$ to 2,500 seconds. A factor contributing to limiting the maximum specific impulse of that engine is the large electrical conductivity of the heated propellant gas at the high temperatures. When the conductivity of the gas approaches the conductivity of copper, the ohmic losses in the external circuit cause a large reduction in the overall efficiency of the system. It is reported

that power efficiencies as high as 55 percent are currently being achieved.

An advantage of electrothermal propulsion is the ease with which the jet velocity can be controlled. Within fairly wide limits, the power consumption of the engine is independent of the mass rate flow of the propellant, but a large mass flow rate of gas lowers the gas temperature, and consequently, the exhaust jet velocity; the thrust, however, is increased. It should be possible, therefore, to design a thermal arc-jet rocket engine for operation with a variable propellant flow.

A serious problem of electrode erosion is encountered with long-time operation of the thermal-arc rocket engine. Some promising methods for surmounting that difficulty are under development.

The thermal arc-jet rocket receives considerable interest as a simple, practical electric rocket engine for satellite orientation, orbit adjustment, and satellite raising missions. Table 5 summarizes the state of the art pertaining to the development of thrusters for thermal arc-jet engines (22).

(ii) Electromagnetic rocket engines: The thrusters for these engines, also called plasma rocket engines, are in the early stages of research and development. The operation of the thruster is based on accelerating a plasma, an ionized neutral gas, to a large ejection velocity by means of electromagnetic fields (24) (25).

TABLE 5.—Arc-jet thrusters under development ¹

Manufacturer	Power (kilo- watts)	I (sec- onds)	Power effi- ciency (per- cent)	Propellant	Remarks
Plasmadyne.....	1	{ 1,100 780	38	Hydrogen....	} To be flight tested in 1962.
Avco.....	3		40	Ammonia....	
		900		Hydrogen....	To be flight tested on a Scout vehicle 1963.
Do.....	30	{ 1,000 1,350 1,000	38	do.....	} Radiation cooled engine.
			41	do.....	
			40	Ammonia....	
General Electric Co.....	30	1,100	45	Hydrogen....	} Regeneratively cooled with hydrogen. Reported that specific impulses up to 2,000 seconds obtained at a power efficiency of 20 percent.
Plasmadyne.....	30	1,000	55	do.....	

¹ Based on "Electric Propulsion—State of the Art, 1961," by E. Stuhlinger and E. Urban, *Astronautics*, December, 1961.

Currently, two principal classes of thrusters for plasma rocket engines are being investigated:

- (1) Those employing electrodes, and
- (2) Those without electrodes.

The thrusters or accelerators employing electrodes use an arc-jet for supplying a partially ionized hot plasma (approximately 7,000 K.) to a flow channel in the thruster. A magnetic field and an electric field are impressed upon the channel so that they are perpendicular to each other and also to the flow direction of the plasma. The resulting electromagnetic force then accelerates the plasma and finally ejects it from the thruster with a large jet velocity. In some cases the electrical conductivity of the plasma is increased by "seeding" it with an alkali before it enters the electromagnetic field.

The type of accelerator just discussed is a steady state device, frequently called a crossed-field accelerator. Experimental devices have delivered specific impulses of 1,400 seconds or less, with thrusts varying from 0.3 to 3 pounds, at power efficiencies ranging from 30 to 70 percent (22). The cross-field accelerator is inherently a simple method for producing and accelerating a highly conducting plasma.

The electrodeless engines, on the other hand, encounter the problem of producing a plasma of sufficiently large electrical conductivity, especially at low values of specific impulse. Furthermore, they require more complex circuitry.

Among the serious development problems pertinent to the crossed-field accelerator are erosion of the electrodes and walls of the thrust chamber, and heat losses to those walls. It is anticipated that as a better understanding of the operation of the cross-field accelerator becomes available, the development of larger thrust engines will be possible, and because of the smaller surface-to-volume ratios of large engines the aforementioned problems should be alleviated.

The electromagnetic rocket engine has not fully emerged from the conceptual and feasibility stages, and a large number of schemes are being studied. Research conducted to date has not delineated with clarity which of the several approaches is the most promising. There is a lack of data pertaining to the operating characteristics of the different schemes, and considerable improvement is needed in diagnostic techniques. Furthermore, many of the research engines are single-shot devices operating from a capacitor discharge, and considerable work will be required to develop a reliable engine capable of repetitive firings.

There appears to be no difficulty in obtaining relatively high specific impulses with current electromagnetic thrustors. The urgent problems are those concerned with raising the efficiency and the reliability of the engines; it is in those areas that significant advances are required.

Although electromagnetic rocket engines are still in an early stage of research and development, the results obtained to date indicate that they will perform well in the specific impulse range above 1,200 seconds, thereby filling the gap between the electrothermal rocket engines and the electrostatic rocket engines. In addition, in theory at least, the plasma-rocket engine is capable of providing a larger thrust per unit area than the ion rocket.

(c) *The ion rocket engine.*—The thrustor for the electrostatic or ion rocket engine has received more research and development attention than the thrustors for any of the other types of electric rocket engine. Theoretical predictions indicate that in its present conceptual form it will operate efficiently only at specific impulses exceeding approximately 2,000 seconds. As indicated in table 4, the ion rocket engine has the potential capability of achieving larger values of specific impulse than any other type of rocket engine without introducing severe heat transfer problems. Its predicted thrust-to-weight ratios are, however, the smallest. Although the basic principle of electrostatic propulsion is relatively simple a large number of complicated problems are as yet unsolved.

The propellant must be a readily ionized material and is fed to an ionizer wherein electrical power is used for producing positive ions; that is, atoms stripped of one or more electrons. The positive ions

are separated from the electrons and flow through the accelerator. The acceleration of the ions is accomplished by an electric field which is established between the ionizer and a grid electrode, called the accelerating grid. To produce a thrust the electrostatic field must act on a region where there is but one type of electric charge.

In most schemes the accelerating grid is followed by a decelerating grid for reducing the velocity of the ion beam to the desired value. The accel-decel system, as it is called, is employed for two reasons:

- (1) From the standpoint of aiding the ion extraction process it is desirable that the accelerating grid be at a high negative potential with respect to the ionizer, as this favors operation at higher current densities;

- (2) The potential distribution is such that electrons are not attracted back through the grid electrodes and so do not bombard the ionizer.

For no electric charge to be built up on the propelled vehicle there must be a balance between the number of positive charges (ions) and negative charges (electrons) ejected from the vehicle. An electron emitter must, therefore, be provided for injecting electrons into the ion beam so that the exhaust jet will be a stream of high velocity, electrically neutral, particles. It is estimated that the power which must be provided to the ion accelerator is in the range of 0.8 to 4 megawatts per pound of thrust. The development of a nuclear electric powerplant which can operate in the required power range continuously and reliably for a year or more, as noted earlier, is an engineering task involving great difficulties.

Currently, the neutralization of the ion beam appears to be a major and most controversial problem. Although it is generally accepted that the ion beam must be neutralized, there is no general agreement on the effectiveness of the techniques for accomplishing the neutralization. Most of the schemes employ electrons from heated filaments downstream from the accel-decel electrodes. Because of the low density of the ion beam the conditions are unfavorable for recombination neutralization, and in addition the great difference between the masses of the ions and electrons is unfavorable for their recombination. It appears that to obtain an exhaust beam which is essentially neutral, the electrons must be distributed adequately in the ion beam and moving with essentially the same axial velocity as the ions. For maintaining the charge neutrality of the space vehicle, the ion and electron currents must be approximately equal.

The question regarding whether or not neutralization of an ion beam can be achieved in the environment of space is not known for certain, although recent laboratory experiments on Earth have stimulated confidence that beam neutralization can be achieved in space. Nevertheless, that question will not be resolved until an ion rocket engine is tested in space itself.

There are problems concerned with the ionization process. The contact ionization process, which makes use of thermal contact ionization of alkali metals, is in the most advanced state. A propellant, usually cesium, is brought into contact with a heated surface of a material, usually heated tungsten, having a work function that is high enough to attract an electron from an atom of the propellant, thereby ionizing it. The ionized material is evaporated from the heated surface and flows to the accelerator. Cesium is the propellant currently

avored because it permits for a given specific impulse and thrust, electrode spacings with higher voltage to be employed.

The feasibility of two different methods for feeding cesium to a contact ionization has been demonstrated experimentally: (a) the cesium is caused to impinge directly upon a heated contact surface, and (b) the cesium is diffused through a porous contact material. In either case, the contact surface must have a large work function and be capable of operating at elevated temperatures, approximately 1,800° F. Currently, the porous feed system is favored, and as mentioned above tungsten is the favored contact material.

Another method of ionization, being investigated at NASA's Lewis Research Laboratory, is the relatively new electron bombardment method, and the results reported recently indicate that the electron bombardment method of ionization has the potentiality of becoming a serious competitor of contact ionization. It has the potential advantage that it may be used with a wide variety of propellants; all experiments performed to date, however, used mercury as the propellant (34).

Regardless of the type of ion source, a high ionization efficiency is essential. Otherwise, un-ionized (neutral) propellant will leave the ionizer and will not be accelerated. Moreover, collisions will occur between the neutral and the charged particles, with the result that the trajectories of the charged particles will deviate from their design values, causing some of them to impinge upon the electrodes. If a high speed ion impinges upon an electrode it may cause "sputtering," a term employed for describing the removal of atoms from a solid surface by high velocity particles that impinge upon it. Sputtering of electrodes by "wayward" ions from the ion beam erodes the electrodes, thereby reducing electrode life, and a long electrode life is a prime requirement for missions requiring long powered-flight times. Consequently, the problem of sputtering must be solved.

One of the problems encountered in developing the ion-rocket engine arises in connection with the simulation of the conditions in space in a laboratory on Earth. A method must be developed for correlating simulated performance on Earth with actual performance in space. It may be necessary to establish a space laboratory for obtaining the information needed for developing electric rocket engines.

Current plans by NASA, as reported by reference (22) indicate that the design of high-performance arc-jet and ion engines for space missions will be initiated during 1963 or 1964, and the requirement for the appropriate nuclear electric powerplants for operating them will arise in 1965. It is anticipated that space testing of the SNAP VIII powerplant will begin in 1965. Because of the long time required for developing a reliable nuclear electric (space) powerplant, the pacign element in developing and applying electric rocket engines during the 1965-80 period will be the state of the development of adequate nuclear electric powerplants (22).

9. CHEMICAL ROCKET ENGINES

(a) *General.*—Of the rocket engines discussed in the preceding, only the chemical rocket engines have attained practical realization, and have a broad well-developed technology. Based on the experience

gained with existing high-thrust chemical rocket engines, there is reasonable assurance that the development of new and larger thrust engines can proceed with confidence. Potentially, at least, chemical rocket engines can be developed for boosting any desired mass of payload into an Earth orbit, or to the escape velocity.

It was pointed out earlier that the energy for propulsive purposes, in the case of a chemical rocket engine, is derived from a chemical reaction which produces gaseous products and liberates heat; the heat of the reaction raises the temperature of the reaction products to between 5,000° F. and 8,500° F. depending upon the specific propellants involved. Only a portion, ordinarily between 50 and 60 percent of the heat of reaction can be used for achieving a large exhaust jet velocity. Consequently, the specific impulse obtainable from a chemical rocket engine, regardless of type, is limited by the heat of reaction of the propellants burned in the rocket motor.

Propellant systems are generally compared at the same combustion pressure (usually 500 psia for liquid propellants) and (1,000 psia for solid propellants) assuming complete (isentropic) expansion of the combustion gases to standard sea level pressure (14.7 psia). The specific impulse depends primarily on $\sqrt{T_c/\bar{m}}$ where T_c is the combustion temperature and $\bar{m}$ the molecular weight of the propellant gas.

For any thermodynamic rocket engine (chemical, nuclear, electrothermal), the specific impulse I increases with the square root of the fraction of the available enthalpy converted into jet kinetic energy, and the available enthalpy change is, of course, limited by the heat of reaction for the propellants. As mentioned earlier only 50 to 60 percent of the enthalpy can be converted into jet kinetic energy. There are substantial differences, however, in the percent of that conversion for different propellant gases.

Currently, the specific impulses obtainable with typical liquid bi-propellant systems exceed those obtainable with solid-propellant systems. For liquid systems, it will be shown later, that the maximum obtainable specific impulse is approximately 400 sec, compared with a possibility that specific impulses approaching 300 sec may be obtainable with solid propellants in perhaps a decade.

High specific impulse by itself is insufficient as a criterion for selecting a chemical propellant system. One must also consider—and this applies also to the propellants for electric rocket engines—the stability of the propellant under storage conditions, its density, the safety and ease of handling, the combustion characteristics, the flame temperature, the compatibility with materials of construction, the physical and mechanical properties, its cost, and its availability. The propulsion system giving the highest specific impulse is not necessarily the best when all of the technological application factors are considered. The most appropriate system is that which satisfies the propulsion requirements with the lowest overall cost, and also is based on an engine having the required reliability. Hence, in judging the merits of different systems for a given space mission, it is the cost of placing a unit weight of payload in the desired location that is the main criterion, assuming equal reliabilities. In military applications the “instant readiness” of the propulsion system may be an overriding criterion, and there is no assurance that “instant readiness” will not become an important criterion for certain space missions.

In a multistage space vehicle, the propulsion engine for each stage must impart a specified "burnout" velocity increment to the stages it propels. The "burnout" velocity increment depends on the specific impulse of the engine and the mass ratio; the ratio of the mass of the vehicle at lift-off to its mass after the propulsion engine has consumed its propellants. Figure 15 presents burnout velocity increment as a function of the mass ratio, with specific impulse as a parameter, for single-stage vehicles. Far-out missions, with substantial payloads, cannot be achieved by a single-stage vehicle propelled by a chemical rocket engine.

In a multistage vehicle, each stage is designed to furnish a specified burnout velocity increment, and because of the small aerodynamic resistance encountered by the upper stages calculations show that it is desirable that the upper stages contribute larger speed increments than the lower stages. Hence, the propellants with large values of specific impulse, if they can be used, should be burned in the later stages; it should be noted that each succeeding stage forms a part of the payload for the stage preceding it. The importance of the specific impulse of the propellants depends primarily upon the incremental speed required from a given stage; the larger the required increment of speed the more important is a high specific impulse. For a space vehicle the most important parameters are the payload and the speed of the final stage after all of the propellants have been consumed.

For the foreseeable future all spacecraft will be multistage vehicles, requiring large-thrust chemical rocket engines for the first or booster stage. Until the nuclear heat-transfer rocket engine becomes operational, the upper stages will use high-energy propellants, such as LOX-LH. As payloads increase, and as our knowledge of space increases, the desired missions will become more ambitious, it is reasonable to expect that the booster thrust requirements will continue to increase.

The only chemical rocket engines that have attained operational status are:

- (a) The liquid-bipropellant rocket engines; and
- (b) The solid-propellant rocket engine.

The discussions will be, therefore, limited to those two types of chemical rocket engines.

(a) *Liquid-bipropellant rocket engine.*—Figure 2 illustrates schematically the essential features of a liquid bipropellant engine. In principle liquid bipropellants are less hazardous than liquid monopropellants from the shock sensitivity and thermal stability standpoints. The fuel and oxidant when separated are ordinarily incapable of releasing energy in an explosive manner. Liquid bipropellants which ignite spontaneously when they come in contact with each other in the thrust chamber of the rocket engine, are said to be hypergolic. Those which require an addition of energy to initiate the chemical reaction are said to be diergolic.

One of the attractive characteristics of the liquid chemical rocket engine is its flexibility. It can be stopped and restarted, and can burn a variety of propellants.

The number of known liquids which are suitable as fuels is almost limitless, but there are only a few liquids which can serve as practical

oxidizers. Even so, the number of possible liquid bipropellant combinations is quite large.

The principal liquid oxidizers are liquid oxygen (LOX), liquid fluorine (LF), chlorine trifluoride (TCF), perchlorofluoride (PCF), the mixed oxides of nitrogen (MON), red fuming nitric acid (RFNA), high strength (80 percent to 100 H_2O_2) hydrogen peroxide (HTP).

The principal liquid fuels are the hydrocarbon fuels, such as jet engine fuels RP-1 and JP-5, hydrazine, alcohol-water mixtures, unsymmetrical dimethylhydrazine (UDMH), diethyltriamine (DETA), anhydrous ammonia, and mixtures made of other fuels with either hydrazine or UDMH, and mixtures of hydrazine with UDMH.

TABLE 6.—*Performance of high-energy chemical bipropellant systems*

Propellant system	Oxidizer to fuel ratio	Specific enthalpy (billion pounds)	Molecular weight of gases	Specific impulse I (sec)	Exhaust velocity V_j (feet per second)	Percent converted per mole
LOX-RPI-----	2.6	2,700	26.3	299	9,600	50.0
$\text{N}_2\text{O}_4\text{--N}_2\text{H}_4$ -----	1.4	2,860	22.1	292	9,400	61.5
LOX- N_2H_4 -----	.9	3,390	21.7	315	10,150	66.5
$\text{F}_2\text{--N}_2\text{H}_4$ -----	2.4	4,540	21.8	366	11,800	62.3
LOX- H_2 -----	7.0	5,660	16.12	376	12,100	51.5
$\text{F}_2\text{--H}_2$ -----	15.0	5,680	17.9	404	13,000	59.3

Table 6 presents calculated values of the maximum specific impulse obtainable from different liquid high-energy propellants. Thermochemical calculations indicate that the mean molecular weight, $\bar{m}$, for propellant gases is approximately 25 for the nitric acid-aniline system, 17 for the liquid oxygen-hydrazine, 10 for liquid fluorine-hydrogen, and 9 for liquid fluorine-liquid hydrogen. The low values of mean molecular weight are associated with hydrogen or fuels rich in hydrogen.

The maximum combustion temperature is limited by dissociation reactions. But from an engineering standpoint it is also limited by the integrity of the available structural materials at the operating temperatures, and the effectiveness of the means for cooling the heated part of the engine.

Because the heated parts of a liquid-propellant rocket engine can be cooled by one of the propellants, such engine can be operated at high values of specific impulse for periods limited only by the capacity of the propellant storage tanks. Furthermore, the thrust of a liquid propellant rocket engine is not affected by the temperature of the propellants. A development advantage of the liquid propellant rocket engine is that it can be fired repeatedly. Furthermore, if a liquid-bipropellant rocket engine burns storable propellants, such as those used in the recent successful flight of the Titan II missile, there is no problem of instant readiness.

A problem that is usually encountered in developing a new liquid-propellant rocket engine is that of oscillatory combustion; termed combustion instability. Because of the large experimental background with regard to that difficulty, whenever combustion instability has occurred, it has been possible to eliminate it by employing an empirical approach. As a consequence, the occurrence of combustion instability has always increased the development time and the cost of developing new thrust chambers. It should be noted, however,

that "the empirical approach has almost always led to successful results, so that combustion instability as such has only been responsible for development delays, rather than actual flight failures" (44). Recent reports indicate that means for the effective control of combustion instability are at hand, and there is an air of confidence among liquid propellant rocket engineers that the long development delays due to high frequency combustions instability will not be a serious matter in the future (44).

Liquid rocket engines have either been built or are being built in thrust sizes up to 1.5 millions of pounds. In recent years the reliability of those engines has improved markedly, and if more emphasis is placed on simplicity, the reliability of large liquid engines should be increased.

(b) *Solid propellant chemical rocket engine.*—High-performance solid propellant rocket engines employ the case-bonded design illustrated in figure 3. The propellant mixture is cast directly into the case of rocket motor after lining its inner wall with a suitable non-combustible material which adheres to both the propellant grain and the wall of the case. The advantage of the case-bonded rocket motor design, using an internal-burning propellant grain, is that the propellant grain because of its relatively poor thermal conductivity protects the forecap and the case-tube from the high-temperature gases flowing through the perforation in the propellant grain. Consequently, the permissible stresses in the fore-cap and the case-tube can be based on operation at low temperatures, so that highly heat treated, highly stressed steels can be employed for making inert parts, thereby reducing the weight of the case. In current designs the propellant mass fraction is approximately 0.90, and with improvements in case materials, and the application of titanium, and glass-reinforced plastics to motor-case manufacture it appears that it may be possible to raise the propellant mass fraction in large booster engines to approximately 0.95 in a few years.

The main disadvantage of the case-bonded design arises from stresses imposed on the propellant and the lining material when the case expands or contracts, under variable atmosphere temperature conditions.

Solid propellents in use today give a specific impulse of approximately 240 sec, and a part of the improvement achieved in recent years is a consequence of including significant amounts of light metals in the propellant formulations. Propellant research and development indicate that the likelihood of having a solid propellant with a specific impulse of approximately 290 sec by 1965 is favorable (37). Since such propellents will undoubtedly have higher flame temperatures, one may expect the problem of protecting the exhaust nozzle, which operates uncooled, will be intensified.

The temperature of a solid propellant affects its burning rate and its general physical characteristics. At low propellant temperatures the burning rate decreases and the physical properties of the propellant are affected adversely. Because of the influence of the temperature of the propellant upon the burning rate and physical characteristics of the solid propellant, it is important that careful attention be given to storing, handling, and firing a solid propellant rocket motor within the temperature range recommended by its manufac-

turer. In the case of a large solid propellant rocket motor the importance of storing, handling, and firing it within a limited temperature range may be expected to increase with its dimensions.

In recent years great progress has been made in the design and fabrication of uncooled exhaust nozzles for operating durations of approximately 100 sec. Significant advances have also been made in applying secondary fluid injection for thrust vector control (43).

Because of the significant advances made in solid propellant rocket engine technology in recent years, and in view of their excellent reliability record, they must be given consideration in many applications that not too long ago were deemed to be the special province of liquid bipropellant rocket engines.

To my knowledge the largest thrust size in which a solid propellant rocket engine has been fired is approximately 600,000 pounds; the propellant weight was approximately 220,000 pounds.

It is my understanding that the joint DOD-NASA committee, generally called the Golovin Committee, has completed its study of large booster engine problem. I have not, however, seen the report of that committee.

10. CONCLUSIONS

In view of the state of the art of electric rocket engines and nuclear heat transfer rocket engines, it is evident that only the chemical rocket engines can be considered for space flight missions, manned and unmanned, for possibly the next decade (1962-72). To achieve the objectives of the manned lunar mission, large chemical booster rockets (first stage), and large rockets burning high-energy propellants for intermediate stages will be required.

The systematic exploration of space for either peaceful or military purposes cannot be accomplished with chemical rocket engines alone. Consequently, adequate financial support must be available for developing the nuclear heat-transfer rocket engine, the electric rocket thrustors, and nuclear powerplants in the megawatt class.

One may expect nuclear upper stages to become available in the early part of the 1970-80 time period. It is premised that their better performance will not reduce the booster engine requirements, but will be utilized for undertaking more ambitious missions.

It is difficult to foretell when electric rocket engines will become available for manned exploration of space. In that connection considerable effort must be expended in developing a large power output (megawatts) reliable nuclear turboelectric powerplant. The electric rocket engines will in any case be heavy and because they are low thrust-to-weight ratio engines will take long periods of time to accomplish their space missions. Consequently, manned vehicles employing electric rocket engines will be heavy.

It appears that the chemical booster engines required for the systematic exploration of space will be larger than any available at this time. Rough calculations indicate that single chemical rocket engines developing 18 to 20 million pounds of thrust will certainly be required. Facilities for testing such large chemical rocket engines should become available by the time such engines are ready for testing. It should also be noted that high thrust (2 to 4 million pounds) liquid rocket engines burning high-energy propellants in the upper stages of a space vehicle, will also require large facilities for testing them.

As the missions in space become more ambitious the problem of cost becomes more important. Undoubtedly, as we stretch the state of the art the cost per pound of the engine increases. Simplification always reduces cost. But is this enough? A major effort should be expended on making reusable as much of the vehicle as possible. At least the booster stage and possibly the second stage. The goal of cost reduction cannot be overemphasized, for if the cost of conducting space missions can be reduced sufficiently space explorations will become possible that otherwise could not be considered.

I wish to close on a note which takes liberty with some remarks made by Adm. Hyman Rickover. One may expect that our paper vehicles will be much lighter than the actual vehicles, our paper rocket engines will be more powerful and more efficient than their actual counterparts, and our paper nuclear electric powerplants will be lighter and more efficient than the real ones. If we underestimate the booster thrust requirements because of excessive optimism regarding payload weights, we will limit the space exploration programs we can undertake. Similar remarks are applicable to the nuclear electric powerplant. Gentlemen, I thank you.

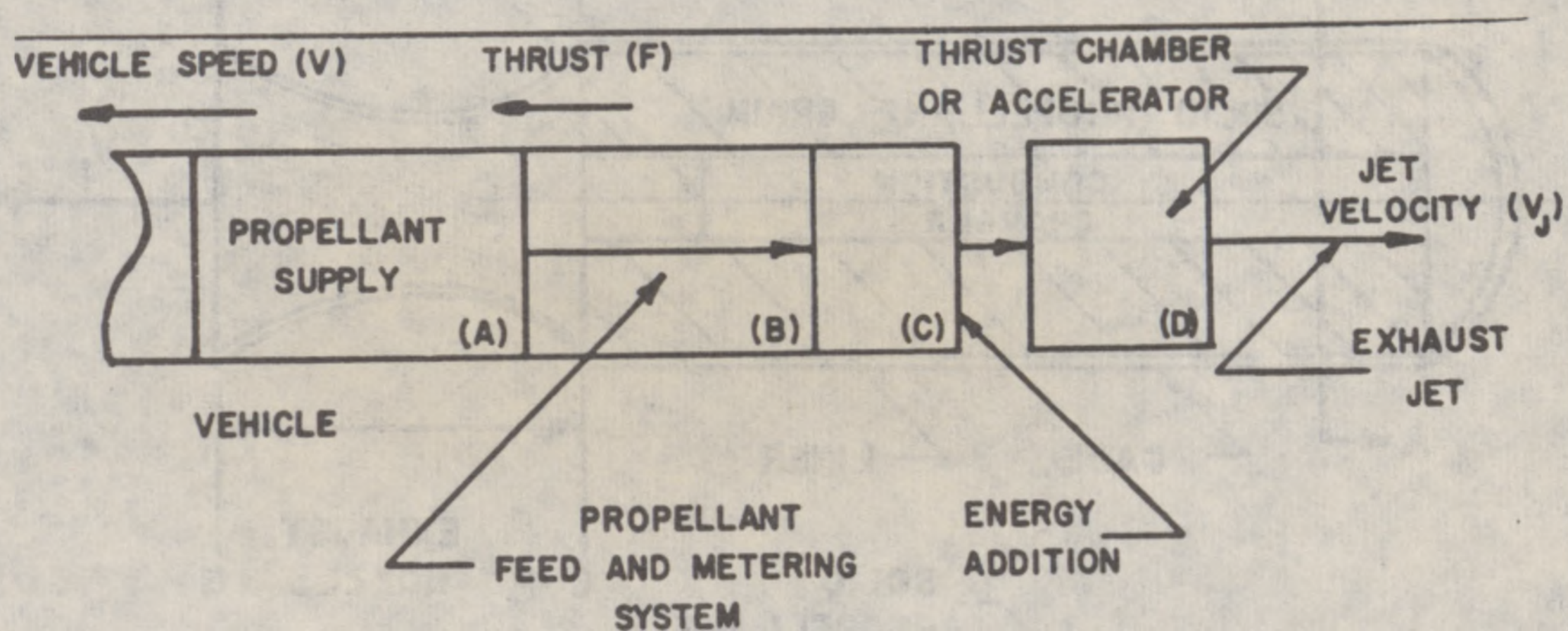
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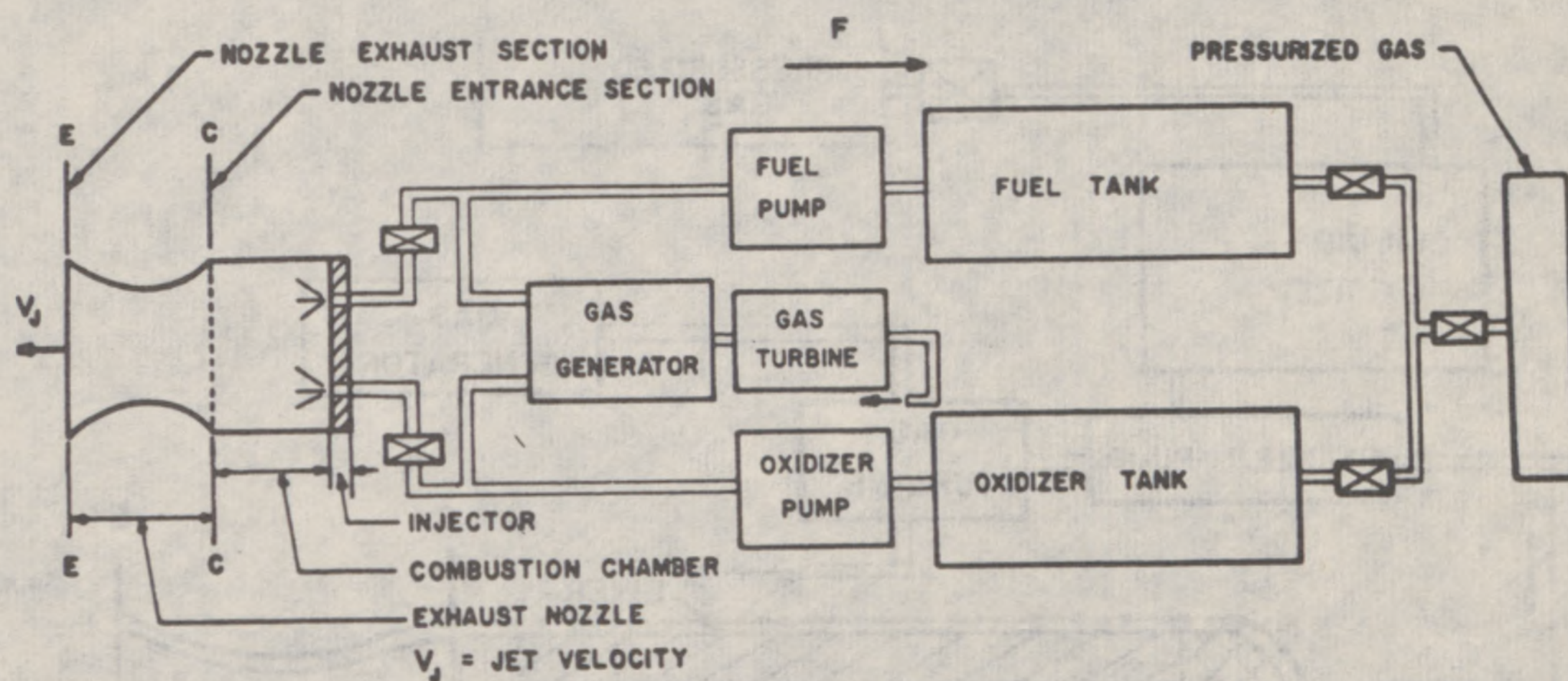
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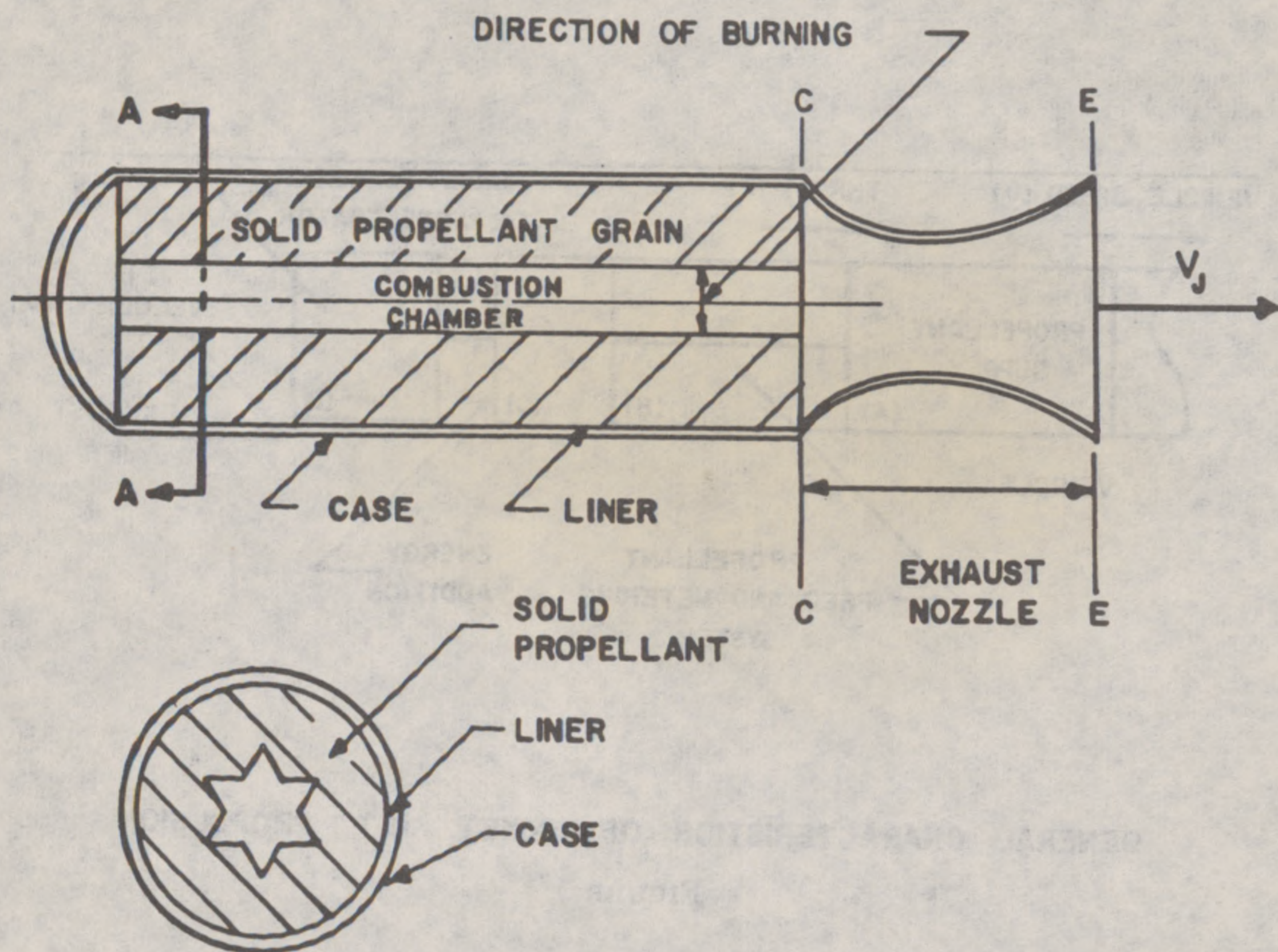
GENERAL CHARACTERISTICS OF ROCKET JET PROPULSION

FIGURE 1



TURBOPUMP FED BIPROPELLANT ROCKET ENGINE

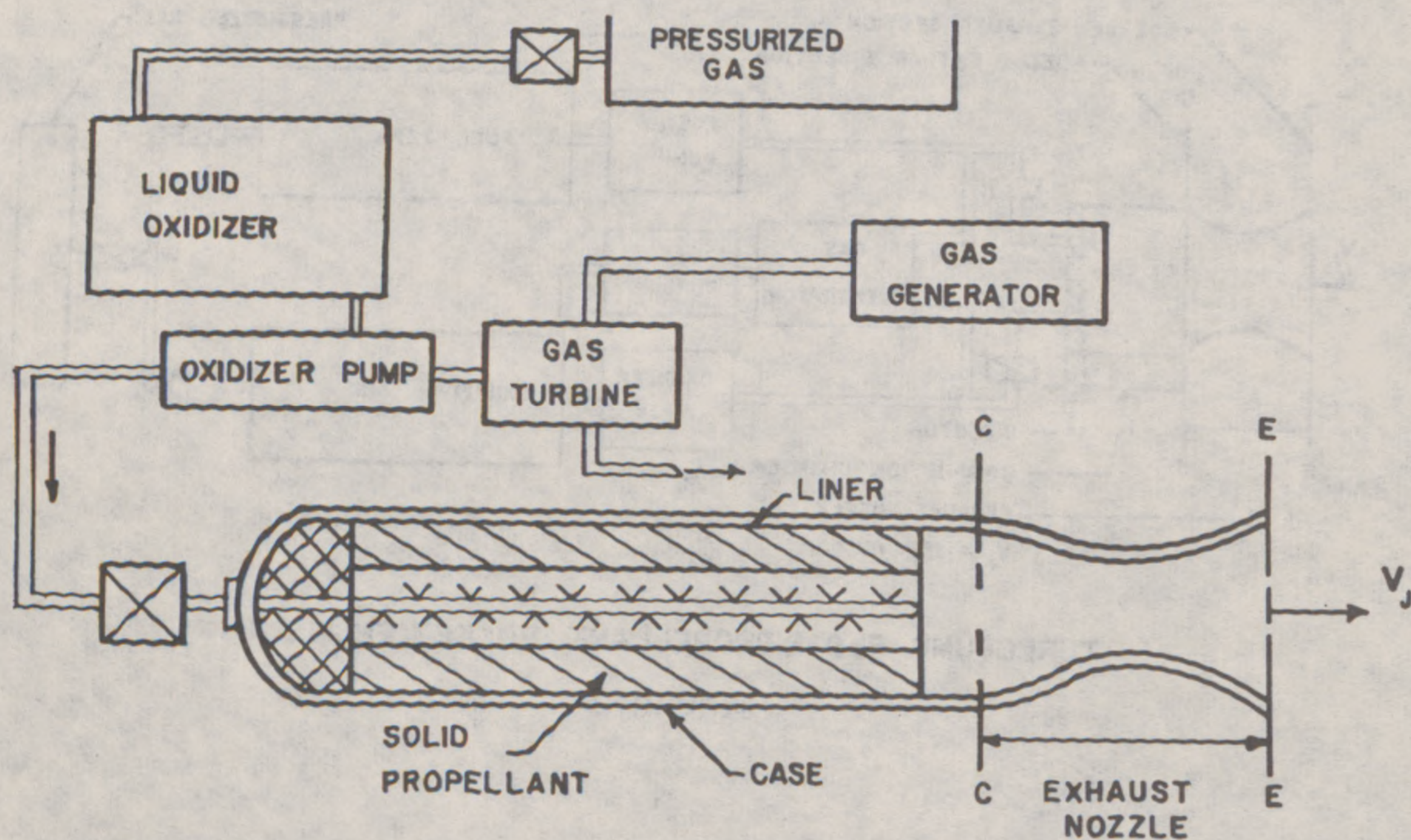
FIGURE 2



CROSS-SECTION THROUGH A STAR SHAPED BONDED
SOLID PROPELLANT ROCKET ENGINE

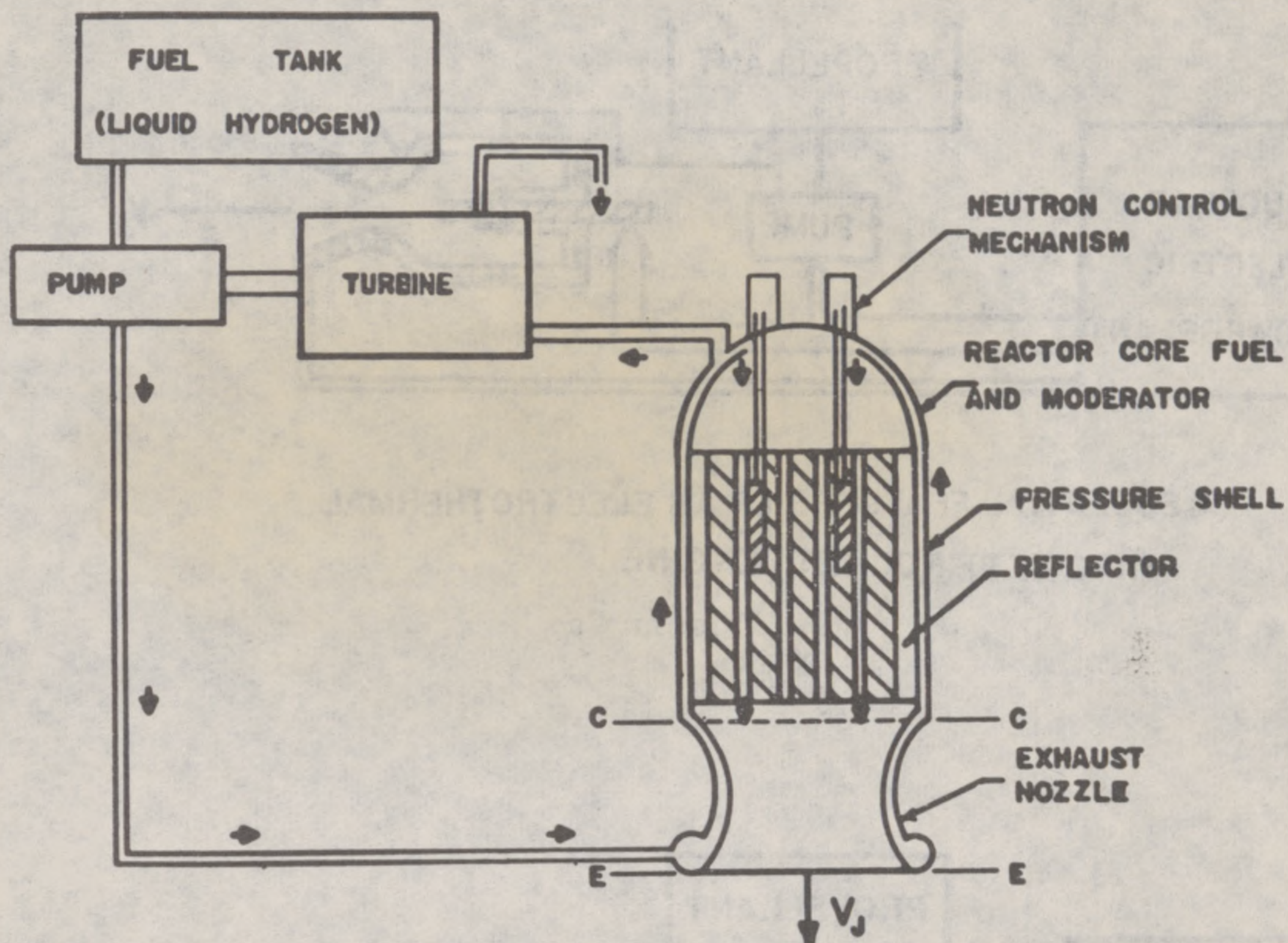
SOLID PROPELLANT ROCKET ENGINE

FIGURE 3



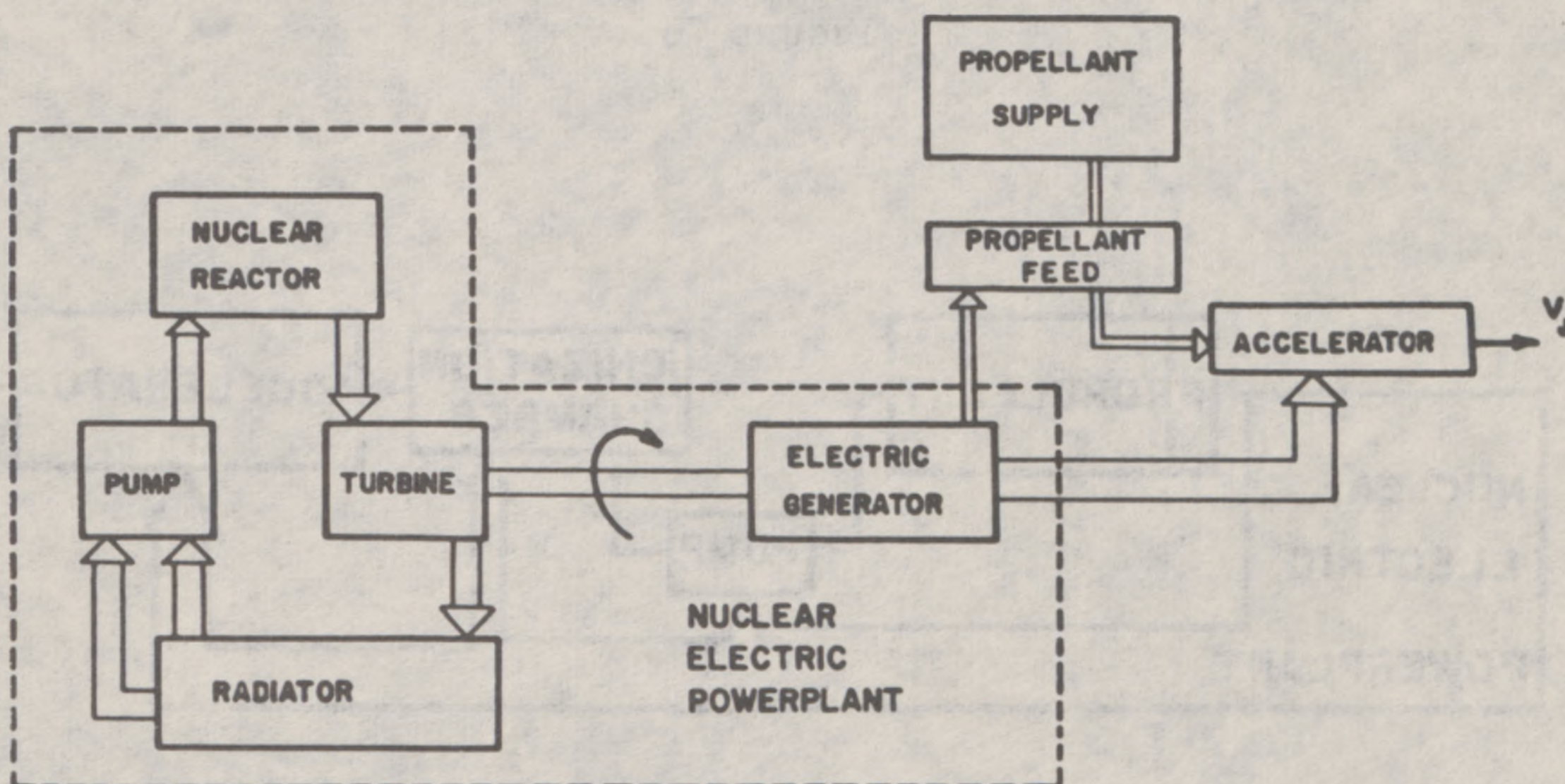
ESSENTIAL FEATURES OF A HYBRID CHEMICAL ROCKET ENGINE

FIGURE 4



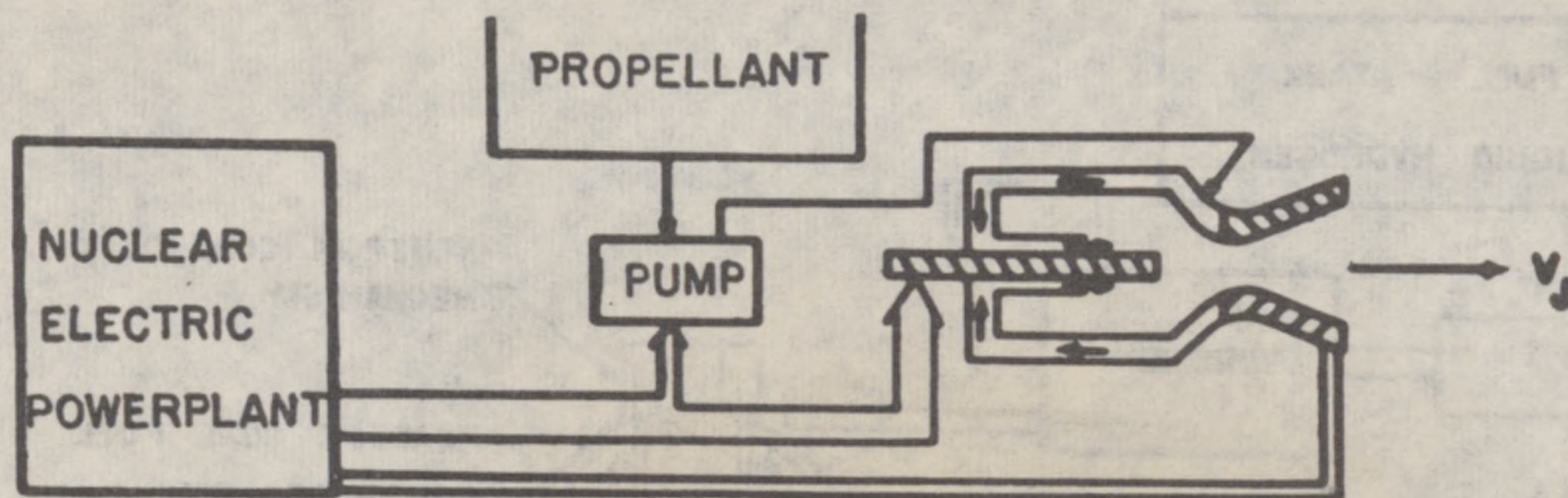
ESSENTIAL FEATURES OF A NUCLEAR HEAT TRANSFER
ROCKET EMPLOYING A SOLID CORE REACTOR

FIGURE 5



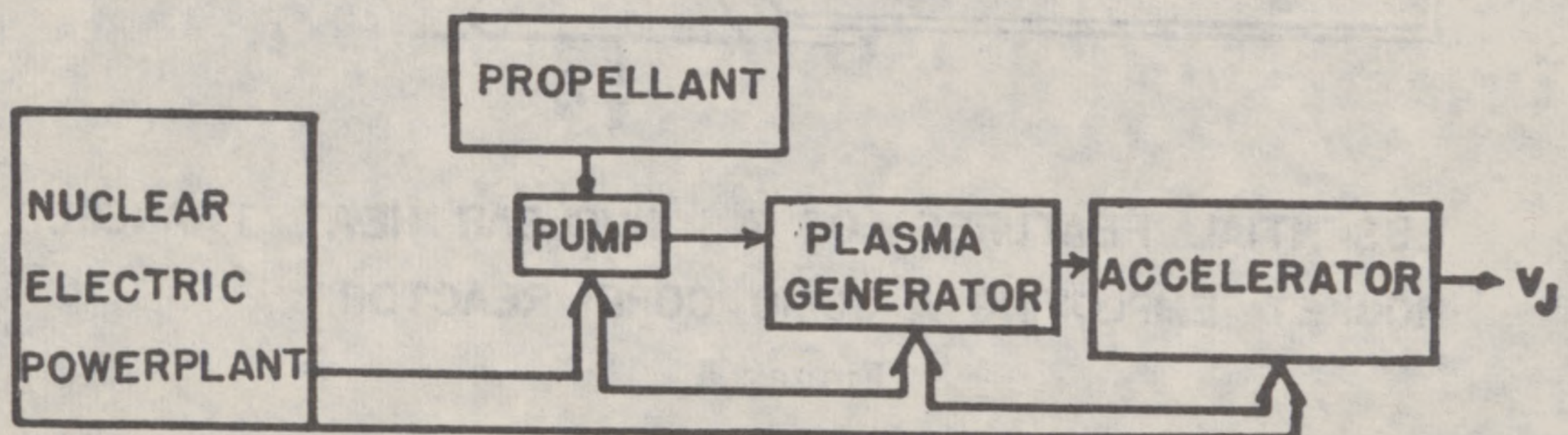
ESSENTIAL FEATURES OF AN ELECTRIC ROCKET ENGINE

FIGURE 6



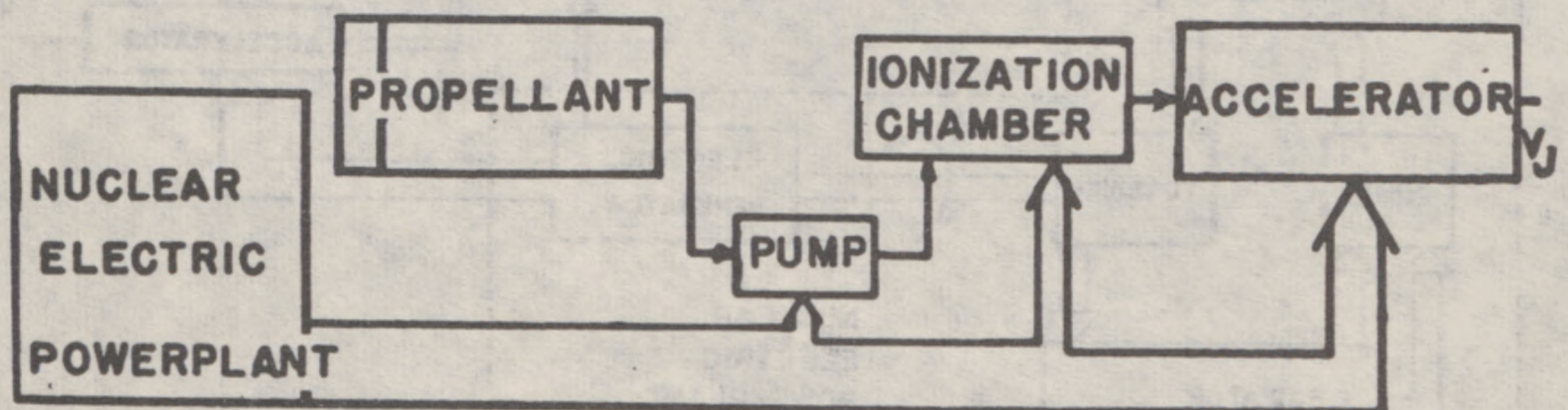
(A) ESSENTIAL FEATURES OF AN ELECTROTHERMAL
(ARC-JET) ROCKET ENGINE

FIGURE 7a



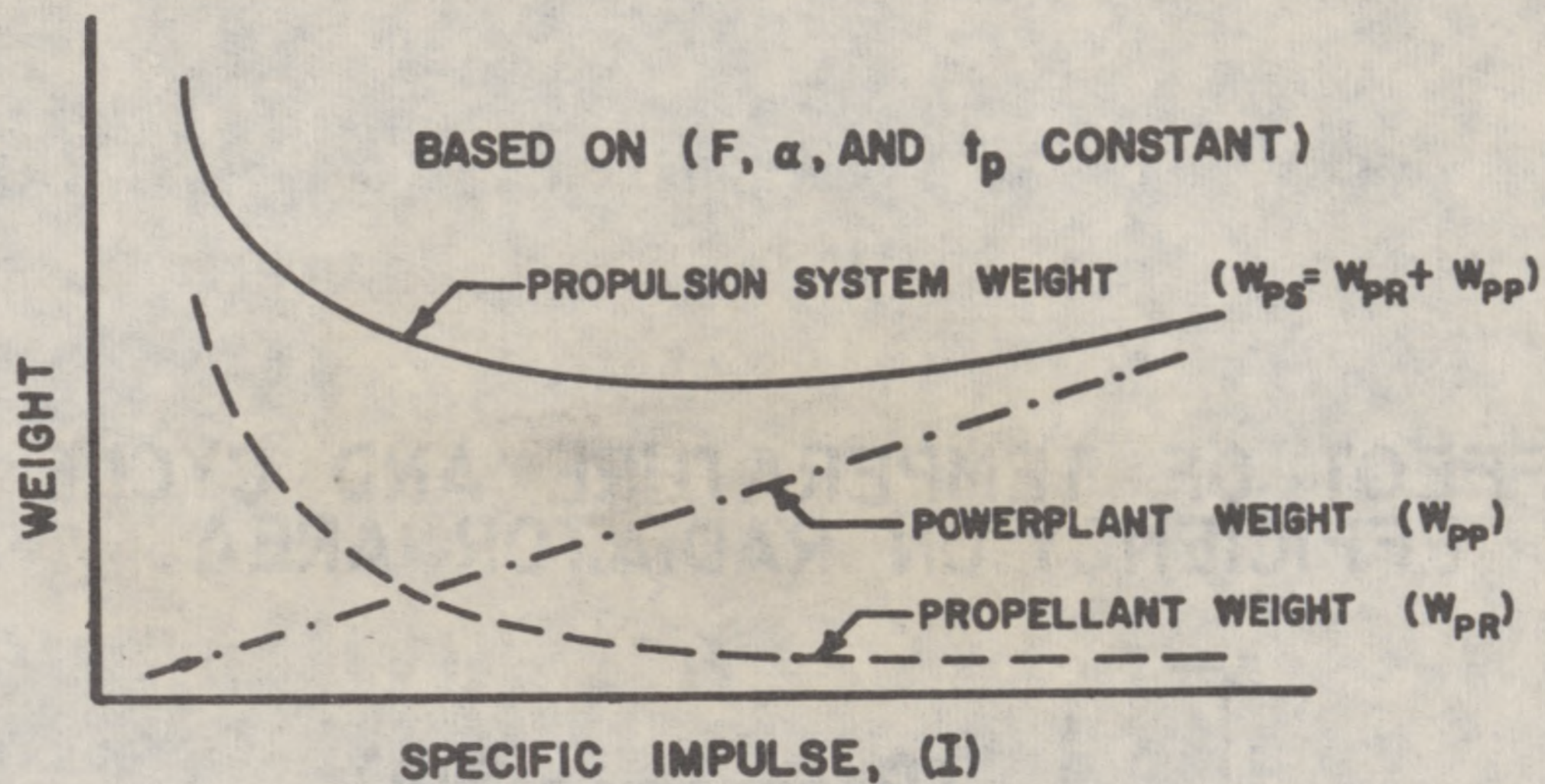
(B) ESSENTIAL FEATURES OF AN ELECTROMAGNETIC
(PLASMA) ROCKET ENGINE

FIGURE 7b



(C) ESSENTIAL FEATURES OF AN ELECTROSTATIC
(ION) ROCKET ENGINE

FIGURE 7c



PROPELLANT, POWERPLANT, AND PROPULSION SYSTEM WEIGHTS AS A FUNCTION OF SPECIFIC IMPULSE

FIGURE 8

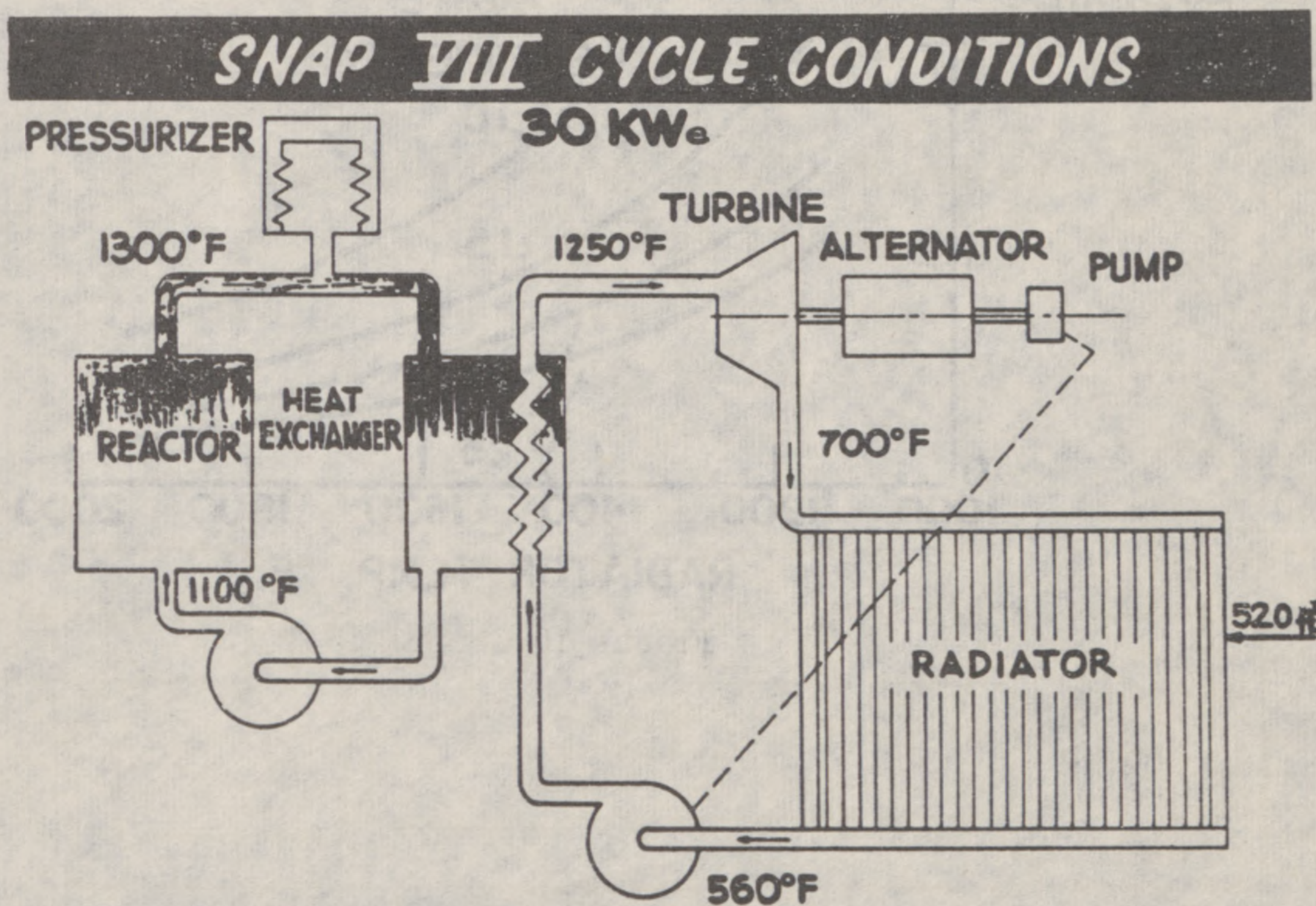


FIGURE 9

EFFECT OF TEMPERATURE AND CYCLE EFFICIENCY ON RADIATOR AREA

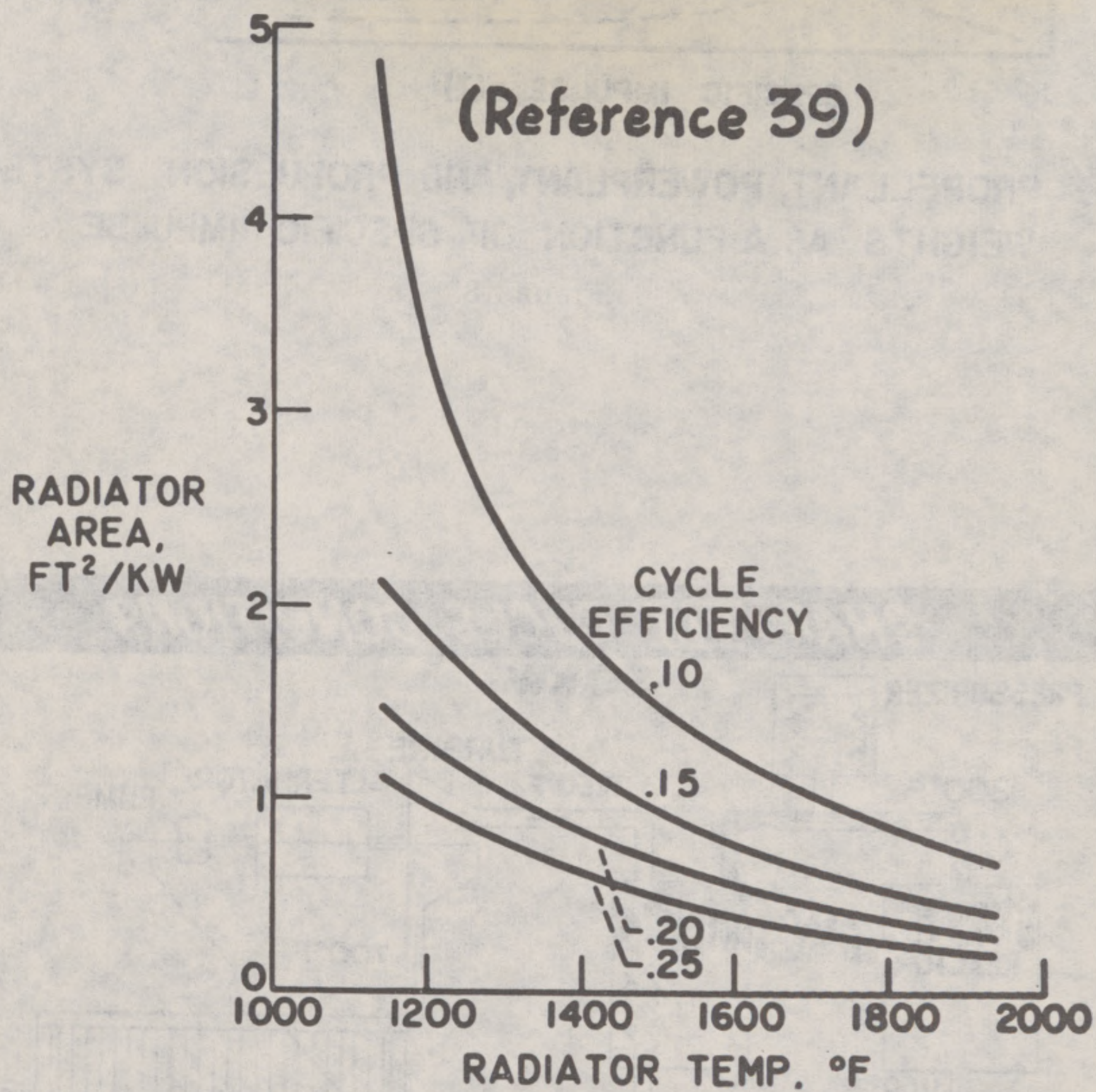


FIGURE 10

RADIATOR COMPARISON AT 1000 KW(e)

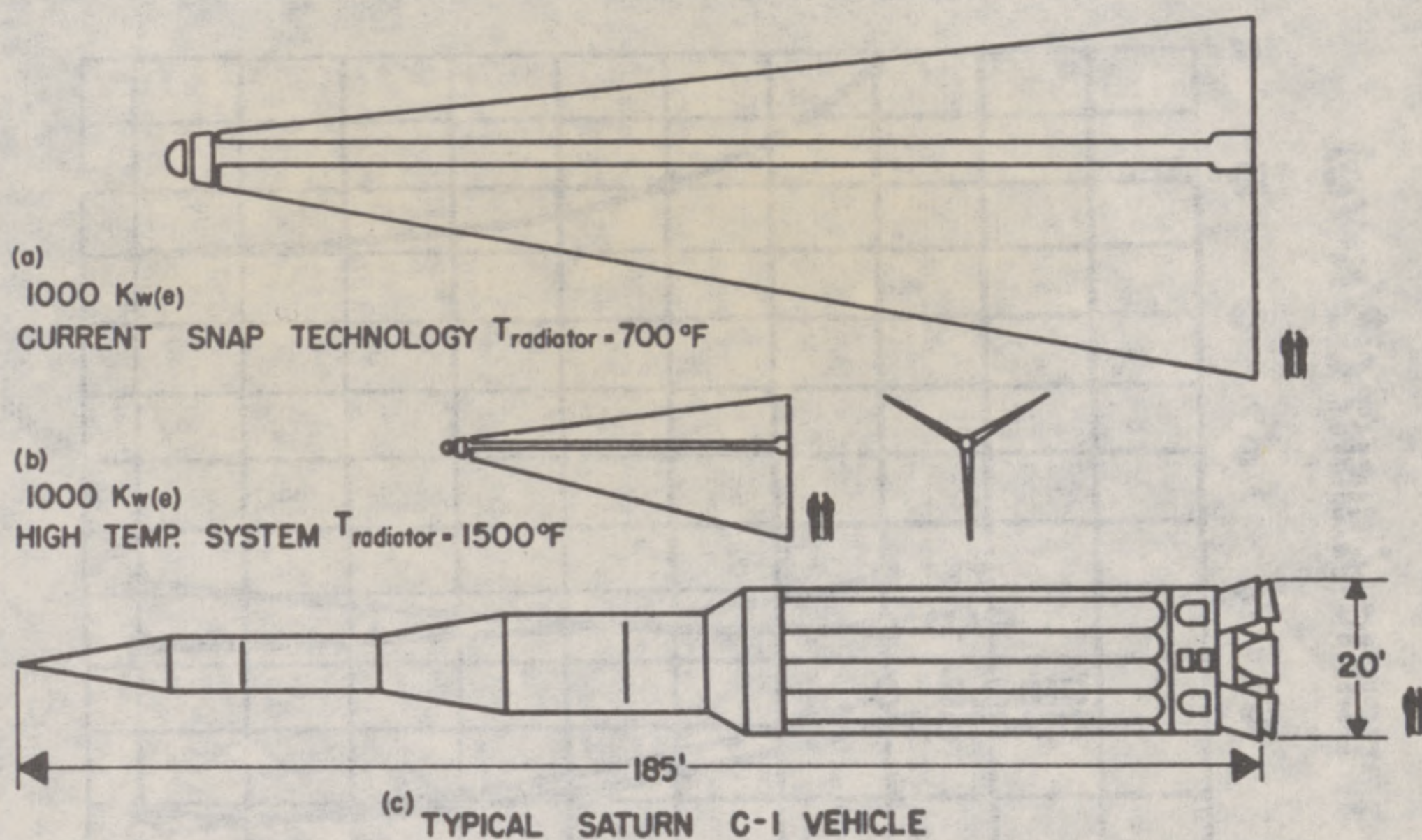


FIGURE 11

FIN AND TUBE RADIATOR WEIGHT (Reference 39)

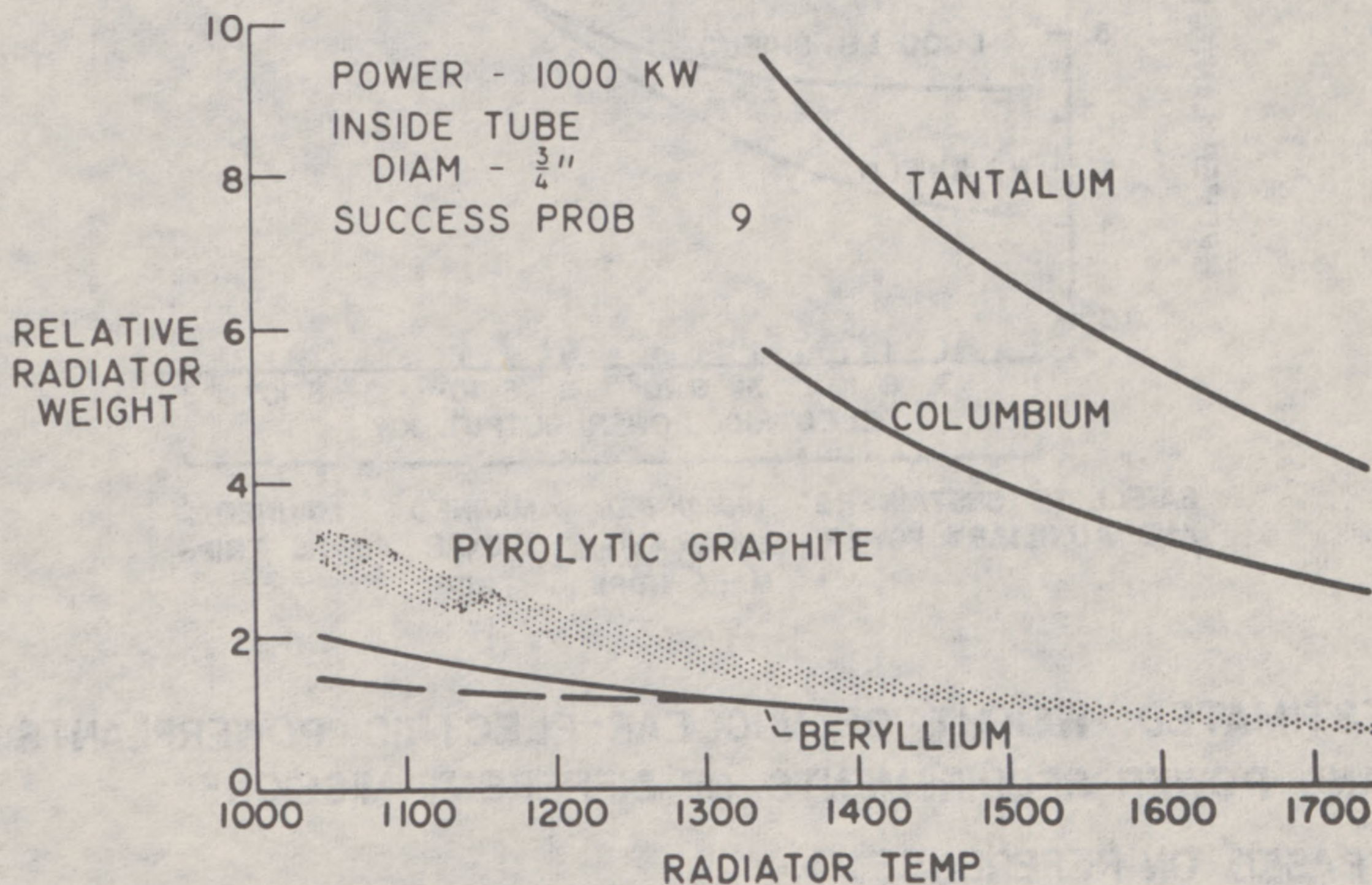


FIGURE 12

SPUR SPECIFIC PERFORMANCE

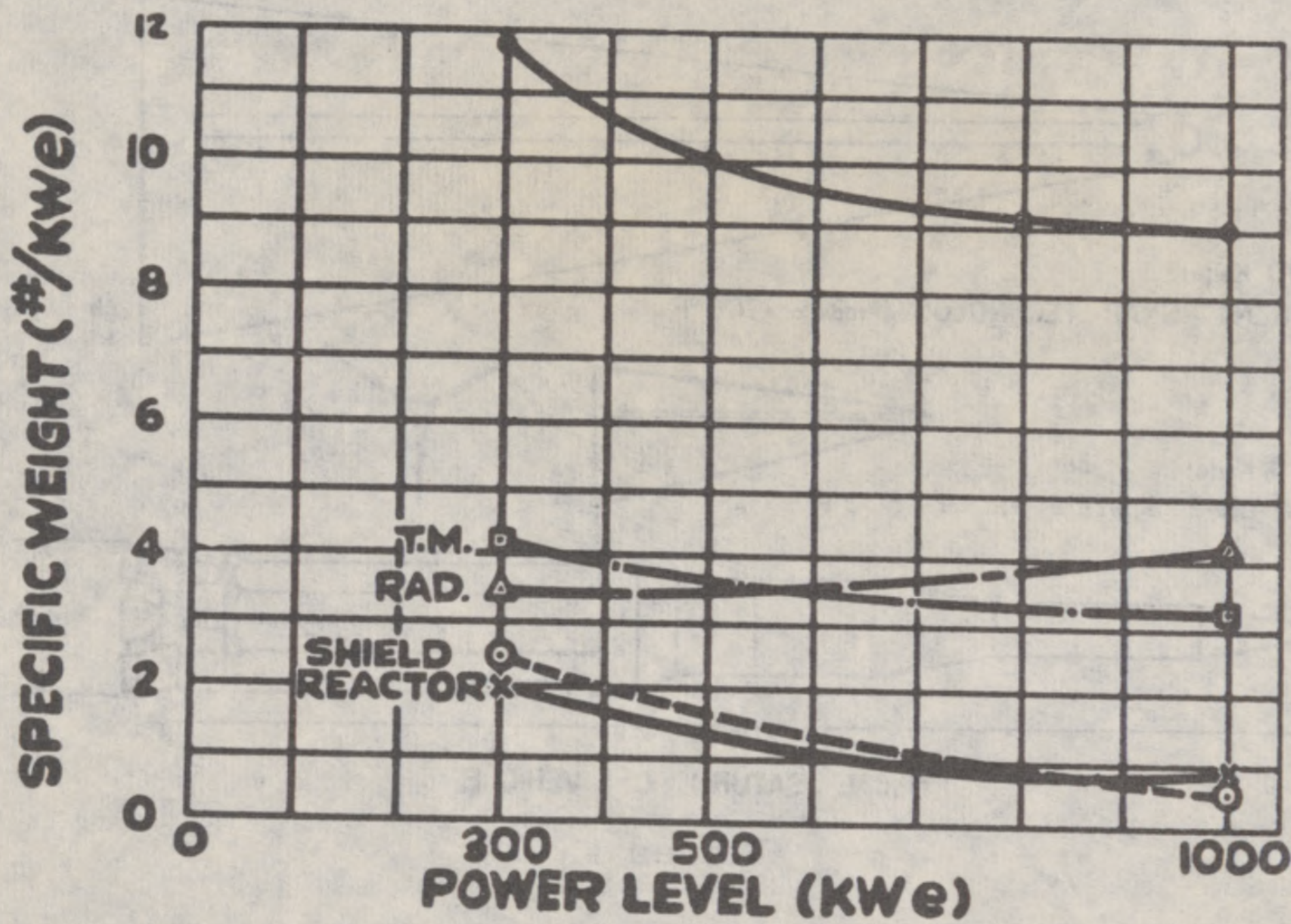
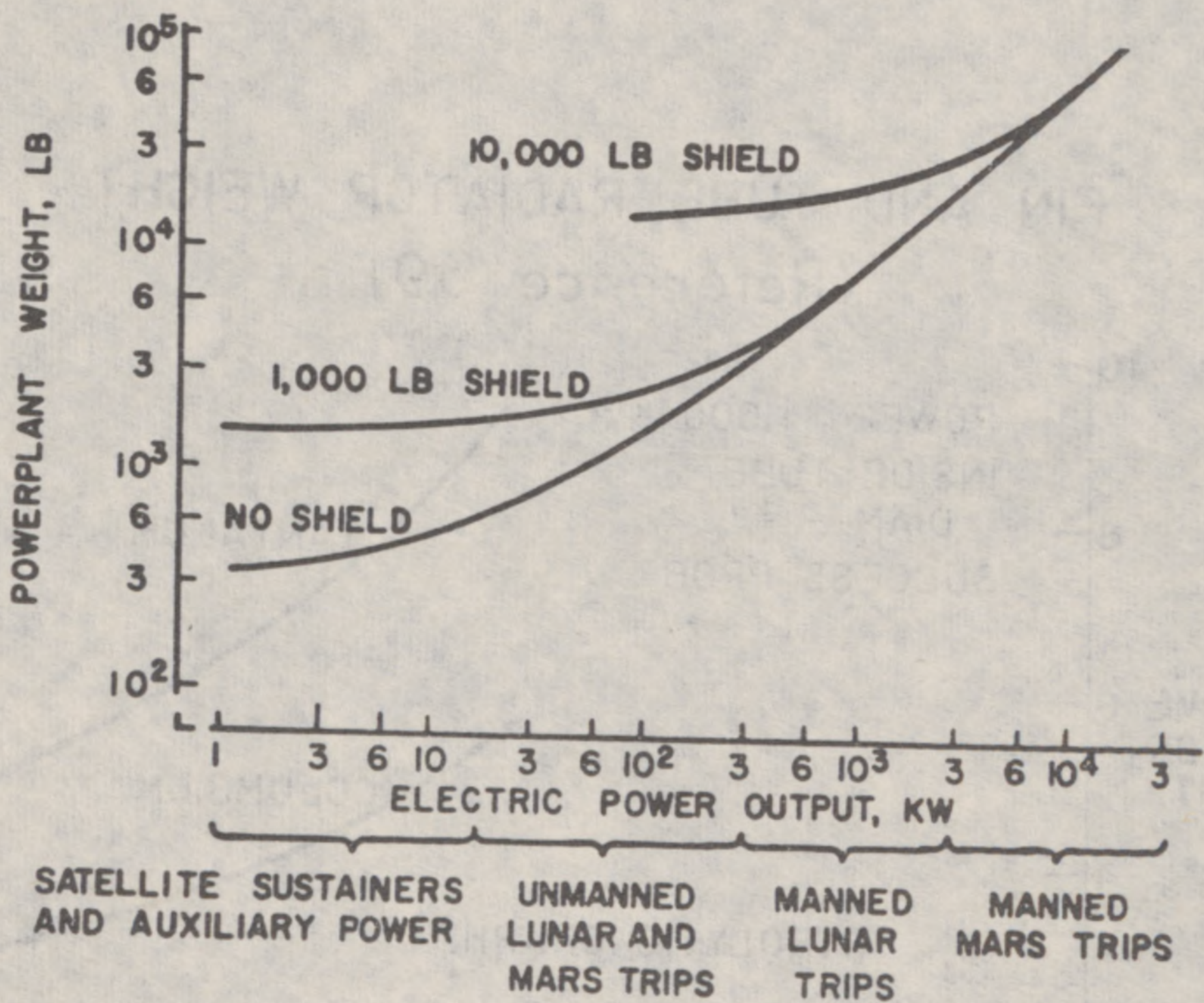


FIGURE 13



ESTIMATED WEIGHT OF NUCLEAR-ELECTRIC POWERPLANTS AND POWER REQUIREMENTS OF DIFFERENT MISSIONS (BASED ON REFERENCE 11)

FIGURE 14

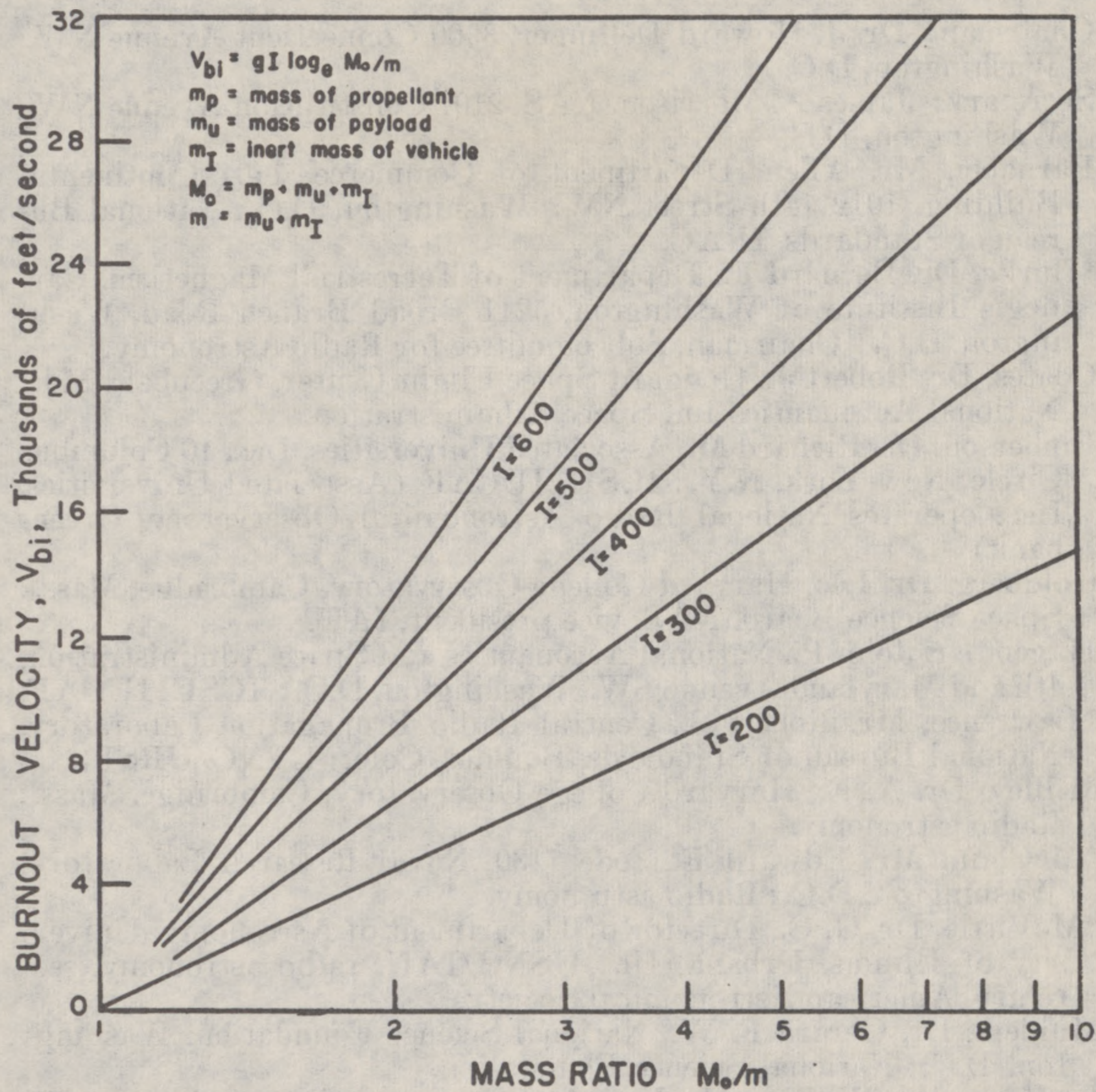


FIGURE 15

APPENDIX E

MEMBERSHIP OF NAS COMMITTEE ON RADIO FREQUENCY ALLOCATIONS FOR SCIENTIFIC RESEARCH AS OF JULY 10, 1962

- Chairman: Dr. J. Howard Dellinger, 3900 Connecticut Avenue NW., Washington, D.C.
- Secretary: James A. Morrison, NAS, 2101 Constitution Avenue NW., Washington, D.C.
- Barnabei, Mr. Allen, Department of Commerce, 1401 Continental Building, 1012 14th Street NW., Washington, D.C.: National Bureau of Standards, IRAC.
- *Burke, Dr. Bernard F., Department of Terrestrial Magnetism, Carnegie Institute of Washington, 5241 Broad Branch Road, Washington, D.C.: Chairman, Subcommittee for Radio Astronomy.
- Coates, Dr. Robert J., Goddard Space Flight Center, Greenbelt, Md.: National Aeronautics and Space Administration.
- Emberson, Dr. Richard M., Associated Universities, Inc., 10 Columbus Circle, New York, N.Y.: ICSU, IUCAF (Associated Universities, Inc., operates National Radio Astronomical Observatory, Greenbank)
- Goldberg, Dr. Leo, Harvard College Observatory, Cambridge, Mass.: Space Science Board, NAS, vice president, IAU.
- Hagen, Dr. John P., National Aeronautics and Space Administration, 4th and Maryland Avenue SW., Washington, D.C.: ICSU, IUCAF.
- *Lawrence, Mr. Robert S., Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colo.: USNC/URSI.
- *Lilley, Dr. A. E., Harvard College Observatory, Cambridge, Mass.: Radio astronomy.
- *McClain, Mr. Edward F., code 7130, Naval Research Laboratory, Washington, D.C.: Radio astronomy.
- *McVittie, Dr. G. C., Director of Department of Astronomy, University of Illinois, Urbana, Ill.: USNC/IAU, radio astronomy, secretary, American Astronomical Society.
- Mulders, Dr. Gerard F. W., National Science Foundation, Washington, D.C.: National Science Foundation.
- Radford, Dr. William H., Lincoln Laboratory, Post Office Box 73, Lexington, Mass.: JTAC (IRE and EIA).
- *Smith, Dr. Harlan J., Yale Observatory, Box 2023, Yale Station, New Haven, Conn.: USNC/IAU, acting secretary for 1962, American Astronomical Society.
- Snodgrass, Mr. James M., Scripps Institute of Oceanography, La Jolla, Calif.: NAS Commission on Oceanography.
- Villard, Dr. O. G., Radioscience Laboratory, Stanford University, Stanford, Calif.: Space Science Board, NAS.

* The persons designated with asterisk, together with Charles L. Seeger, Stanford University, and Frederick T. Haddock, University of Michigan, constitute the Subcommittee on Radio Astronomy.

APPENDIX F

STATEMENT OF FUNCTIONS AND ACTIVITIES, COMMITTEE ON RADIO FREQUENCY ALLOCATIONS FOR SCIENTIFIC RESEARCH OF THE U.S.A. NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL

In the spring of 1961 the National Academy of Sciences of the United States of America established a Committee on Radio Frequency Allocations for Scientific Research. Broadly defined the Committee's responsibilities are two:

(i) to consider and determine the needs of U.S. science for radio frequency allocations and assignments and to work actively with the U.S. Government in securing them;

(ii) to work with the Inter-Union Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF), established by the International Council of Scientific Unions.

The membership of the Academy's Committee includes, among others, representatives of the U.S. counterparts of the three international bodies represented on the Inter-Union Committee: U.S. National Committees for the International Astronomical Union and the International Scientific Radio Union and the Space Science Board (Committee on Space Research), and also members from governmental organizations concerned with radiofrequency allocation and assignment. The Committee has established a Subcommittee on Radio Astronomy to represent the scientific interests in that field.

Examples of matters handled in meetings of the Committee are: Frequency allocation requirements of radio astronomy; CCIR questions referred by the U.S. National Committee for CCIR Study Group IV, Space Systems; and the broad subject of securing and protecting adequate frequencies for scientific research.

The Committee maintains effective liaison with U.S. Government agencies concerned with the assignment and regulation of radio frequencies in the United States as well as those Government organizations concerned with development of U.S. positions and recommendations for radio frequency allocation at international conferences.

Future Committee activities will be concerned with radio frequency allocation matters of interest to U.S. programs of basic research in all fields, as specific needs arise. Committee activities on behalf of radio astronomy and radar astronomy will continue; increasing attention will be given to the needs for radio frequency allocations for space science, meteorology, oceanography, and other areas of basic research as frequency allocation or assignment problems appear to be of current importance.

The Governing Board of the National Academy of Sciences on December 10, 1961, approved the following proposal of the Committee:

(i) That the National Academy of Sciences' Committee on Radio Frequency Allocations for Scientific Research assume responsibility for staying currently advised in detail on U.S. Gov-

ernment actions on frequency allocations and assignments, as they affect science in this country;

(ii) That it keep scientists in this country informed;

(iii) That it provide a channel of communication between scientists and the U.S. Government;

(iv) And that the staff of the National Academy of Sciences be added to, if necessary, in order to provide these services on a continuing basis.

APPENDIX G

STATEMENT OF FUNCTIONS—SUBCOMMITTEE ON RADIO ASTRONOMY

1. Recommend to the main committee, and hence to the Academy, actions which need to be taken to insure maximum utilization of spectrum space for radio astronomy.

2. Assess the impact of new developments in radio astronomy on the matter of frequency allocations.

3. Assess progress in other fields of science as it might affect the radio astronomy frequency allocation picture.

4. Keep in touch with developments in IRAC and FCC with respect to radio astronomy frequency allocation matters.

5. Serve as a nucleus for supplying the necessary experts to the Academy when required by the Academy's dealing with other organizations.

6. Advise the Academy through the main committee, when necessary, concerning changes in its staff and effort in the matter of frequency allocations for radio astronomy.

7. As a specific task, annually review and update the list of radio astronomy observatories in the United States and the radio frequencies in use at those observatories.

APPENDIX H

NATIONAL ACADEMY OF SCIENCES NATIONAL RESEARCH COUNCIL
2101 Constitution Avenue, Washington, D.C.

STATUS REPORT ON RADIO FREQUENCY ALLOCATIONS FOR RADIO ASTRONOMY

At the first meeting of the NAS Subcommittee on Radio Astronomy in Washington on April 30, 1962, the members considered that it would be appropriate to prepare a brief summary, for your information, of the present status of radio frequency allocations for radio astronomy. The basic reference material is contained in the report "Frequency Allocations for Radio Astronomy—A Statement of Position" (June 1961), issued by a committee of the National Academy of Sciences under the chairmanship of Prof. A. E. Lilley, which may be considered as supplementing this memo.

I. FREQUENCIES FOR OBSERVATION OF CONTINUUM EMISSION

The basic need, as outlined in the Lilley committee report, is for exclusive bands approximately every octave throughout the radio spectrum.

From the presently allocated band 1400–1427 megacycles to higher frequencies, this general requirement is met by the present table and will be strengthened by the changes proposed in two FCC dockets now pending (14475 and 14477). We are hopeful that these allocations will prove most useful. Some widening of the bands, notably at 2700 and 5000 megacycles, may be necessary, but experience must be gained before further recommendations can be made.

Between 74.6 megacycles and 1400 megacycles, there is only one allocation (404–406 megacycles); and its removal is being considered by the FCC. At least three, and preferably four, bands must be found in this region of the spectrum.

(a) The first octave below 1400 megacycles would be covered by an allocation coinciding with the present channel 37 UHF-TV allocation (608–614 megacycles). The FCC has so far declined to grant permanent station allocations for this channel, and it is extremely important that this policy be continued until a permanent allocation to radio astronomy can be made.

(b) The next octave is covered by the present allocation, 404–406 megacycles. In the dockets 14475 and 14477 now pending, the FCC proposes to remove this allocation and substitute a secondary allocation in the ILS band, 328.6–335.4 megacycles. This change, in the opinion of the subcommittee, is highly premature. Calculations indicate that in the near future interference in the band 328.6–335.4 will be probably caused at the most remote radio astronomy sites, both from tropospheric scatter and by scatter from satellites. Investiga-

tion of the suitability of this proposed band can proceed without a secondary allocation. Indeed, the first measurements could be highly misleading, since the sensitivity of radio telescopes will continue to increase, and the resulting tolerable level of interference will continue to decrease. The band 404–406 megacycles, on the other hand, is already known to be useful, and consequently the immediate substitution of a doubtful band for one of proven value is disturbing.

(c) The next octave below, which falls in the region 150–200 megacycles, presents an extremely difficult problem. Radio astronomers will be most grateful for constructive suggestions from knowledgeable Government officials as to the best course to follow in this crowded region of the spectrum.

An excellent band has been allocated at 73–74.6 megacycles. The next octave below contains a band 40.66–40.70 megacycles, that would be much more useful if it were wider. At still lower frequencies, there are no wide bands allocated, because of the tremendous complications presented by the present heavy use of the spectrum below 25 megacycles. The guard bands of the standard-frequency bands are supposed to be kept clear. While some useful observations have been made in these narrow channels, there is still too much unauthorized transmission in these bands.

II. FREQUENCIES FOR SPECTRUM LINE OBSERVATIONS

The only natural spectrum line detected so far is the 1420.4 megacycles (21.1 centimeters) hydrogen line, for which an excellent band, 1400–1427 megacycles, has been allocated. Failure to detect the 327.4 megacycles (91.6 centimeters) deuterium line so far weakens the case for an allocation, but the special arrangements which have been made on occasion with the appropriate Government agencies has been of definite help when searches have been made. Other attempts to detect the line should be made, and similar arrangements will prove valuable in the future. The OH radical should be detectable, and dockets 14475 and 14477 include a band (1664.4–1668.4 megacycles) that should be useful. Only a secondary allocation is provided, but until definite detection is announced, this should prove sufficient.

Other lines exist in the radio spectrum, and when we feel that there is a definite chance of their detection, we shall be happy to notify the FCC, IRAC, and other appropriate agencies, of the bands in which these lines fall.

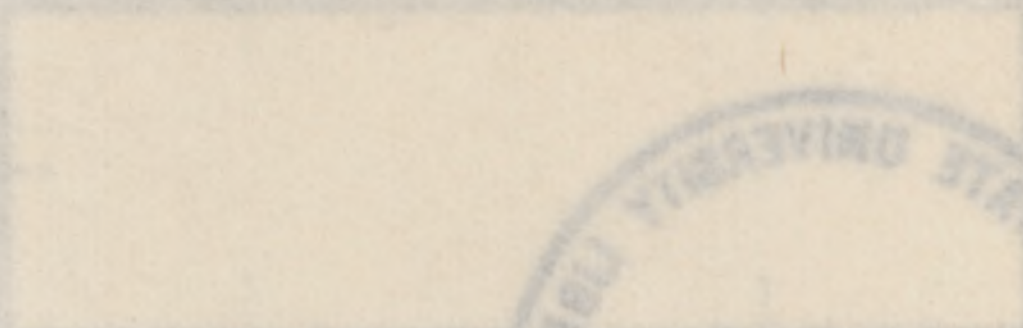
The subcommittee will be pleased to provide additional information, if it is needed, and its members, individually and collectively, have expressed their willingness to provide their services whenever such help is needed.



THE HISTORY OF THE
CITY OF BOSTON
FROM THE FIRST SETTLEMENT
TO THE PRESENT TIME
BY
JOHN B. BOWEN
OF THE CITY OF BOSTON
IN TWO VOLUMES
VOL. I.
BOSTON: PUBLISHED BY
J. B. BOWEN, 1822.

The history of the city of Boston, from the first settlement to the present time, is a subject of great interest and importance. It is a city of great antiquity, and has been the seat of many of the most important events in the history of the United States. The city was founded in 1630, and has since that time been a center of commerce and industry. It has been the site of many of the most important battles and events in the history of the United States, and has played a prominent part in the development of the nation. The city is now one of the most important and prosperous cities in the United States, and its history is a subject of great interest to all who are interested in the history of the United States.

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