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NUCLEAR SPACE PROGRAM: ORGANIZATION AND PLANS

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Ladies and Gentlemen:

The subject that I am discussing today is broad and the time available is short. I will, therefore, be able to cover only the major points that define the organization under which space nuclear systems developments are being carried out, the operating philosophy of that organization, improvements that are being made, and improvements still required. I will then describe where we stand today in these technical program areas; what our plans are for the immediate future as a logical extension of our current status; and where we go from here in the longer term future.

ORGANIZATION

The organization that I headed until June of this year and with which many of you have been familiar for some years is shown in Figure 1 (SEPO-1). The Nuclear Systems and Space Power Division in NASA is responsible for NASA's program of nuclear electric power development work. This includes such items as the SNAP-8 power conversion system, its integration with the reactor being developed by the AEC and development of more advanced conversion equipment. Work on vehicle technology that would be needed for nuclear rocket propulsion systems, development of solar and chemical power and electric propulsion are also included in this Office. Nuclear rocket propulsion work is carried out, with all the elements shown, in the joint AEC-NASA Space Nuclear Propulsion Office (SNPO) which was established in August of 1960.

In June of this year the AEC established a revised organization of its space activities which is added to these previously existing organizations in Figure 2 (SEPO-2). The Space Nuclear Systems Division includes the work of SNPO and the Space Electric Power Office (SEPO). The Space Electric Power program includes the isotope power work, the SNAP reactor power work and advanced reactor electric power systems including the liquid metal cooled reactor work in the Lawrence

Radiation Laboratory at Livermore, the boiling potassium reactor (the MPRE) at Oak Ridge, and the gas-cooled reactor work (710 reactor) at General Electric. In addition, this organization is responsible for developing thermoelectric conversion and dynamic conversion systems technology. The only change made in the previously existing organizations (SNPO and Nuclear Systems and Space Power) as a result of this latest organizational change is the addition of the Commission's isotope heated thruster development to the SNPO responsibilities.

This recent organizational change brings all of the AEC work on space nuclear systems together in the Space Nuclear Systems Division. Furthermore, it brings all of the AEC and NASA work on space nuclear systems together in such a way that the work is conducted in a collaborative way. The current and planned program activities are reviewed and discussed by all of the responsible NASA and AEC people, drawing on the talents of both agencies including their laboratories. Although this organizational chart does not reveal the similar coordination and cooperation with the agencies in the Department of Defense, such cooperation does exist through the close working level relationships that have been established over the years. Air Force personnel assigned to the AEC add to the effectiveness of that cooperation and the existing NASA and Department of Defense coordination groups - particularly

the Aeronautics and Astronautics Coordinating Board panels - help to assure close cooperation in this nuclear systems area.

Because it is the only new element of this over-all organization, the AEC's Space Electric Power organization is shown in Figure 3 (SEPO-3) in somewhat greater detail. The organization has three major elements: isotope power systems, reactor power systems, and aerospace safety development. This points up one recent change made within the past two weeks when responsibility for aerospace nuclear safety directly applicable to the space power systems development work was transferred from the Reactor Development and Technology Division to the Space Nuclear Systems Division. Much of that work is under the direction of the Sandia Corporation and it will continue to be managed in that way.

AEC Representatives at Mission Centers

To assure that the user agencies are fully aware of the progress of particular developments required for their missions and that these developments are closely integrated into the spacecraft development, we have taken another step to substantially improve communication and working arrangements. The Space Mission Project Manager must be sure that he has a direct source of information and control of every part of the spacecraft system, including the nuclear power

system. We have, therefore, decided to assign AEC personnel to the NASA and DOD mission centers responsible for mission execution when specific mission assignments are made to particular nuclear power systems. These AEC personnel will report to the Space Nuclear Systems Division and will be responsible for the development of that particular nuclear power system using the capability existing in the AEC Headquarters' organization, operations offices, and laboratories. The AEC man will also report to the spacecraft project in the mission center.

We have already assigned an AEC man, Mr. Charles Baxter, formerly of the AEC New York Operations Office, to the Goddard Space Flight Center to become part of the Nimbus Project; he will report to the Nimbus Spacecraft Manager and have responsibility for the development of SNAP-19 for Nimbus. While there he will be available to assist the Goddard organization in evaluating the possible use of isotope systems for other space missions. His prime responsibility is, however, SNAP-19 for Nimbus. Similar arrangements are being made for assignment of an AEC man to the Manned Spacecraft Center in Houston to work on the SNAP-27 for the Apollo Lunar Surface Experiments Package (ALSEP) that I will discuss later. As DOD requirements firm up, I would expect that similar arrangements will be made to place AEC personnel at the Space Systems Division or other DOD locations responsible for particular missions that are defined.

I believe the need for such an organizational arrangement is apparent. The subsystems that must go into a spacecraft to make its operation fully successful must be so closely interrelated, their operating characteristics so closely integrated, that changes to any one of them may have a significant effect on any other subsystem in the spacecraft. Further, the mission launch date depends on every component of the spacecraft; schedule charts and management controls must be established on a uniform basis for all subsystems. Only by close and intimate working relations can such coordination be assured. The assignment of an AEC representative will help to provide such coordination and will give the NASA or DOD mission Project Manager the kind of information and control that he must have to assure that his mission will be successful at the time required.

AEC Laboratory Support

Another important element bearing on the success of the nuclear systems development program is the need for detailed Governmental awareness and control of the development work on space systems with close enough supervision and cognizance of the work to assure the high reliability and high quality that is required.

The Government is ultimately responsible for the success or failure of its development programs. The

Government selects what it considers it to be the contractor with the best capability to perform the work required and delegates a very major measure of authority and responsibility to that contractor; however, the Government is never relieved of ultimate responsibility for the development. This requires that the Government have adequate technical and management competence to provide technical assistance, backup technology, and general program support when development program problems appear or are anticipated, and to provide direction and guidance to the work when it is necessary to increase the probability of successful achievement of the development objectives.

Much of the technical capability needed in the nuclear power programs obviously resides in the AEC laboratories, which are large technical organizations that have deep competence in most of the disciplines involved in this work and also have test equipment that can be applied when technical problems require supplemented test activities. We are, therefore, working toward applying that competence in the isotope development program as a means of strengthening our management in this rapidly expanding area. The laboratory will, in a continuing way, provide technical assessment of the development work, direction when needed, technical assistance, quality and reliability assessment, conduct safety studies, evaluation

of long-term program needs, preliminary conceptual studies, and some level-of-effort work in advanced technological areas. I should emphasize that we will continue to rely on the broad industrial competence that has been and is being established in this area. Industry will continue to develop and provide the isotope power systems that will be needed for mission application and we will also rely on them for development of advanced capabilities in this area.

NUCLEAR ROCKET PROGRAM STATUS AND PLANS

I would like now to leave this organizational discussion and review the technical status of our nuclear programs, the activities we see for the immediate future and also for the longer-term future. I will cover first the nuclear rocket program and then go on to the nuclear electric power program.

Progress (Figure 4 - RN65-858) in the nuclear rocket program during the past year is a continuation of the achievements made in 1964. In the NERVA reactor experiments (NRX-A3) conducted in the spring of this year, a specific impulse of over 750 seconds was achieved for altitude equivalent conditions; reactor operating times of over an hour were achieved with over 16 minutes at the full power condition; two restarts and three operating cycles were achieved in the process of conducting the planned test program. Rapid startups are now a way of

life in the nuclear rocket program and are similar to those that would be required in a flight engine. The reactor tests that are still to be run in the NERVA program and in the first phase of the Phoebus program under the Phoebus-1 (KIWI sized) reactors will be aimed at getting longer operating times in reactor systems than those achieved and longer than those that are anticipated in future missions. In the Phoebus program, we will also work toward higher temperatures and power density.

Later this year we will start a complicated test series involving what will probably be the world's first nuclear rocket engine tests. The test system is shown in Figure 5 (NP065-16148). Although this will be a breadboard engine in which the reactor, turbopump, controls, and propellant tank will not be arranged in the configuration that would exist in a flight engine, the NERVA reactor engine system test (NRX/EST) will nevertheless be a self-contained, self-sustaining, bootstrap start, engine test system. That test system is being carefully analyzed, its components are being carefully tested to assure that it has a high probability of working successfully. There are, however, portions of the operating cycle that cannot be fully analyzed; analog techniques and digital techniques are limited by computer capacity and by the models that must be established to analyze the system. These tests

will provide a real check of those models and computational techniques. They will provide the experimental note of realism that is always needed to give confidence that the analysis is complete, that component and system performance, heat capacities, volumes, time constants, natural frequencies are sufficiently well simulated in the analytical model, and that they can be predicted from component tests in such a way that the model accurately integrates them into a system on an analytical basis.

This will be the first time such a system integration will be done for the nuclear rocket in a configuration capable of going beyond the first ten or fifteen seconds of startup into the power phase of operation. The first ten or fifteen seconds of startup have already been evaluated in a cold flow system (Figure 6-NP065-1622) in which no fission energy was generated. System analysis techniques were used to predict results of engine system startups in the cold flow development test systems (CFDTS). In general, the results followed the trends predicted by the analyses, however, the accuracies of these startup predictions were limited by the difficulty of predicting two-phase flow chill down characteristics and uncertainties in the torque-flow characteristics of the turbopump at low rotational velocities.

Early in 1967 we will start the next phase of engine testing when the first ground experimental engine, the XE engines (Figure 7 - NP04129-11.64), are placed in the Engine Test Stand #1 at the Nuclear Rocket Development Station in Nevada to provide continued experience on an over-all engine system - this time with the components more closely aligned into a flight configuration. This test system will also provide the technology of the complicated engine test stands with cooled structures, shielded, nitrogen inerted engine compartments, the exhaust deflector duct with its high heat flux, and the altitude ejector system that provides altitude conditions at the exhaust of the engine. Such altitude conditions are required in nuclear rocket system development, not only to provide a system test in which the space environment is simulated, but also to provide meaningful test information. The pressure required in the propellant tank will depend directly on the exhaust pressure level; as a result, the testing of nuclear rocket engine systems with propellant tankage similar to that which would be required in flight requires an altitude exahust system if the design tank pressure is not to be exceeded. Engine tests could, of course, be run at high tank pressure. However, even in that case, the concern is that real operating characteristics associated with lower tank pressure and the increased possibility of pump cavitation

would not be possible without suitable altitude exhaust conditions. The down firing engine test systems will therefore provide facility technology information for nuclear rocket development, in addition to engine system information.

Now for the longer term future - where do we see the nuclear rocket program going? We have been able to define a single engine system and, even further, a single propulsion module (Figure 8 - NP065-15278) made up of a nuclear rocket engine and its associated propellant tankage having a thrust level between 200 and 250 thousand pounds that could perform all of the missions that we foresee for nuclear rockets. These missions include direct flight lunar landing missions, deep space unmanned space missions, and manned planetary missions. In the manned planetary missions, this propulsion module would be used in clusters for the earth departure stage and in single modules, for the planetary orbit and earth return stages. It would be used singly in the lunar and unmanned missions. This single propulsion module therefore offers a development goal for our program that is as independent of the particular mission definition as possible, that aims at a broad class of future missions, that would extend the useful mission capabilities of the Saturn V vehicle, that would utilize the technology that is already available and being developed through the KIWI, NERVA, and Phoebus reactor

programs, that could utilize the development capabilities already existing in the program. Therefore, as the NERVA technology work phases out with the completion of the NERVA reactor experiments and NERVA engine system tests that I have already mentioned, we foresee phasing over into the development of the NERVA nuclear rocket engine, having a thrust of 200,000 to 250,000 pounds using reactors designed for four to five thousand megawatts.

A pacing element in conducting such an activity is the need for facilities to permit the testing of such engines. It is important in this regard to recognize that in the nuclear rocket program all power testing will be done in Nevada and the facilities available to the country must be provided by the Government. We cannot utilize, for nuclear power testing, the many, many test stands available throughout the country at various contractor installations for the development of chemical rockets. Therefore, if the country is to have any capability to develop nuclear rockets it must provide the necessary facilities in Nevada. The first step toward achieving those facilities is now being taken. We have selected Kaiser Engineers to conduct a study of the engine test stand complex that would be needed for development of this large engine system and that would also be suitable for testing the entire propulsion module and stage at these thrust levels. This study will define these facilities well enough that we may have a more

realistic estimate of their cost, their complexity, their configuration, and the schedule of their development.

I should emphasize that a commitment need not be made to fly such a large NERVA engine at the time we initiate its development. We still intend to include in our program planning technical restraints that would pace each successive element of our program by required technical accomplishments in the early portions of the work. All of the work undertaken would be required for a program leading to flight, however, there is no need to make a commitment to develop a flight stage or a full propulsion module at the same time that we undertake development of the large NERVA engine.

In order to reduce costs in the nuclear rocket program, we have decided to close one of the reactor test facilities, Reactor Test Cell A, at the Nuclear Rocket Development Station. This is the cell that was used for most of the KIWI reactor testing and has been used for the NERVA reactor testing. It will also be used later this year for the NERVA reactor engine system test. After tests of the NERVA reactor (NRX-A5) to be conducted next spring, we will close Test Cell A and conduct all of our reactor operations in Test Cell C. This will indeed complicate our scheduling; however, we believe that we will be able to cope with that problem, and the reduction in costs that would be achievable justifies the added complication of conducting operations in a single cell.

NUCLEAR ELECTRIC SYSTEMS

I would like now to move on to the development of nuclear electric power systems. Although there is much that remains to be done, the four flights that have been conducted to date of isotope power systems in Navy satellites (Figure 9 - SEPO-4) and the flight of the SNAP-10A reactor - thermoelectric power system (Figure 10 - 7561-02931) demonstrate clearly that nuclear electric power systems can be used in space, that they present no mysterious problems associated with their use, that they can be developed in ground test facilities using environmental test procedures common to the development of any of our space systems, and that they can be reliable.

More important than almost any other result of its flight, the SNAP-10A reactor system flight demonstrated that the operating characteristics of such a system in space can be duplicated in ground test facilities. The system started up after its launch in April of this year and operated for 43 days, almost exactly as it had in ground vacuum facilities. Its shut-down after 43 days of operation came suddenly and unexpectedly. Failure mode analysis and ground testing, which will be described later in this session in more detail, have indicated that the most probable cause of the shut-down was a sequential failure of electronic components in the spacecraft initiated by the failure of a voltage regulator. The exact cause of failure of the voltage regulator cannot be absolutely and finally identified, but the ground testing has demonstrated that a

sequence of electronic component failures which would result from high voltage would completely explain all aspects of the sudden shut-down of the SNAP-10A system in flight, the delay in telemetry transmission after shut-down, and the data that finally were received.

I believe that these isotope systems that have already been used in space and the SNAP-10A flight should serve as ample proof to mission planners that nuclear systems can be relied upon. What is required, however, is continued development of these systems so that they are demonstrated to have high reliability with minimum performance degradation over the long operating times desired. This will require a thorough and extensive ground development program that includes evaluation of all components, full system testing, and a thorough understanding of all phenomena encountered.

Isotope Power Systems

It is clear in looking ahead in the space program that the isotope systems will play a major role long before any of the reactor systems are brought into useful service. SNAP-19 is now being developed as an experimental power source on the Nimbus-B mission (Figure 11 - RN64-2004) which is scheduled to fly in 1967. Two of these SNAP-19, thirty watt, plutonium-238 fueled isotope power units would be flown in Nimbus as shown in the figure. A major effort in this development is associated with the assurance of safe operation under all normal and abort flight conditions. The current plans are that this system be burned

up on re-entry in a manner similar to the burn-up approach used in the SNAP-9A units that were flown in Navy satellites. Current planning calls for the plutonium fuel to be dispersed in a particulate form that would cause no biological hazard.

Another major program already under way is the development of the SNAP-27 system. This SNAP-27 unit will deliver 50 watts and will be fueled with plutonium-238. As indicated in the next figure (Figure 12 - SEPO-5), it will power the Apollo Lunar Surface Experiments Package (ALSEP) that will be placed on the surface of the moon by astronauts in early Apollo flights. No other power system is being developed for this application and the three study contractors now working for NASA on the design of the experiment package have been instructed to mate their experiments with the power system. For the first time, therefore, a space payload and an isotope power supply are being designed concurrently to fit each other rather than trying to integrate the isotope power system into an existing spacecraft. We certainly hope and expect that the future will see more spacecraft developments that take this approach and make early commitment to the isotope power supplies.

SNAP-27 is also the first isotope power development program that incorporates all of the management control procedures, reliability apportionment and assessment procedures, quality assurance, detailed environmental testing, flight qualification

testing required to assure that the product delivered will operate as intended with the high probability of success required. The one weakness in this program is the short time available for the development. This one weakness, I believe, demonstrates the importance of proceeding into development of advanced hardware before firm mission requirements must be specified.

In order to meet the schedules that are required, the design of the flight qualification units must be frozen at about the same time that the development test systems become available for test. The only data that will be fed from the development program into these flight qualification units will be component test information. The full system test information will not be available until the flight qualification units are available for test. This is required to meet the schedules that have been specified. It is not a desirable approach and it would obviously be more desirable if system development testing could be done in advance of commitment of the flight qualification units to full fabrication.

It is important, therefore, that as we plan our future program - not only in the isotope power area, but in all of the advanced technology development areas required to assure the capability to perform future space missions - advanced hardware be developed far enough that the lead time remaining for completion of that development for a particular mission application fits, in a sound technical way, within the lead time required for the development of the total mission.

There are still some items that have not been firmly defined in the ALSEP power supply and in the ALSEP mission. A decision must still be made on whether to install the fuel capsules into the power unit at launch or to carry the fueled capsules in the spacecraft and install them into the power unit on the surface of the moon. This decision has not yet been made. It indicates how details of mission requirements can significantly effect the design of the power system. This decision may very well be determined from a mission operations viewpoint on the basis of giving the astronaut the greatest flexibility and safety of operation and it will obviously affect the handling of the isotope during launch and during the flight to the moon.

In addition to these missions that are firmly committed to the use of isotope power we are conducting systems studies, as initial phases of development activities, of a 250-300 watt generator that would be fueled with plutonium-238 or, if it is determined to be feasible in ground checkout and safety assurance, strontium-90; we are also working on a higher powered polonium-210 fueled generator design study requested by the DOD that may have applicability in a wide range of NASA and DOD manned missions, such as advanced manned applications where logistic requirements would permit the refueling of the power supply. Isotope power is also being considered in substantially higher power levels. Specifically, we are studying kilowatt size isotope heat sources that could generate from one to ten electrical kilowatts,

depending on the power conversion system available. The isotopes being considered are plutonium-238, curium-244, and polonium-210. We are also initiating technology development work on isotope-thermionic units. All of these development activities are aimed at assuring the availability of power when the needs develop.

It is clear that more and more mission planners are considering the use of isotope power in their spacecraft and are becoming familiar with its capabilities. Air Force organizations including the Space Systems Division, the Navy's Applied Physics Laboratory, the NASA Centers at Houston, Goddard, Langley, Marshall, Ames, and Lewis, are all involved in evaluating, and some, in testing isotope power systems. As a result of a recent expression of interest, instruments from Ames' Pioneer spacecraft will be set up next to a SNAP-19 generator at the AEC's Lawrence Radiation Laboratory to determine the sensitivity of these scientific experiments to the radiation levels emitted by an isotope power supply. Pioneer type solar probes appear to be logical users of isotope power.

As a result of the potential needs that we foresee in the isotope power area, the isotope program in the Space Nuclear Systems Division has grown from about $3 million that was spent in FY 1965 to over $8 million in the FY 1966 budget. Along with this increase in emphasis on isotope power system development it has become clear that increased activity is needed to assure that fuel forms are available for use over the range of temperature,

power, and life that will be required in these systems. As a result we have indicated the importance of rapidly pursuing a technology development program that would provide higher temperature fuel forms for application with high temperature thermoelectrics, thermionics, Rankine and Brayton cycle systems. In essence, the isotope fuel program must be considered comparable in difficulty and complexity to the work that has been required to develop reactor fuel elements and fuel element materials. Compatibility with the clad materials, with coolants used, and with the environmental conditions to which the capsule may be exposed over operating times of tens of thousands of hours will be required.

In considering the isotope power area it is important to recognize that there are many variables involved including the type of isotope, the type of conversion equipment, the safety criteria to be established, the power level required, etc. Were it not for the factors of cost and availability, I believe the isotope preferred would be plutonium-238, or if we knew more about it, possibly curium-244. Because of the high cost of these isotopes there is a premium on the development of more efficient conversion equipment. It is for this reason that the country is working on more efficient thermoelectric elements, thermionic conversion, dynamic conversion equipment, including the mercury Rankine and organic Rankine systems, and, most importantly, the Brayton cycle system which offers the potential of the highest possible conversion efficiency.

Reactor Power Systems

Considering all of these factors, it is probable that the highest power to which we would go with isotopes is about 10 electrical kilowatts but power levels above 10 kilowatts will ultimately be required. For this reason, we believe we must continue to pursue work on reactor power systems aiming at the tens of kilowatts on up into the megawatt level. While doing so it should always be recognized that we are also trying to develop solar cell systems capable of going to high power (tens of kilowatts) in light weight, readily packaged arrays that can be deployed to provide the large areas that would be needed for high power application. It is clear, however, that reactor power with its independence of the sun will be indispensible for many long life, high power missions. (It should be pointed out that there is a possibility that reactors may be economically attractive for certain missions at low kilowatt power levels.)

The AEC's SNAP-8 reactor work aimed at developing a reactor having a thermal power of 450 to 600 kilowatts is continuing. The first experimental SNAP-8 reactor (S8ER) (Figure 13 - 7568-56110) was started up in May, 1963, and was shut down in April of this year, after having operated a year at SNAP-8 powers (400 to 600 kwt) with rated coolant outlet temperature. This included a single continuous run of over 200 days.

Since the shutdown, detailed examination of the S8ER fuel has revealed that about 80% of the elements have cracks in the Hastelloy N cladding. The cause and full significance of the cracking problem have not yet been fully determined, however, our investigation is continuing, and we should have a complete answer within a few weeks. Tentatively, it appears that the cladding cracks could have resulted from irradiation embrittlement of the Hastelloy clad combined with fuel swelling. We are delaying fabrication of the next SNAP-8 reactor, S8DS, until a full diagnosis can be completed and corrective action can be taken.

The NASA portion of this program, aimed at achieving 35 ekw and as much test time as possible on the Rankine power conversion system components within available FY 1965 funds, is making progress. One area of concern in all mercury Rankine systems is the inconsistent performance of mercury boilers. This has been referred to as the problem of conditioning mercury boilers or the failure to produce the required superheat. Once they are conditioned, they sometimes become deconditioned. Work is underway now to determine the effectiveness of extreme cleanliness in the mercury loops and of various design parameters on the performance of the boiler. Obviously it is necessary that the boiler provide the required performance consistently and that there be no erratic operation if we are to achieve the high reliabilities that are required for any space system.

Funds have been provided by the Congress in the NASA FY 1966 budget which could be used for continuing the NASA portion of the SNAP-8 program. However, no firm decisions have yet been made regarding such continuation. Furthermore, such decisions would depend also on the actions to be taken in regard to the FY 1967 budget. Continuing the program in 1966 would obviously require a continuing effort in 1967 and beyond.

There have also been suggestions for combining the SNAP-8 reactor with thermoelectric elements to provide higher powers than could be delivered by isotope systems. The work underway in the AEC on thermoelectric conversion of either the direct radiating type used in SNAP-10A or of the compact thermoelectric converter type designed to operate at the 1300°F. temperature capability of SNAP-8 could produce about 15 kilowatts of electric power. Such a system would have an overall efficiency of perhaps as high as 4%. It is, however, not necessary to develop such a system now since the major components - the reactor and the thermoelectric subsystems - are under investigation and the SNAP-10A itself provided verification of the overall operating capabilities of such a system. If mission requirements for such a system developed, we could then undertake the overall system development.

Powers higher than the tens of kilowatts will require more advanced reactor power systems than those that could be provided

using the zirconium-hydride reactor technology and mercury Rankine or thermoelectric conversion equipment. We should certainly anticipate the eventual need of hundreds and perhaps even thousands of kilowatts for powering orbital laboratories, lunar and planetary bases, and deep space communications systems. In addition, if deep space, high payload, electric propulsion missions, such as those that would be required to carry men to the more distant planets is to be realized, we will need megawatts of electrical power in extremely light-weight power supplies. The country is now carrying on an advanced technology development effort aimed at providing such power systems. We do not yet know that we can achieve the performance goals for these systems.

The liquid metal cooled reactor work being undertaken at the Lawrence Radiation Laboratory as a follow-on to the SNAP-50 work is directed at trying to determine how to build the highest temperature reactor system that could lead to high power in the lightest weight and longest life package. Such reactors could be used with Rankine cycle conversion equipment, high temperature Brayton cycle equipment, or, if thermionic element power density increases significantly at reduced temperatures, with out-of-core thermionic devices. Work on thermionic devices for in-core reactor applications has been proceeding well and is now beginning to accumulate significant operating time in inpile testing. Studies are required and will be undertaken to evaluate the reactor characteristics for

various concepts that would utilize the thermionic cathode as the fuel element. These advanced reactor concepts are suitable for both the auxiliary power and the electric propulsion needs. They do offer the potential of low weight and the thermionic systems offer the added desirable feature of small radiator size.

In addition to these systems, we are continuing work on a gas cooled reactor which could be combined with a Brayton cycle system to provide power in the hundreds of kilowatts. This inert gas system offers an alternate power generating capability that may be inherent in liquid metal and metal vapor systems. We are also investigating a boiling potassium reactor that may also offer some advantages in this power range. Studies are underway to determine the growth capability of such a system.

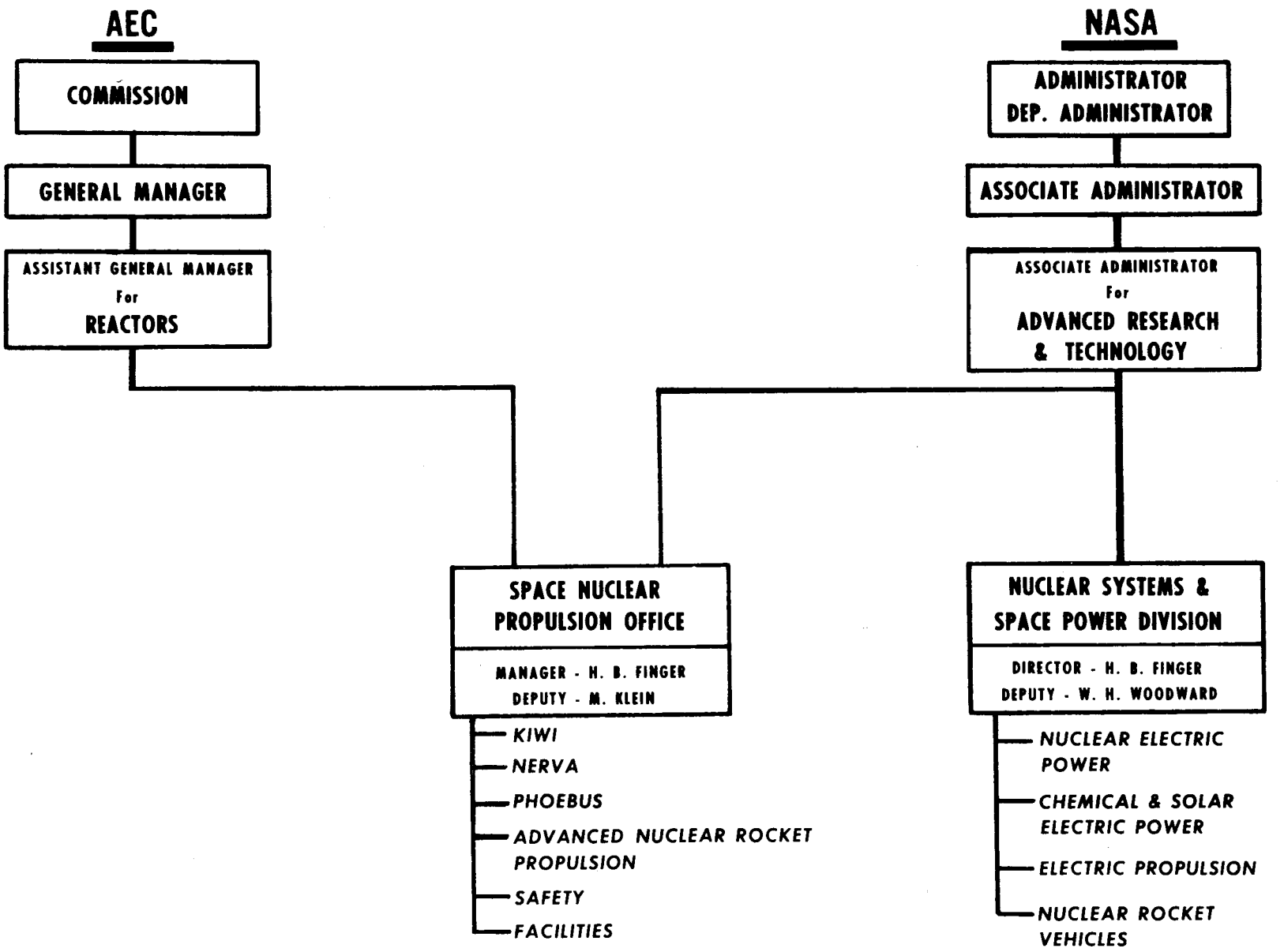
The lead-time for the development of all of these advanced nuclear reactor systems is long; the feasibility of developing them to their advertised or potential performance characteristics is as yet uncertain and undemonstrated; the real advantages of one system over another cannot now be predicted with assurance and the paper calculations cannot be considered sufficiently factual to justify narrowing down to one of them. It is necessary to work on several of these concepts but studies are underway to try to develop a factual comparison rather than a sales comparison that may provide a basis for some further narrowing of the concepts being investigated.

CONCLUDING REMARKS

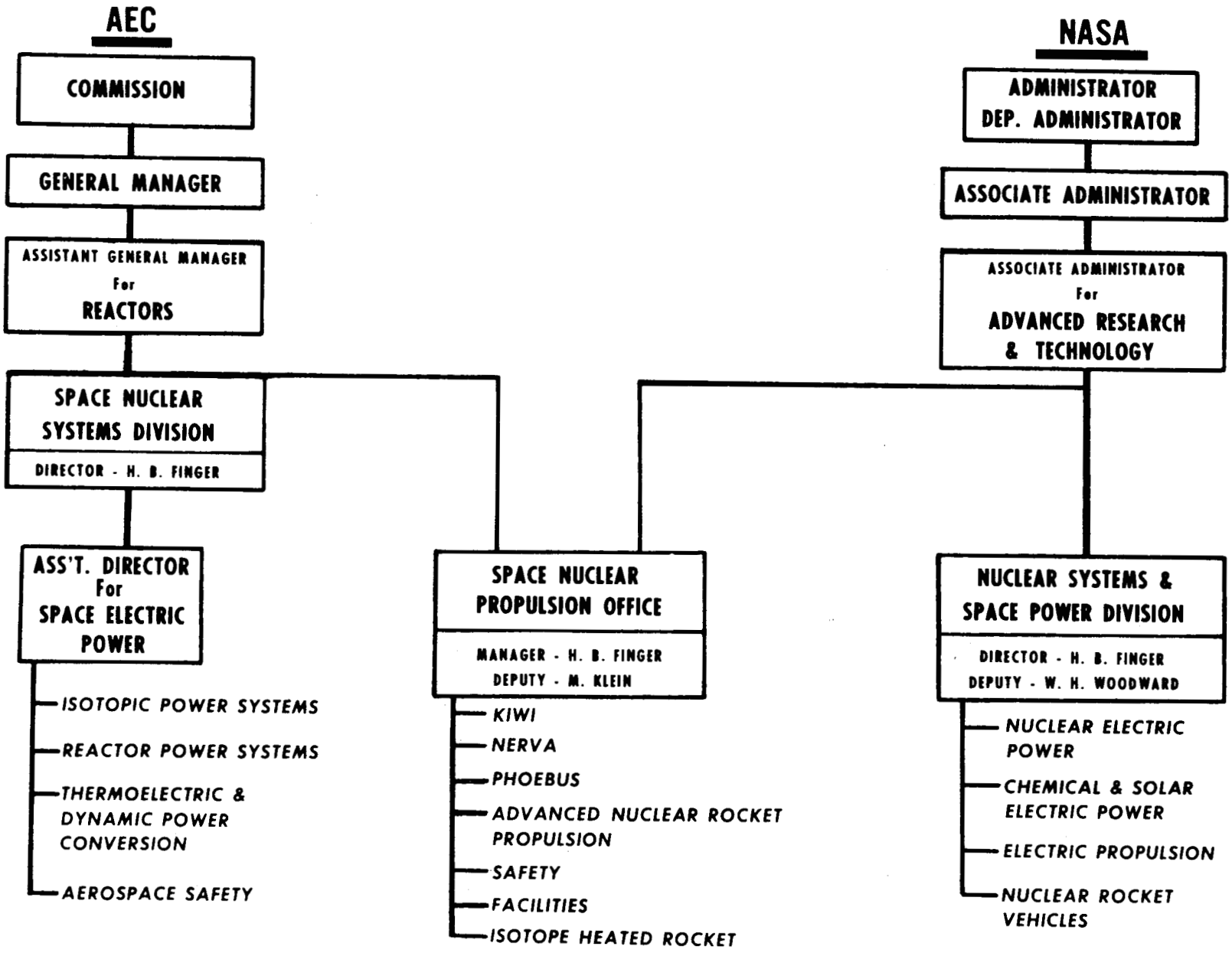
As you can see, this country's program on the development of nuclear systems is very broad. Very clear progress is being made in both the propulsion and in the power area. Most importantly, it is clear from the increasing interest in and commitment to isotope systems that as the mission needs indicate advantages for the nuclear power supplies, these supplies will be used in space. It is our job to be ready for those uses with established technology and with hardware that is well enough and far enough developed to satisfy the needs when they are presented to us. With the real limitations in budget that will always exist in a country that has broad needs and broad interests, we will not be able to do everything that we might like to do. We will not be able to fulfill every detailed or specific need that may be expressed, but we should be able to provide a family of propulsion and power systems that will cover the major needs that are anticipated and that will be adaptable to detailed requirements.

Thank you very much.

ORGANIZATION OF SPACE NUCLEAR SYSTEMS PROGRAMS

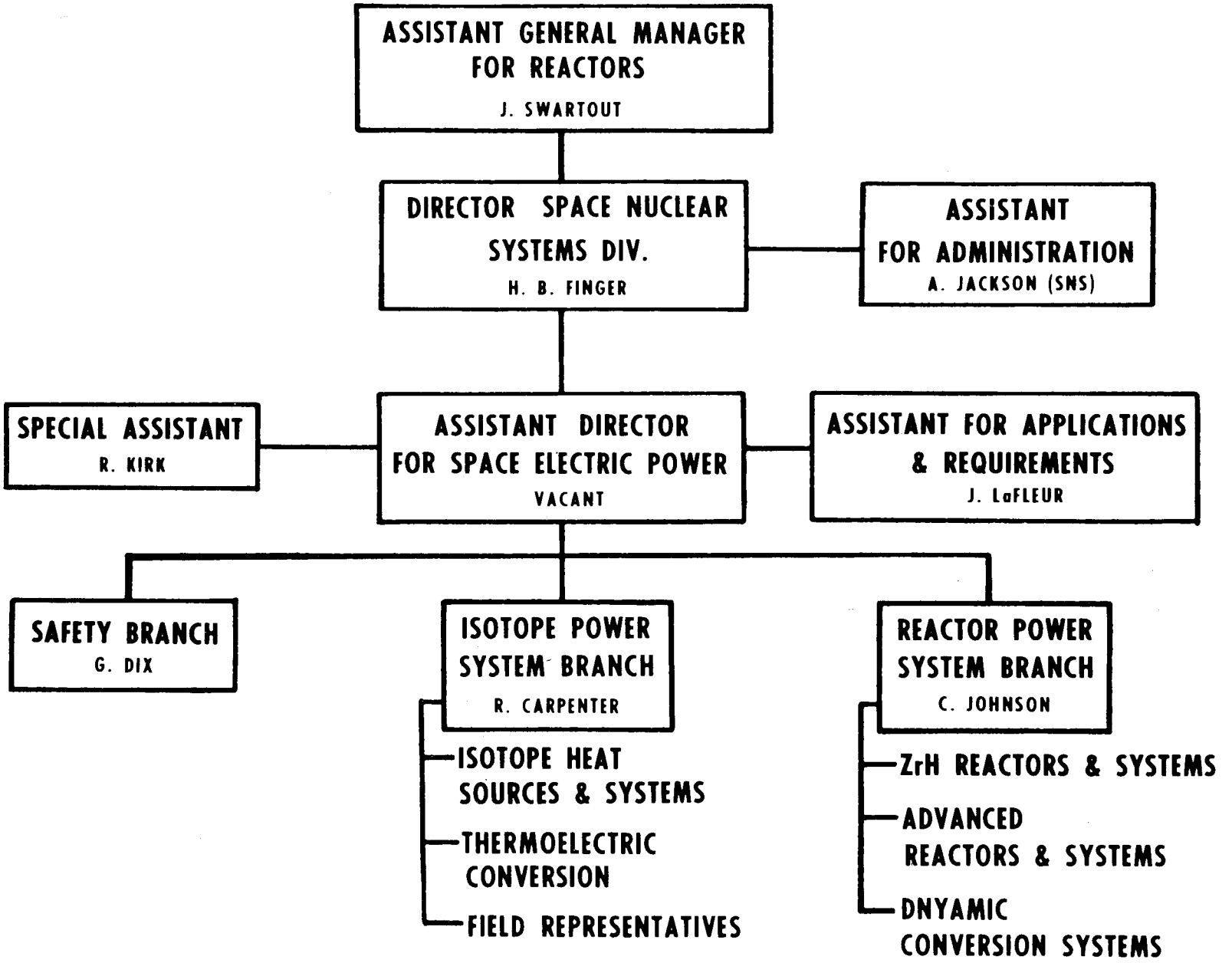


ORGANIZATION OF SPACE NUCLEAR SYSTEMS PROGRAMS



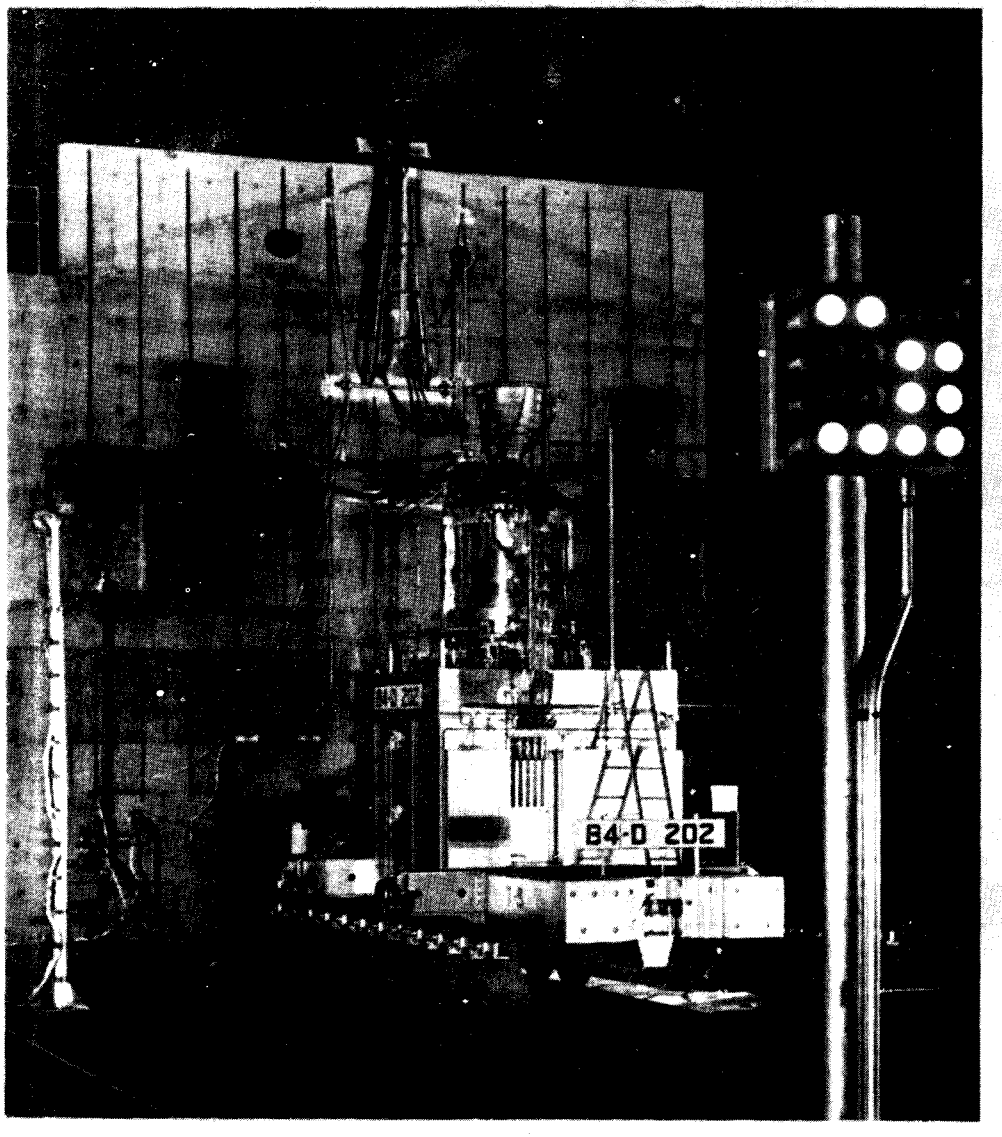
SEPO-2

SNS - SEPO ORGANIZATION



GRAPHITE REACTOR

TEST ACCOMPLISHMENTS

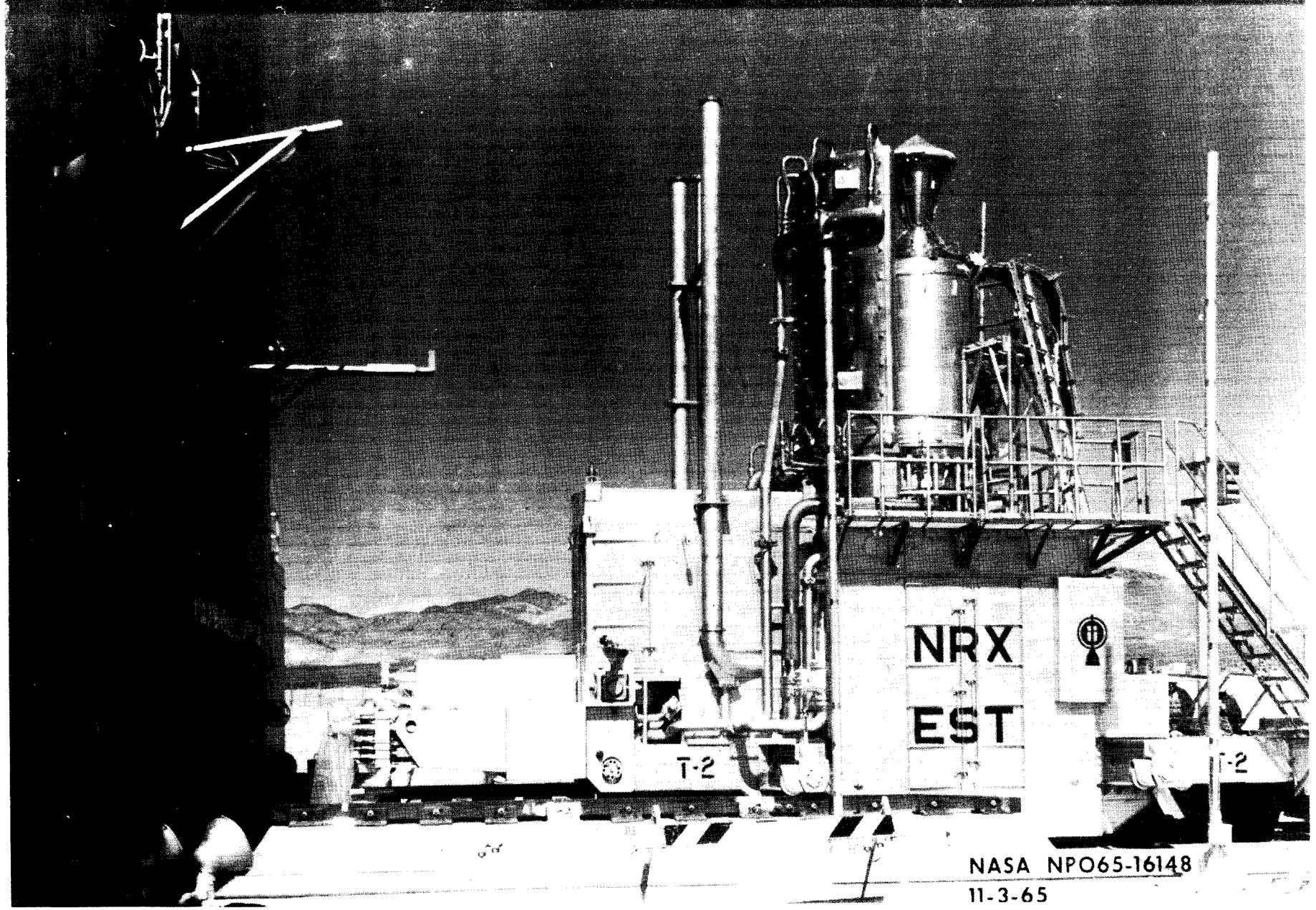


• KIWI-B4D POWER	MAY 13, 1964
• KIWI-B4E POWER	AUGUST 28, 1964
• KIWI-B4E RESTART	SEPTEMBER 10, 1964
• NRX-A2 POWER	SEPTEMBER 24, 1964
• NRX-A2 RESTART	OCTOBER 15, 1964
• KIWI TRANSIENT NUCLEAR TEST	JANUARY 12, 1965
• NRX-A3 POWER	APRIL 23, 1965
• NRX-A3 RESTART (1st)	MAY 20, 1965
• NRX-A3 RESTART (2nd)	MAY 28, 1965
• PHOEBUS 1-A POWER	JUNE 25, 1965

NASA RN65-858
REV. 7-16-65

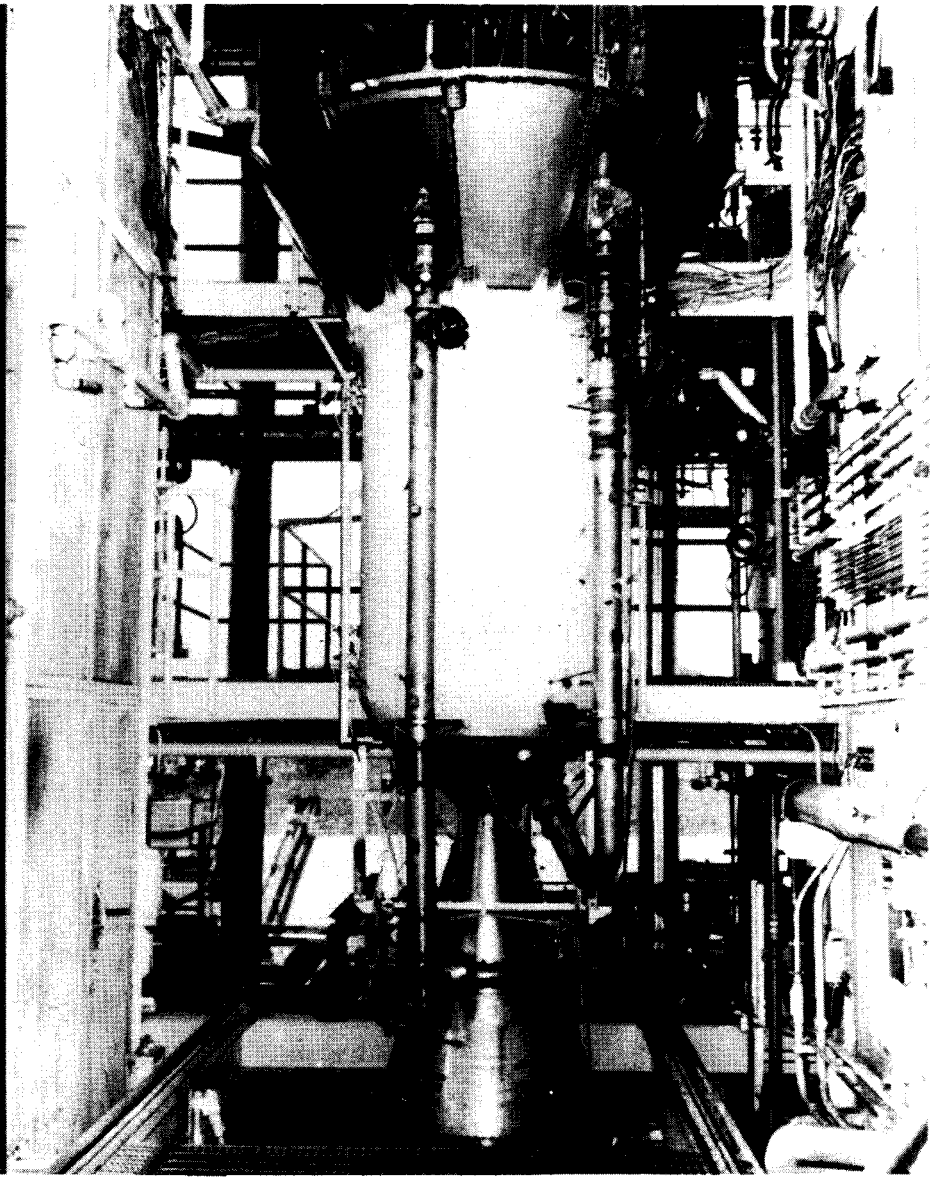
NERVA REACTOR / ENGINE SYSTEM TEST

NRX EST



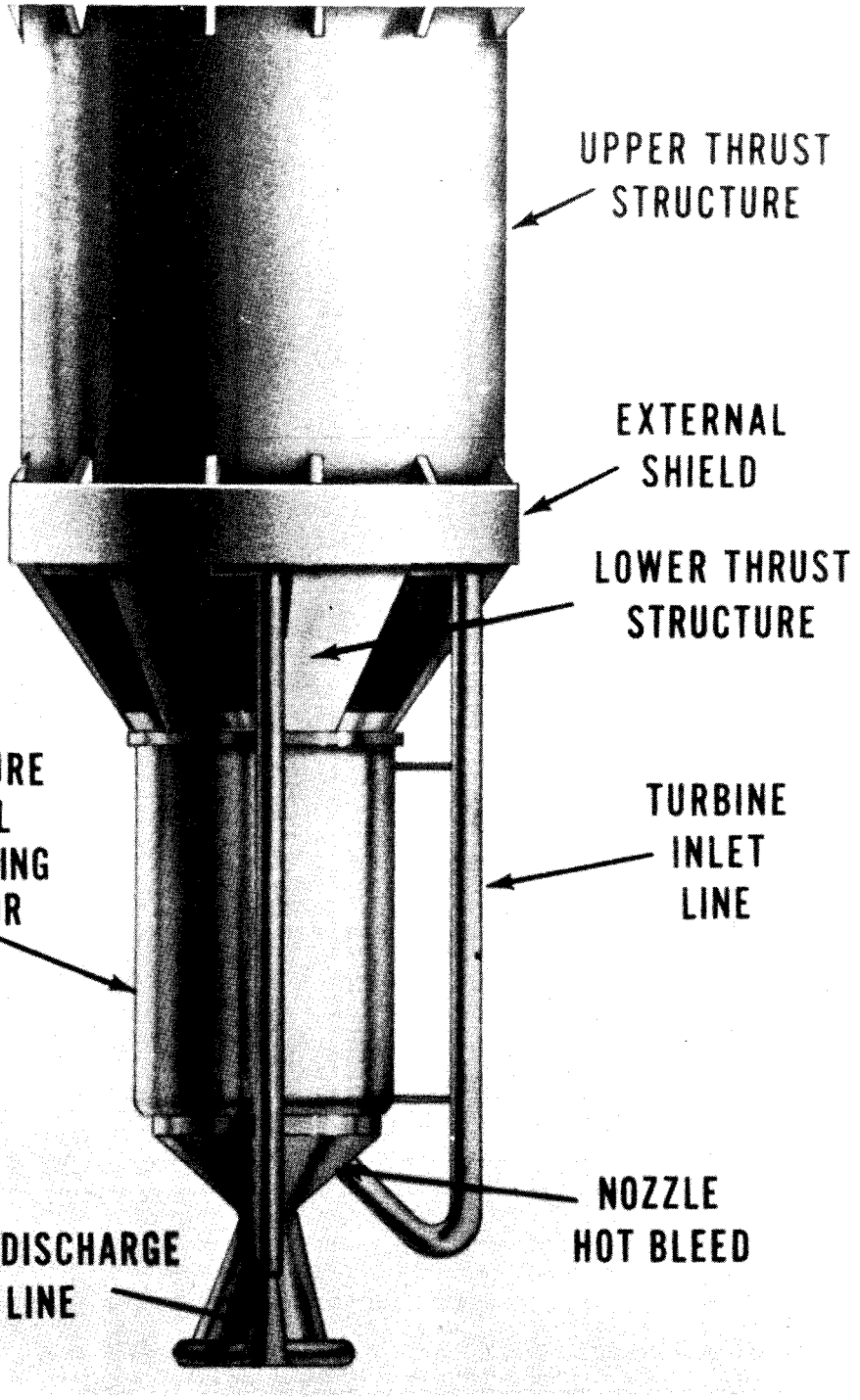
NASA NPO65-16148
11-3-65

COLD FLOW DEVELOPMENT TEST SYSTEM (CFDTS)



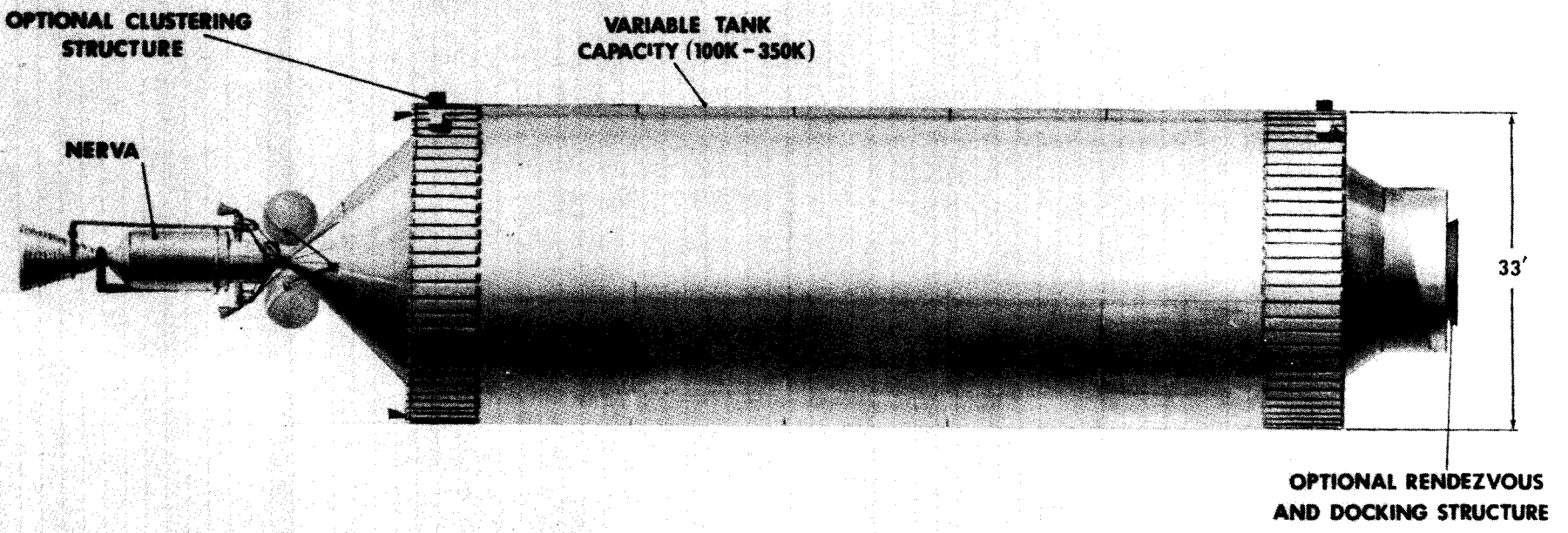
NASA NPO 65-1022
11-10-65

GROUND EXPERIMENTAL ENGINE

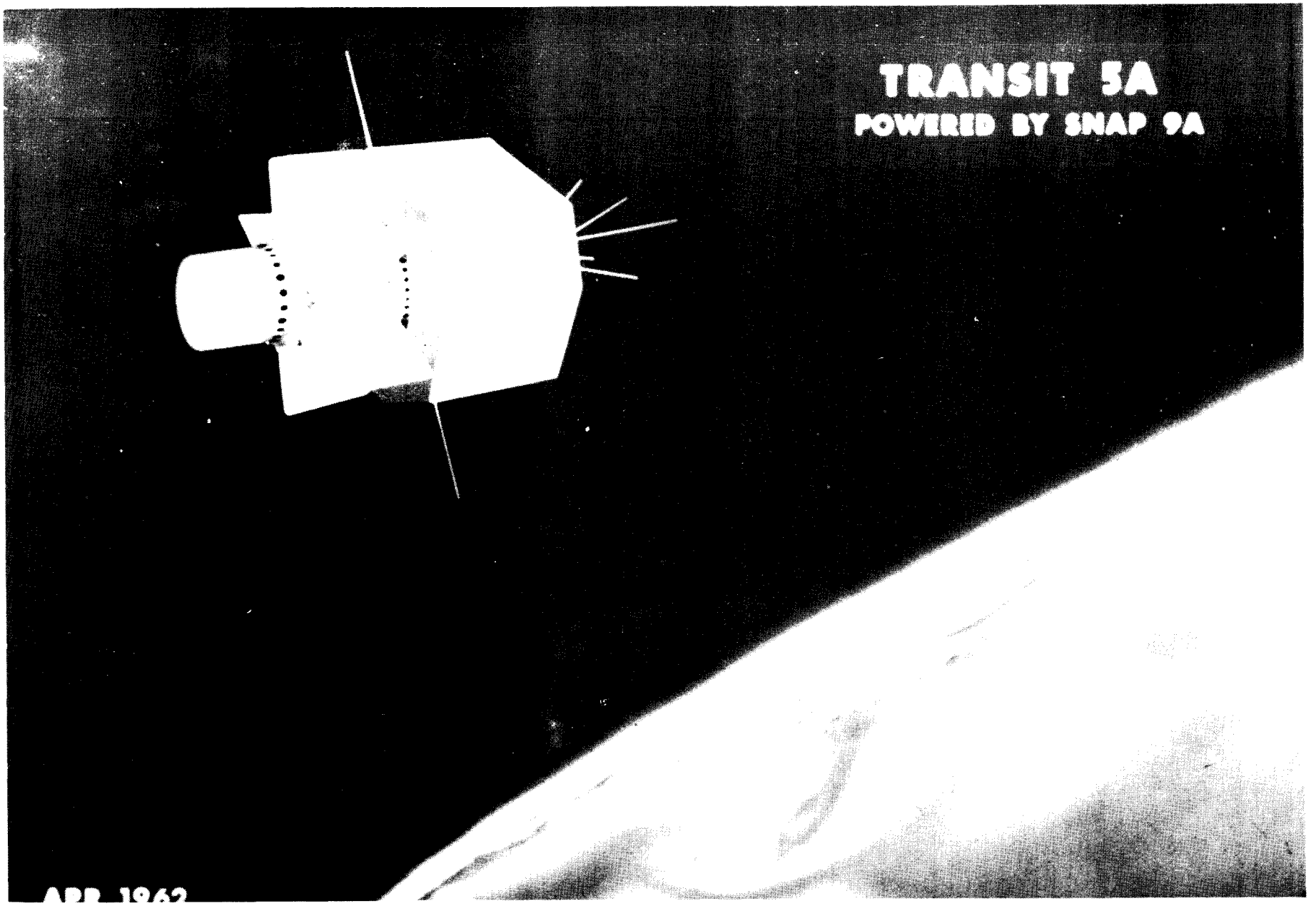


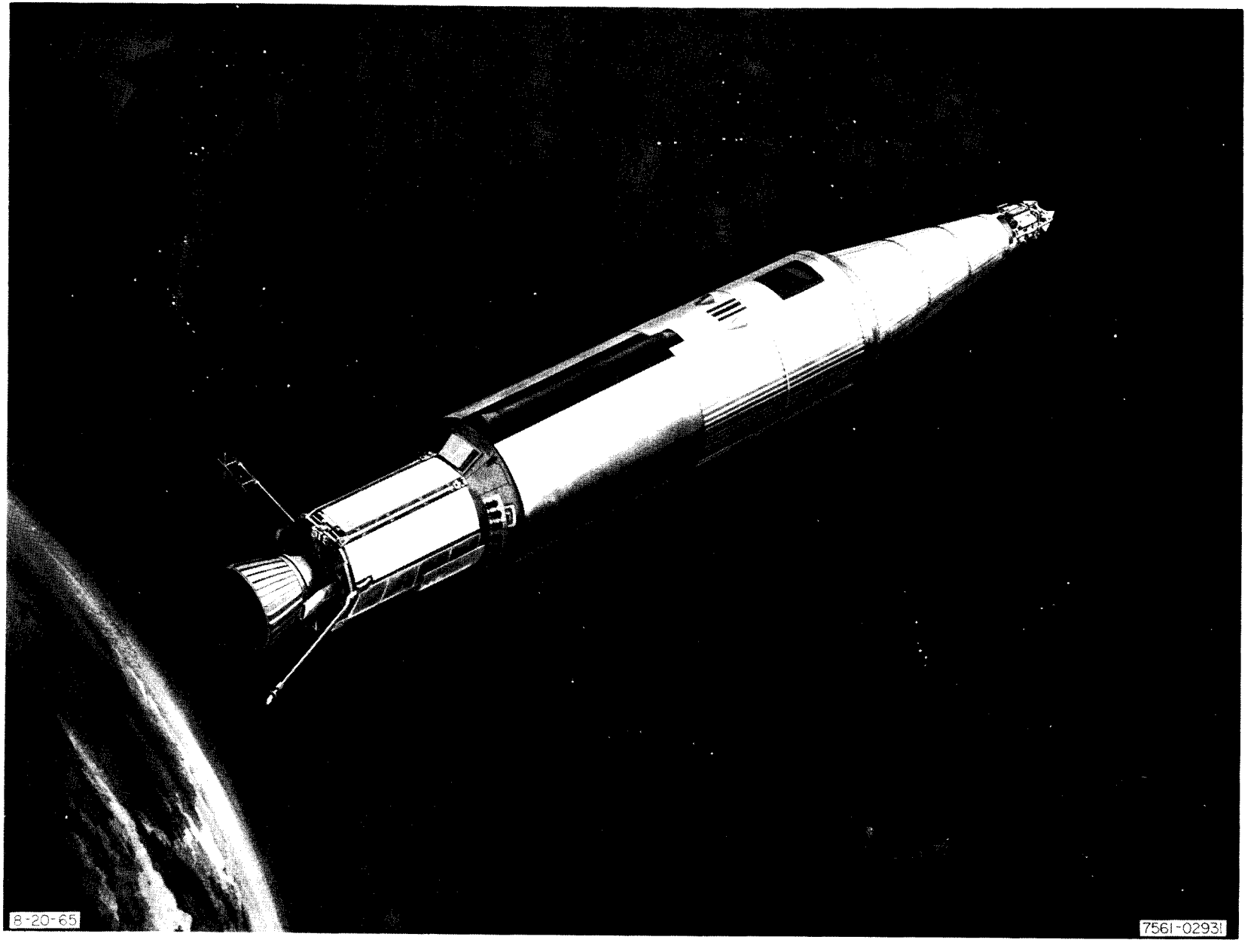
NASA NPO 4129-11.64
Rev. 2-26-65

Propulsion Module Concept



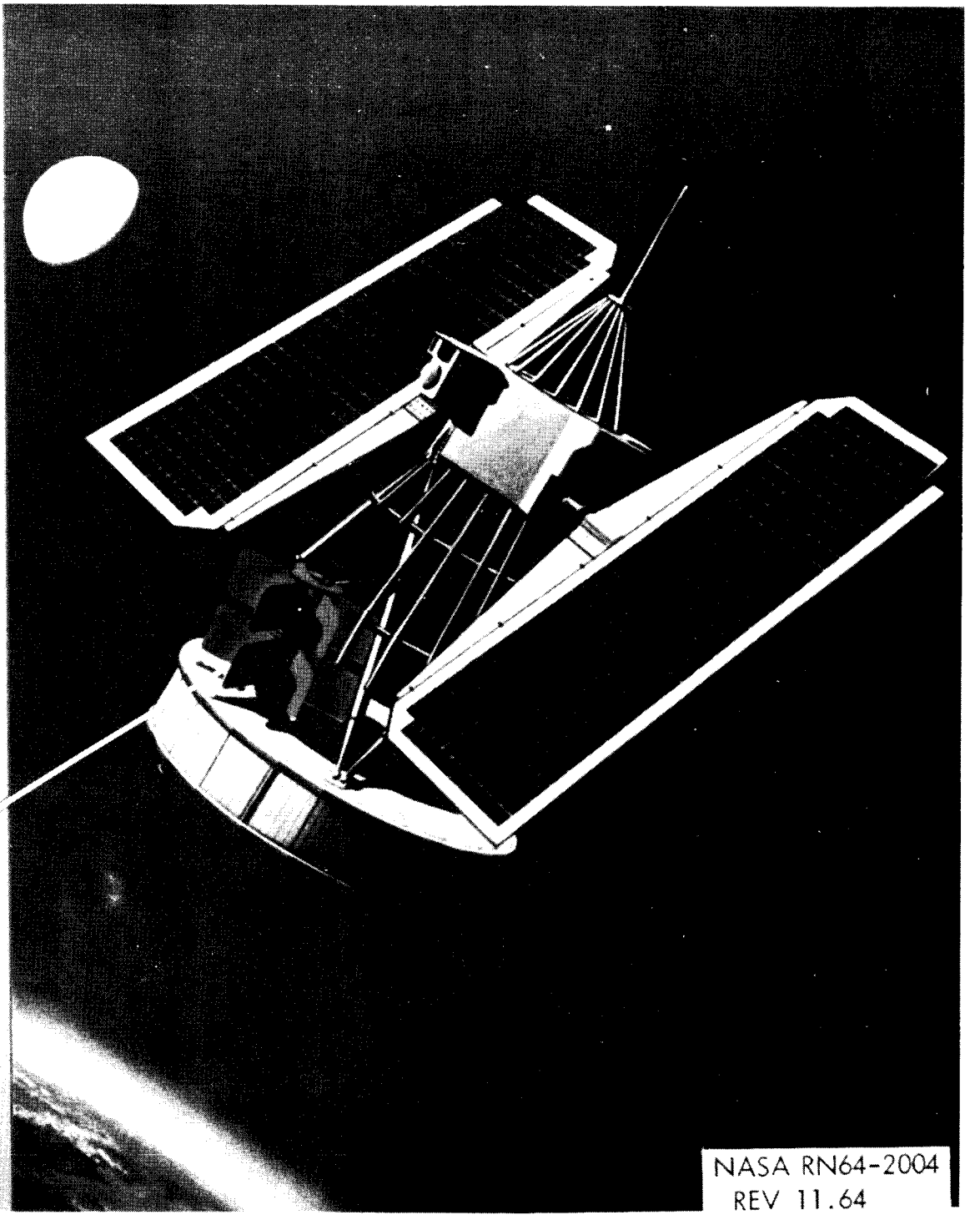
NASA NP065-15278


TRANSIT 5A
POWERED BY SNAP 9A
APR 1962

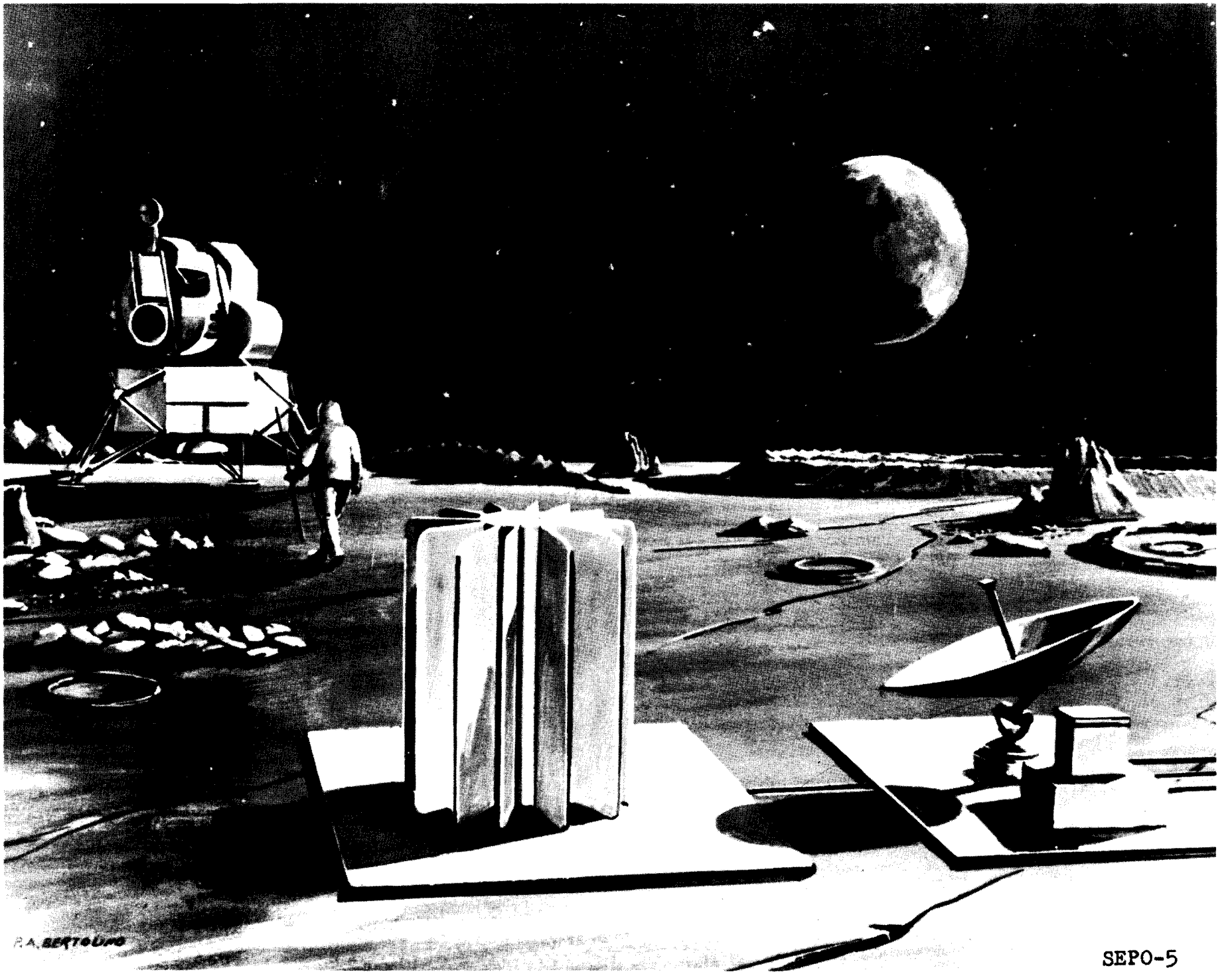

8-20-65
7561-02931

NIMBUS B

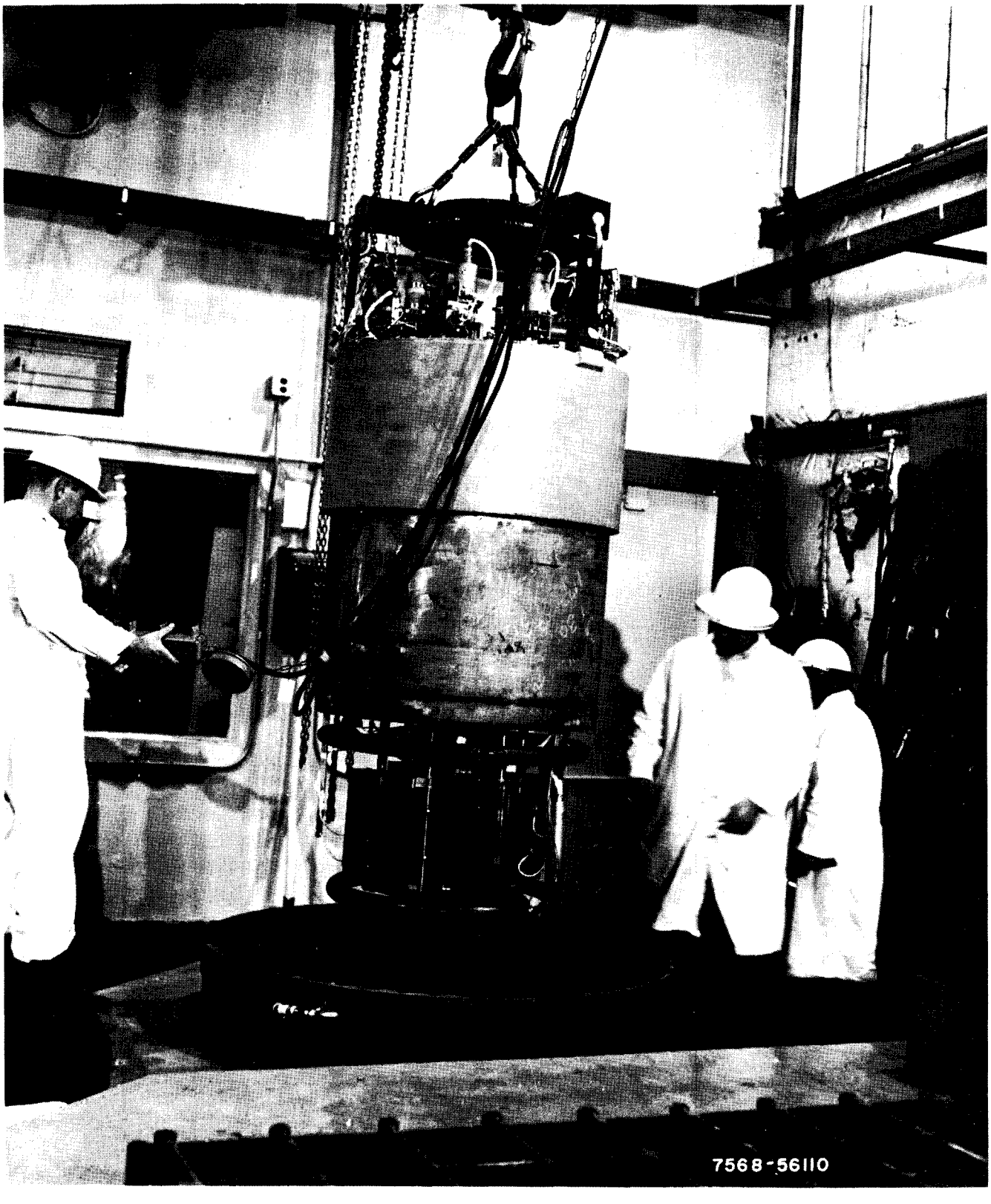
RADIOISOTOPE
GENERATORS



NASA RN64-2004
REV 11.64



SEPO-5


7568-56110