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Statement of
Harold B. Finger
Director, Nuclear Systems
Manager, Space Nuclear Propulsion Office
National Aeronautics and Space Administration
before the
Committee on Aeronautical and Space Sciences
United States Senate

Mr. Chairman and Members of the Committee:

Nuclear energy offers to the space program a source of high energy required to perform difficult, long range, high payload missions which cannot be duplicated by other systems. The nuclear systems that are receiving emphasis in our program are listed on the first chart (R62-298). They are the nuclear rocket (ROVER) system and the nuclear electric power generating systems that are to be used for providing large amounts of auxiliary electric power and also for providing the power required in electric propulsion systems. The nuclear rocket system can be used to perform heavy payload, manned, round trip missions to the moon and the near planets, Mars and Venus. The electric rocket indicates performance potential for missions even beyond Mars and Venus. Although these nuclear propulsion systems have excellent capability for difficult missions that will be required later in our space program, I must emphasize that these advanced nuclear systems could be combined with the chemical rocket launch vehicles that are now being developed to significantly increase the payload capability of these chemical rockets in

their near Earth missions. It is my purpose today to discuss our work in these areas and the mission capability that is potentially available from these systems.

I would like first to discuss our nuclear rocket program being conducted jointly by NASA and the Atomic Energy Commission. The next slide (R62-338) indicates a little more specifically the performance potential of the nuclear rocket. At the bottom of the chart is shown a conceptual drawing of a nuclear powered space vehicle which would be placed into an Earth orbit to perform a Mars manned landing mission. The nuclear space vehicle would leave the Earth orbit with a full load of hydrogen propellant. As the hydrogen was used up the hydrogen tanks would be jettisoned. The nuclear rocket would propel the spacecraft into a Mars orbit and a chemically propelled landing craft would, in this calculation, land three men on Mars. The men would then return to the orbiting nuclear propelled spacecraft using a chemical rocket to take off from the surface of Mars and the spacecraft would then return to Earth. The total space vehicle weight in the initial Earth orbit is estimated at a million pounds. This initial weight will vary significantly with the radiation doses that will be encountered during the flight and the shielding required to protect the men from this space radiation. Much more definitive information is required on this space radiation and our space sciences program is concentrating on a better understanding of it. In any case, the important point to be made here is that the performance of this mission with an all-chemical vehicle would require an initial weight in an Earth orbit about ten times the value of the nuclear vehicle weight.

A cutaway drawing of a nuclear rocket engine is shown on the next slide (R62-339). Hydrogen is pumped from the propellant tank to the regeneratively cooled jet nozzle where the liquid hydrogen is used to cool the nozzle walls. The hydrogen is then passed through the reflector portion of the reactor and on through the reactor core. The energy released by the fissioning of uranium in the reactor core heats the hydrogen to high temperature. The resulting high temperature gas is accelerated through the jet nozzle to high velocities producing the thrust that propels the vehicle. The specific impulse produced by this system could be two to three times the value possible with chemical rocket systems.

The most difficult problem that must be solved in this system is the development of a reactor which will withstand the high temperatures that are required at the imposed thermal stresses and flight loads. In addition, the system must be capable of restart and reuse for almost all of the space missions for which nuclear rockets have been proposed. There are also other difficult development problems associated with the jet nozzles, turbopumps, bearings, controls, etc. Our program is aimed at obtaining the necessary basic information, general technology, and specific hardware required for the nuclear rocket system, as well as research information required for the most advanced nuclear rocket concepts.

The major elements of our nuclear rocket program are summarized on the next chart (R62-340). Because it is the most difficult part of the nuclear rocket propulsion development our major effort has been concentrated on the research and development of the KIWI reactors. Our work

on these reactors is intended to lead to a reactor design which will be incorporated into our first nuclear rocket engine, the NERVA engine, meaning Nuclear Engine for Rocket Vehicle Application. This NERVA engine will be flight tested in the RIFT, meaning Reactor In-Flight Test, stage. Our program is aimed at such flight tests in the 1966-67 time period. In addition to this program aimed at flight testing we are conducting an advanced research and technology program on reactors that will provide higher power and higher specific impulse in a given size and weight, on turbopumps that will deliver larger quantities of hydrogen propellant efficiently over a wide range of operating conditions, on heat transfer processes and fabrication methods in jet nozzles, on advanced system concepts that will permit us to operate at temperatures above those to which we are limited with solid reactor fuel elements, and many other advanced items. Because of the unique facilities that are required for development of nuclear rocket components and propulsion systems, a major part of our program is devoted to facilities design and construction.

The KIWI reactor part of our program is conducted by the Los Alamos Scientific Laboratory of the AEC. Three research reactors were run during 1959 and 1960 as a part of the so-called KIWI-A series. These reactors were not intended as flight reactors and were, therefore, named after the flightless New Zealand bird. The first tests of our KIWI-B reactor test series, which are intended to provide a design that can be incorporated into a flight engine, were completed with a power run on December 7, 1961. A photograph of that reactor is shown on the next chart (R62-341). The

reactor is shown at the test cell in the AEC's Nevada Test Site. A hydrogen regeneratively cooled jet nozzle is installed on the reactor. For these early reactor experiments it was determined that this upward firing configuration greatly simplified the test installation and operations. The following short movie was taken during the test run on December 7. The test was run using gaseous hydrogen as the reactor coolant. Although the test was cut short because of a hydrogen leak, the results have been encouraging. Several important results were obtained. Among these was an evaluation of the effectiveness of the use of control rods in the reflector portion of the reactor to control the neutron power generated by the system. In addition, this test provided us with the first preliminary hot tests of a hydrogen cooled jet nozzle intended for use in reactor testing, and it also provided us with a preliminary evaluation of one of the several reactor designs that will be evaluated in the KIWI-B reactor series.

Much more work is still required to arrive at a firm reactor design During this year we are planning to test several reactors using liquid hydrogen to permit us to make a selection of a reactor during this year for incorporation into the NERVA engine. A reactor selection this year is essential if we are to meet our proposed flight test schedules. The first reactor test using liquid hydrogen rather than gaseous hydrogen as a propellant will be a major milestone in our program and will be conducted later this year. An indication of successful reactor operation with liquid hydrogen is required before we commit the program to major engine hardware procurement and development.

The first six months phase of our contract with the Aerojet-General Corporation as the prime contractor for the development of the NERVA engine has been completed satisfactorily. The nuclear engineering development work required to make the Los Alamos reactor design a flight device is being performed by the Westinghouse Astronuclear Laboratory under a subcontract with Aerojet-General. Here is a model of the NERVA engine as it is now visualized. On the chart (R62-395) is a drawing of a preliminary design version of the engine. The flange that mates to the propellant storage tank is shown here. Hydrogen enters through this duct housed inside of a conical shell thrust structure. The tank shut off valve, the gimbal bearing to permit movement of this entire engine to provide control of the thrust direction, and the turbopump are located inside this thrust structure. The reactor and its control rods and control rod actuators are located in this area, and this is the hydrogen cooled jet nozzle. The development of the NERVA engine will require extensive tests on the system components in the simulated flight environment, including the reactor radiation environment. These component and subsystem tests will be followed by many full system tests to insure that the system can be safely flown with high reliability. We believe that we will require 30 to 40 reactor engine assemblies to achieve the reliability desired. All of this work is directed by the joint AEC-NASA Space Nuclear Propulsion Office, which I manage.

This NERVA engine will be flight tested in the RIFT, or Reactor In-Flight Test, stage in a manner similar to that indicated in the next chart (R62-342). We are now in the process of selecting the industrial contractor who will do the necessary research and development of the RIFT stage. This

work is being directed by the Marshall Space Flight Center. The nuclear powered stage will be launched from its launch pad by a chemical rocket booster. After the chemical stage has burned out, the nuclear stage will be started. In this manner, any possible hazard at the launch site is significantly reduced. The nuclear stage will propel itself on a trajectory of carefully controlled range and course. Indicated on this chart is the possibility that the nuclear stage may be fired a second time during the test trajectory. The chemical boost vehicle I have shown here is the Advanced Saturn S-1B 7.5 million pound thrust stage with a dummy second stage.

By designing the RIFT stage to mate with these Advanced Saturn stages, we will be obtaining technical information which is directly applicable to the earliest possible development of a three-stage combined chemical-nuclear vehicle. Such a vehicle is shown on the next chart (R62-343A). This vehicle is made up of a nuclear third stage on the first two stages of the Advanced Saturn, which has already been discussed. I have plotted here the escape payload of this vehicle against the thrust of the nuclear third stage. The payload increases somewhat as the thrust of this nuclear third stage increases. These escape payloads are more than double the value for the three stage, all-chemical Advanced Saturn and are higher than the payload that could be achieved with the NOVA 12 million pound thrust vehicle.

It is important to point out that the Advanced Saturn vehicle is being designed so that the nuclear stages can be incorporated when they are developed. The early development and availability of the nuclear stage could, therefore, provide an alternate means of landing on and exploring the moon.

Obviously extensive facilities are required to conduct such a program aimed at flight operations. In many respects these facilities are similar to the component and system facilities that are used in developing chemical rocket systems. However, because of the nuclear radiation encountered in these nuclear rocket systems, development must be conducted in a radiation environment and a remote site is desirable for development testing. It is planned that all testing involving nuclear rocket reactor radiation will be conducted in the Nuclear Rocket Development Station in Nevada. The facilities at this site will include reactor test cells, engine test stands, vehicle stands and various supporting facilities, including an Engine Maintenance, Assembly, Disassembly Building. Such a building is essential for remote maintenance and disassembly of engines that have been tested.

To indicate some of the differences that must be incorporated in nuclear rocket stands as compared with the chemical rocket stands, I have prepared the next chart (R62-565) showing a model of our first engine test stand. The engine will be brought to the stand on the railroad car and connected into the stand. These heavy shields will enclose the engine during test operations in order to reduce the radiation levels in the vicinity of the test stand and to reduce the activation of the test stand. These shields also provide a sealed vacuum chamber around the engine. After the engine has been tested and removed from the stand by remotely controlled means, the shielding plug will be inserted over the opening into the flame deflector duct. This is required in order to reduce the radiation levels due to the activation of the duct so that men may quickly come into the stand area to

provide whatever maintenance is necessary. This door will cover the exhaust duct discharge to reduce the radiation levels in the area immediately after a test.

In addition to these program tasks directed at early flight testing with a system which may, with continued development, provide us with an operational nuclear rocket system as early as possible, we are, as I mentioned earlier, conducting work aimed at even more advanced nuclear rocket systems.

Our entire program on nuclear rockets is aimed at developing the technology of these systems as rapidly as possible. We have brought, or are bringing, into the program the talents and facilities that are required to insure that we are in a position to take advantage of all successes so that we may start using nuclear rockets at the earliest possible time.

The other nuclear system that is receiving considerable attention is the nuclear reactor electric generating system for the production of large amounts of auxiliary electrical power in spacecraft and also for the production of the electric power required in electric rocket propulsion systems.

The objectives of our work on nuclear electric rocket propulsion are indicated in the next chart (R62-347). As I indicated early in this discussion, electric propulsion offers us the potential of difficult missions to the distant planets, even to Jupiter and beyond. However, in order to achieve such mission capability, it is essential that we learn to build electric propulsion systems that are extremely light in weight

and are capable of operating without maintenance for extremely long times. Specifically, we are aiming at engine weights in the neighborhood of ten pounds per electrical kilowatt generated and life in excess of a year. These requirements for extremely long life and extremely light weight are very difficult requirements to meet. We do not know yet how to achieve these performance characteristics. As a result, a well planned and coordinated advanced research and technology program is required to provide the potential performance that is theoretically possible with these systems.

A schematic drawing of a nuclear electric rocket system is shown on the next chart (R62-348) for purposes of defining the principal components of the system. The principal subsystems of the nuclear electric rocket are the electric generating section, made up of the reactor power source loop and the heat-to-electric power conversion system, and the electric thrust system, including a propellant tank. Obviously, the AEC is responsible for the development of the nuclear reactor, while NASA is responsible for the development of the energy conversion equipment and for the mating of the reactor and the conversion equipment into a reliable and operational system. In addition, NASA is responsible for the development of the electric thrust system.

The heat of the reactor is transferred by a liquid metal to the secondary heat-to-electric power conversion loop where another liquid metal is boiled or vaporized in the boiler. The vaporized metal is then used to drive a turbine, much as steam drives the turbines of our ground steam power generating plants. The turbine drives the electric power generator and some of the pumps in the system. In order to reject the

waste heat of the cycle and condense the metal vapor back to a liquid so that it may be continuously reused and recirculated through the secondary loop, it is necessary to have a large area condenser-radiator. It is this radiator that is the heaviest and largest part of the system when we get to systems capable of generating megawatts or thousands of kilowatts of electric power. In order to achieve the low specific weights that I indicated were necessary for successful electric rocket operation, the radiator must be made as small and as light as possible through the use of high temperatures in the working fluid (above 2000°F) and through the use of thin walls in the radiator tubes through which the working fluid passes. The use of high temperature is limited by corrosion of the metal surfaces of the system and the permissible minimum wall thickness of the radiator tubes is limited by the probability of meteoroid penetration. Much more information is required in these areas and our program is directed at obtaining such information. The electric power of the system is taken off at the generator and is used to accelerate the propellant in the electric thrust chamber indicated at the lower right of the chart.

For direct power conversion systems which are in an early stage of research and development, the boiler and rotating equipment shown in the turbogenerator system may be omitted. Direct conversion systems are those that convert heat directly to electrical power without requiring the use of this complicated boiler, turbogenerator conversion system. These direct conversion systems still require radiators and, in fact, the radiator may be larger than for the turbogenerator because of the low efficiencies that are now achievable in such devices. The direct conversion system

that is receiving the greatest emphasis for high power systems is the thermionic emitter which is much like a radio diode. It is a device in which two plates are closely spaced in a low pressure atmosphere of cesium vapor. One of the plates, the cathode, is heated to high temperatures causing it to emit electrons which flow to the cold plate, the anode, when load is put on the outside of the device. Much work is still required on these promising direct conversion devices to achieve high power output at the efficiencies and the life that is desired for our electric power systems.

Our major advanced technical development program on nuclear electric power generation is the development of the SNAP-8 electric power generating system. A drawing of this system, in one of the forms in which it is now visualized, is shown on the next chart (R62-349). The components are similar to those indicated on the schematic drawing that I just showed. Specifically, the reactor, the radiation shield, the boiler, the turbines and pumps of the system, and a large area radiator are shown in the chart. Also shown is the structural support which would bolt to the launch vehicle. In this case, the radiator would be wrapped around the structure and enclosed inside the vehicle nose cone during the ascent or launch from the ground. Once established in an orbit around the earth, the radiator panels would be released and would form the flat, two-sided radiators shown. The SNAP-8 system is not as advanced in performance as the systems that I indicated would be desired for applications required to carry heavy payloads to the distant planets. The SNAP-8 system is designed to deliver 30 kw of electric power, or with two of these conversion systems operating with a single reactor, it could deliver 60 kw of electric power. Our major effort

at the present time is the development of the 30 kw system with enough work on the 60 kw version to show that such a system is feasible. Testing has been conducted on all of the components of this conversion system. Each of the components has been set up and tested in component test loops. Continued test time, design and development work is, however, still required to provide for reliable components. The first test of the full conversion equipment heated electrically rather than by the reactor will be conducted during this year. The first tests of a developmental reactor will be conducted by the AEC's contractor during this year. The first test of the full conversion system with the reactor is scheduled for late 1963 but obviously very reliable components and non-nuclear system operation must be established before the system is mated with the reactor. The development of high reliability for the long operating times desired is undoubtedly the most difficult job in the SNAP-8 program.

The specific weight of the SNAP-8 system at 30 kw would be approximately 60 lbs/kw and at 60 kw about 50 lbs/kw, compared with the 10 lbs/kw I indicated earlier was desired. The maximum temperature of the working fluid in this system is 1300°F., compared with the 2000 to 2500°F. that would be required to achieve the extremely low specific weights that I indicated for the Jupiter mission. However, the SNAP-8 system will still provide us with an important capability to provide large amounts of auxiliary power, in addition to providing us with a capability to perform early electrically propelled missions on comparatively small chemical booster vehicles now being developed.

For example, the SNAP-8 propulsion capability is indicated by the performance figures on the next chart (R62-350). I have presented here the propulsion mission capabilities of the 60 kw version of SNAP-8 propelling a spacecraft after the spacecraft has been placed in an Earth orbit by the Centaur boost vehicle. The payload that can be delivered to the 24-hour orbit and to a Mars orbit are shown in the middle column.

If 60 kilowatts of electric power are required to provide auxiliary power once the spacecraft has reached its objective, then the useful payload should include the weight of the SNAP-8 power generating system, in addition to the values shown in the middle column. The resulting effective payloads are shown by this column at the right. An example of such a possible mission might be a 24-hour orbit mission involving a TV communications system where all of the 60 kilowatts available would be required to power the TV system after propulsion into the 24-hour orbit was accomplished. These payload capabilities of a SNAP-8 60 kw electric propulsion system on the Centaur booster are significantly higher than the capability of the all-chemical Centaur vehicle. In order to provide the mission capabilities shown here I have of course assumed that the SNAP-8 system is combined with a suitable electric thrust chamber to propel the spacecraft which is launched by the Centaur vehicle.

We are planning to flight-test the 30 kw SNAP-8 system in combination with one of several thrust generators that could perform the missions indicated on this chart. The purposes of such a flight test of SNAP-8 are to evaluate the effects of zero gravity on full system operation where boiling

and condensing are required to evaluate orbital startup of these systems, meteoroid penetration, bearing life and vacuum effects on the system.

I would like now to discuss our program aimed at the development of efficient, long-life electric thrust chambers which will have to be combined with our electric power supplies to provide electric propulsion systems. The three general types of electric thrust chambers that we are investigating are shown on this next chart (R62-351). I have here models of some of the engines that are under development. First we have the arc jet engine in which an electric arc is struck from a cathode to an anode, heating a gas that passes through the arc. The gas is heated to high temperatures as it passes through the electric arc and is then accelerated in a fairly conventional thermal jet nozzle. In 1963 we will be undertaking the development of a 30 kw flight test engine which will be combined with the SNAP-8 system in the flight tests we are planning. In addition, we will continue our advanced engine technology program.

Next is the ion engine in which electrons are stripped from the atoms of the cesium or mercury propellant, leaving a flow of charged particles called ions. These ions are then accelerated through an electric grid or electric accelerator (somewhat as electrons are accelerated in a television tube) producing a high velocity ion jet. In order to produce thrust, electrons must be discharged into the jet downstream of the accelerator in order to neutralize the jet; that is, to give it a neutral charge rather than a positive charge that was required to permit acceleration through the engine. Here is a working model of one such engine being worked on by our Lewis Research

Center. During Fiscal Year 1962 we did work on a 1 kw flight engine and also did work at evaluating the methods of increasing the power and thrust of these engines. During Fiscal Year 1963 we will be conducting the development of a 30 kw flight test engine, as well as continuing our advanced engine technology program.

Finally, we are doing work on the magnetohydrodynamic accelerators, sometimes referred to as plasma jets, in which a plasma is generated and accelerated. A plasma is made up of both positively charged ions and electrons, giving a neutral stream. This plasma is accelerated electromagnetically, using high strength magnetic fields to give a high velocity jet. There have been many concepts proposed for this MHD accelerator system. It is our feeling that it is yet too early on the basis of our present state of knowledge to define a suitable engine configuration. As a result, in Fiscal Year 1963 we will be continuing our research and technology program and continuing small-scale engine component investigations prior to proceeding into a full-scale development effort.

In order to fully evaluate the performance of some of these electric thrust generators, it is necessary that space flight tests be conducted. There are certain space environmental conditions that cannot be duplicated in any ground laboratory facility. In recognition of this difficulty, we have initiated the development of systems which will permit flight testing of these electric thrust generators using battery electric power on the Scout vehicle.

A model of the Scout flight test payload is shown here. During launch these arms will be folded up and this package will be installed in the nose cone

of the four-stage Scout vehicle. (In a later design, these arms will actually be folded down). When this payload package is separated from the Scout vehicle, these arms will swing out. At the end of each arm will be one of the test electric thrust engines. In the first test planned for the Fall of this year, an ion engine being developed by Hughes will be installed on one arm and the Lewis ion engine I showed earlier will be installed on the other arm. The Hughes engine will be fired first for 25 minutes and the spin rate of the spacecraft will be measured; then the Lewis engine will be fired in the opposite direction and the change in spin rate will be measured. The battery power supply, power conversion equipment, and telemetry are housed in this central compartment. The capsule will follow a limited range trajectory of sufficient altitude to give us meaningful test data.

An actual working prototype of the Hughes engine as it will be packaged in this Scout test vehicle is shown here and is also shown on the chart (R62-353). The engine will be sealed in this heavy pod housing and when it is ready for firing this cover will be removed. A similar general configuration will be used for packaging the Lewis engine in the Scout vehicle. Later Scout flight tests are being planned for arc jet engines and other ion engines.

As is the case for every flight system that is launched, extensive tests are required of the full system in the spacecraft on the ground under conditions that simulate, as closely as is possible, the space environmental conditions that will actually be encountered by the system. This is particularly true in the case of these electric propulsion systems where extremely long life is required and where, therefore, extremely

high reliability must be achieved. In addition, these systems represent such a new technology that full system tests are required before all of the operating problems and even fundamental problems are uncovered. The only alternative to such ground tests is a long and, many times, a costly flight program with no real assurance that a satisfactory system can be developed.

A facility that is capable of tests of electric space propulsion systems and their components is being requested in our Fiscal Year 1963 budget for construction at the Lewis Research Center's Plumbrook Installation at Sandusky, Ohio. A conceptual drawing of that facility with a full nuclear electric propulsion system installed is shown in the next chart (R62-354). This facility will be the only one available in this country capable of testing a complete operating nuclear electric propulsion system in the kilowatt power range under environmental conditions approaching those of space. In addition, it will have the capability of testing power generation components and systems in the megawatt power range. The fact that no such facility exists today emphasizes our need to proceed with its construction as fast as possible. Accordingly, we have started advanced design work ($175,000) in Fiscal Year 1962 in an effort to make the facility available at the earliest possible time.

Here you see the electric propulsion system installed in the large vacuum tank. Vacuum pressures less than a billionth of atmospheric pressure will be required to permit us to satisfactorily evaluate such systems. The large vacuum tank on this facility is 50 feet in diameter and 150 feet long.

The rest of the facility consists of hot handling and disassembly cells, pumping systems, coolers, transformers and other support equipment.

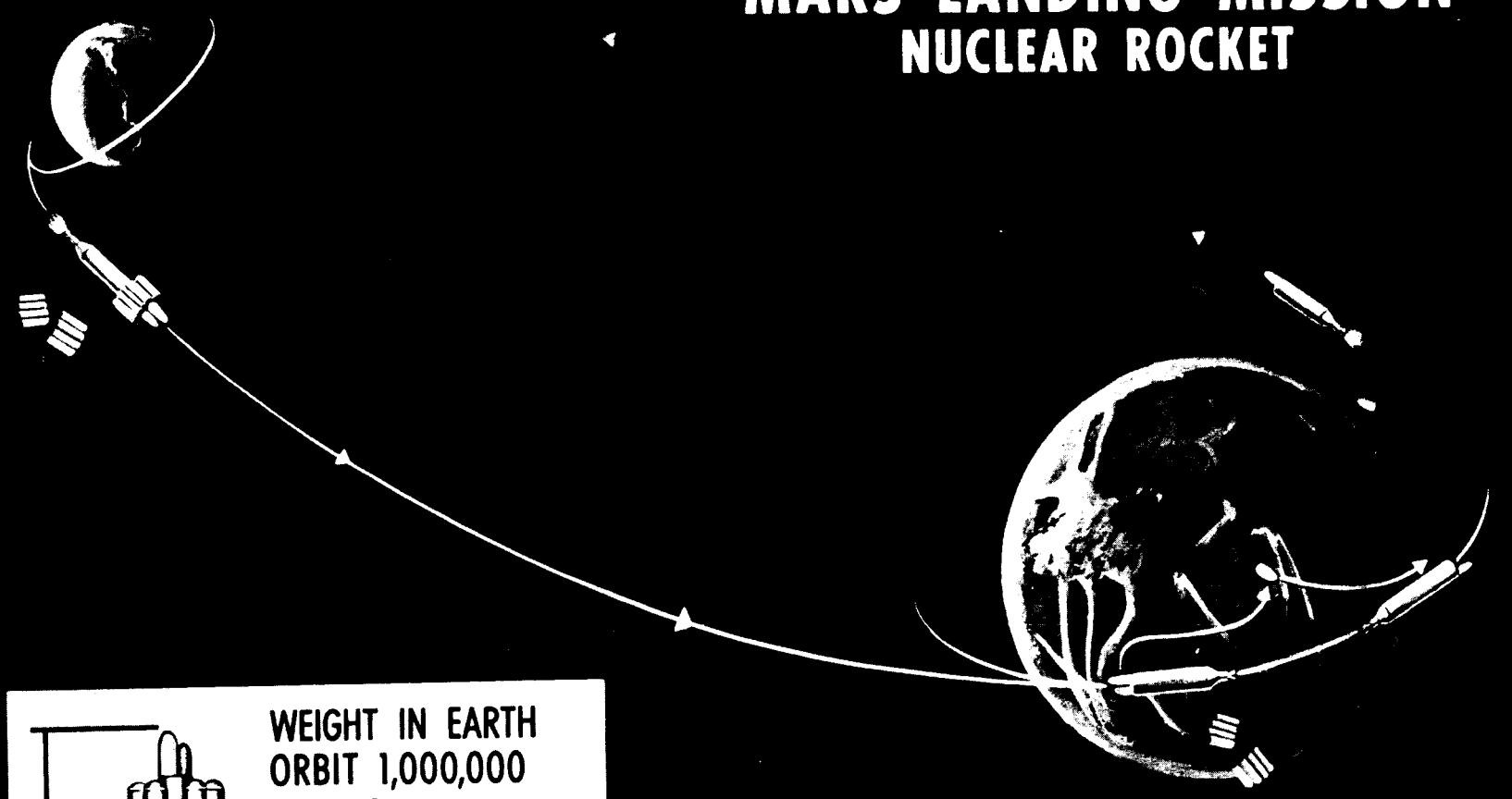
Our program on these advanced nuclear propulsion systems recognizes the large potential performance advantages that will result when they are used for the performance of high energy, long range missions. We believe this performance potential provides sufficiently strong justification for conducting the advanced technology programs that I have outlined on both the nuclear rocket and the nuclear electric propulsion systems and power systems on an aggressive basis with a high sense of urgency. There are many difficult problems that remain to be solved and difficult questions that must still be answered. These research and development programs require significant lead time in order to insure that the necessary fundamental information and technology required for effective systems development are obtained in time to permit us to perform the advanced missions that will undoubtedly be a part of the long-term space program.

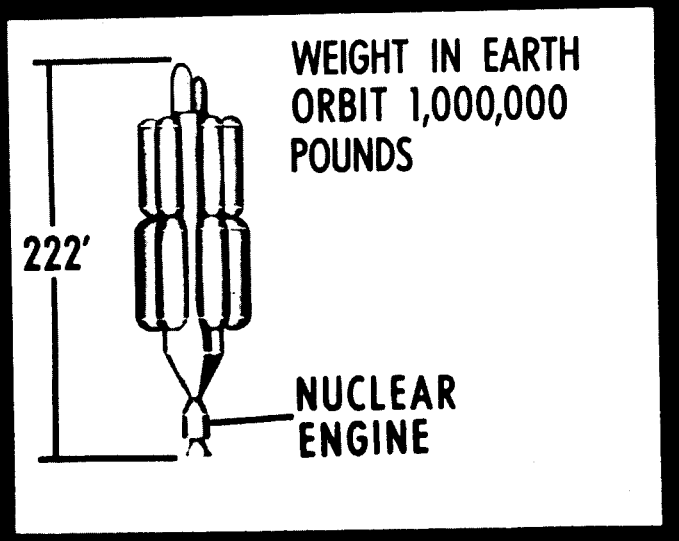
NUCLEAR SYSTEMS TECHNOLOGY

- NUCLEAR ROCKET PROPULSION
- NUCLEAR ELECTRIC POWER GENERATION
- ELECTRIC PROPULSION

R 62-298
REV 4-12

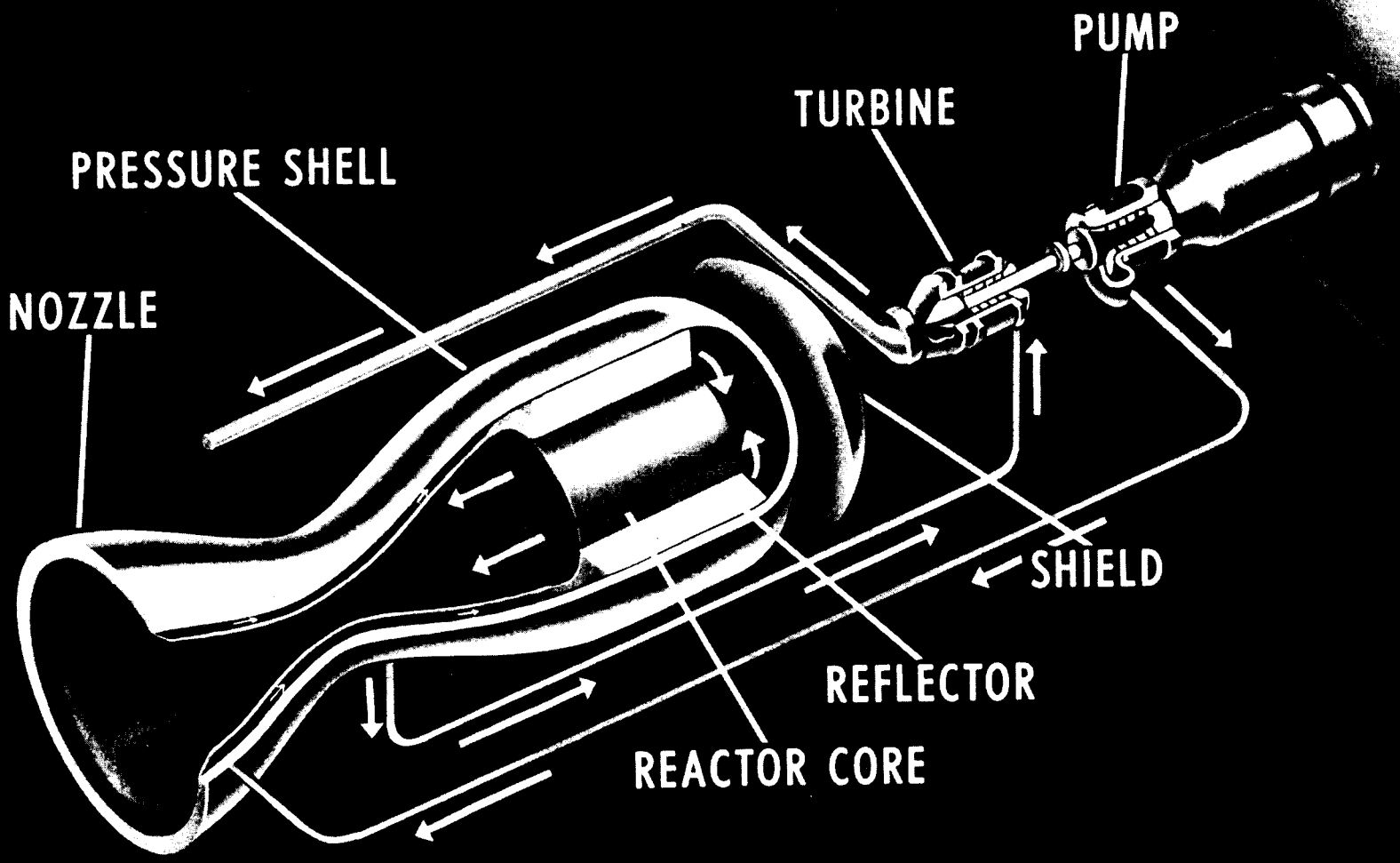
MARS LANDING MISSION
NUCLEAR ROCKET





R 62-338

NUCLEAR ROCKET ENGINE

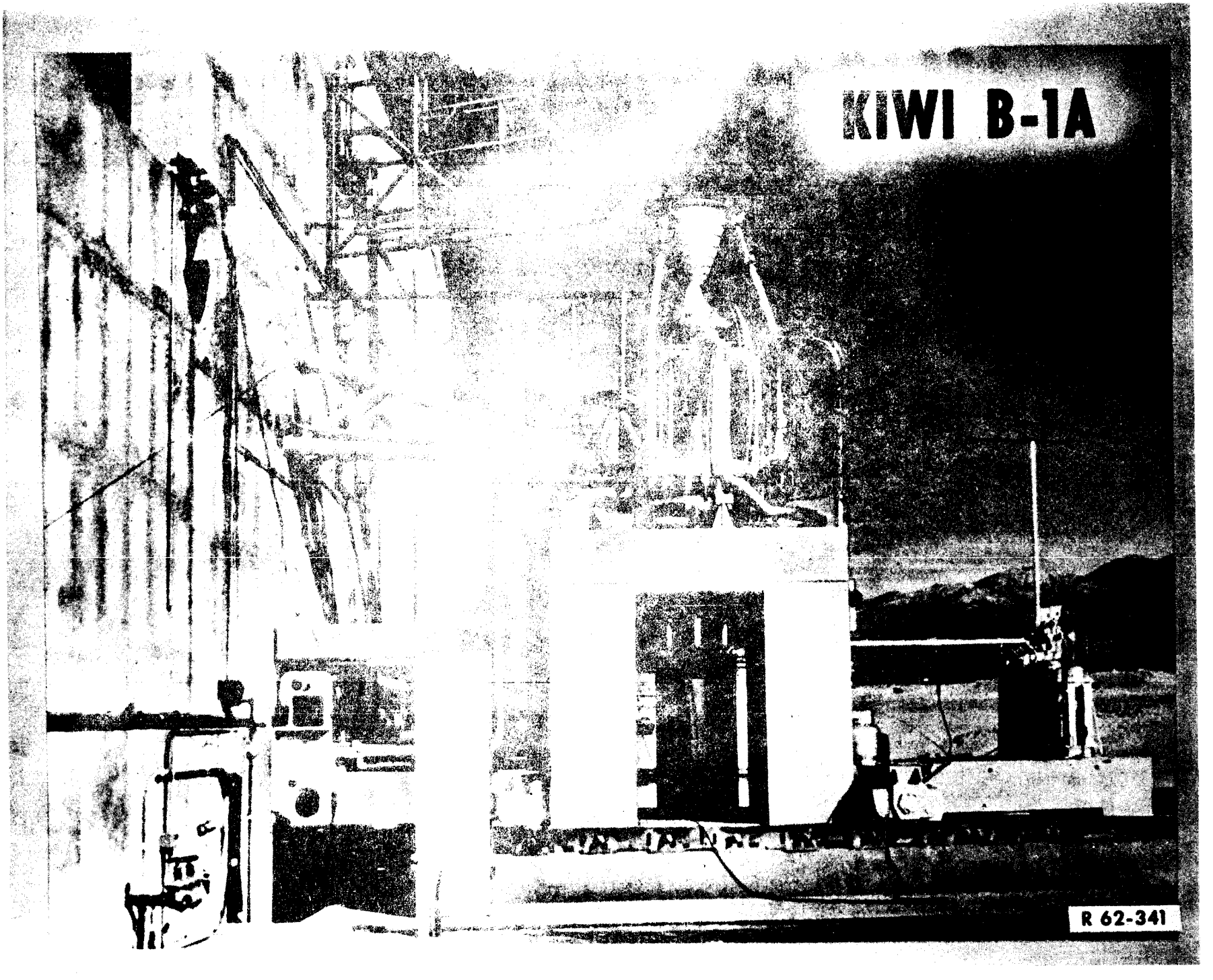


R 62-339

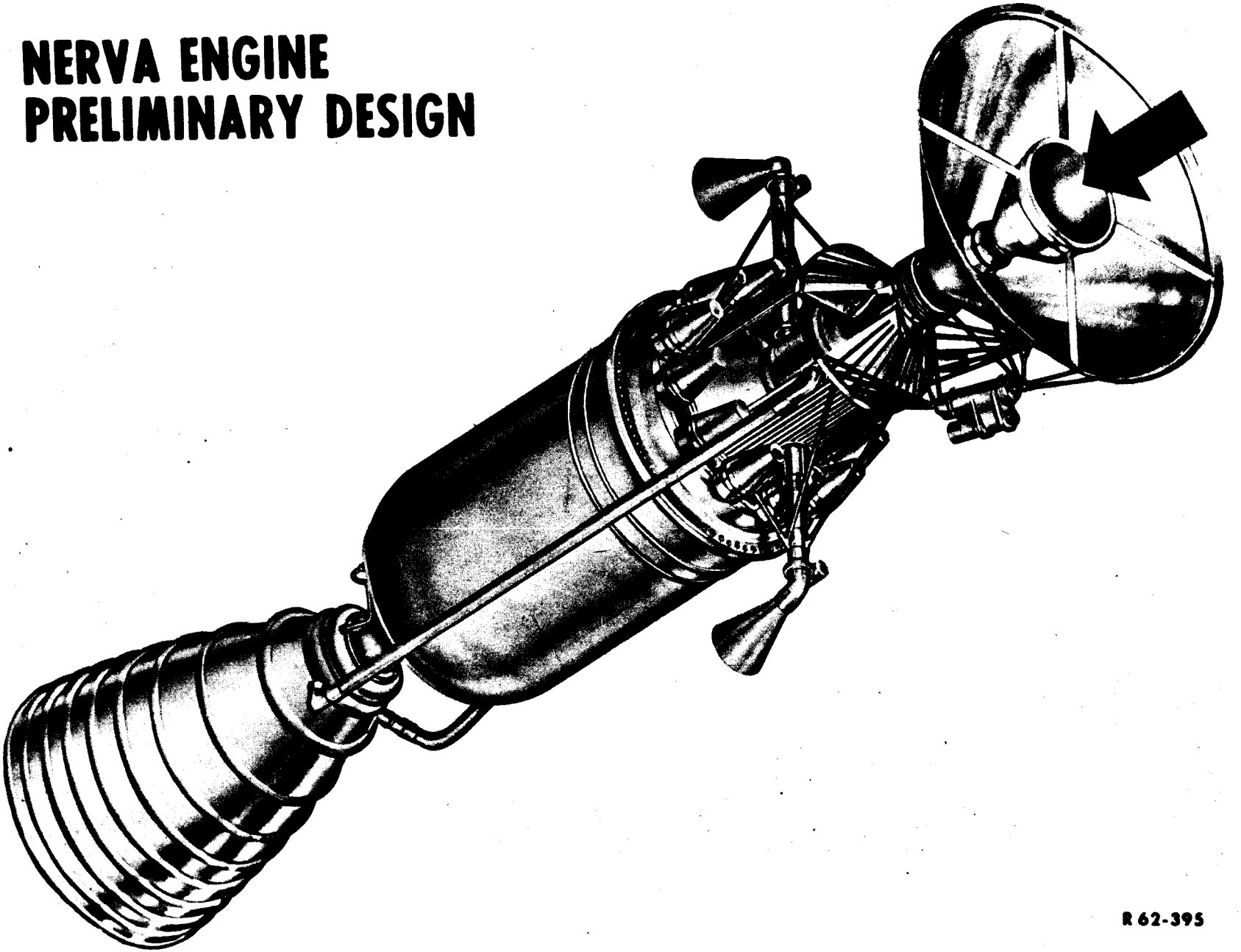
NASA/AEC NUCLEAR ROCKET PROGRAM

- KIWI REACTOR TESTS
- NERVA ENGINE
- RIFT STAGE
- ADVANCED TECHNOLOGY
- FACILITIES

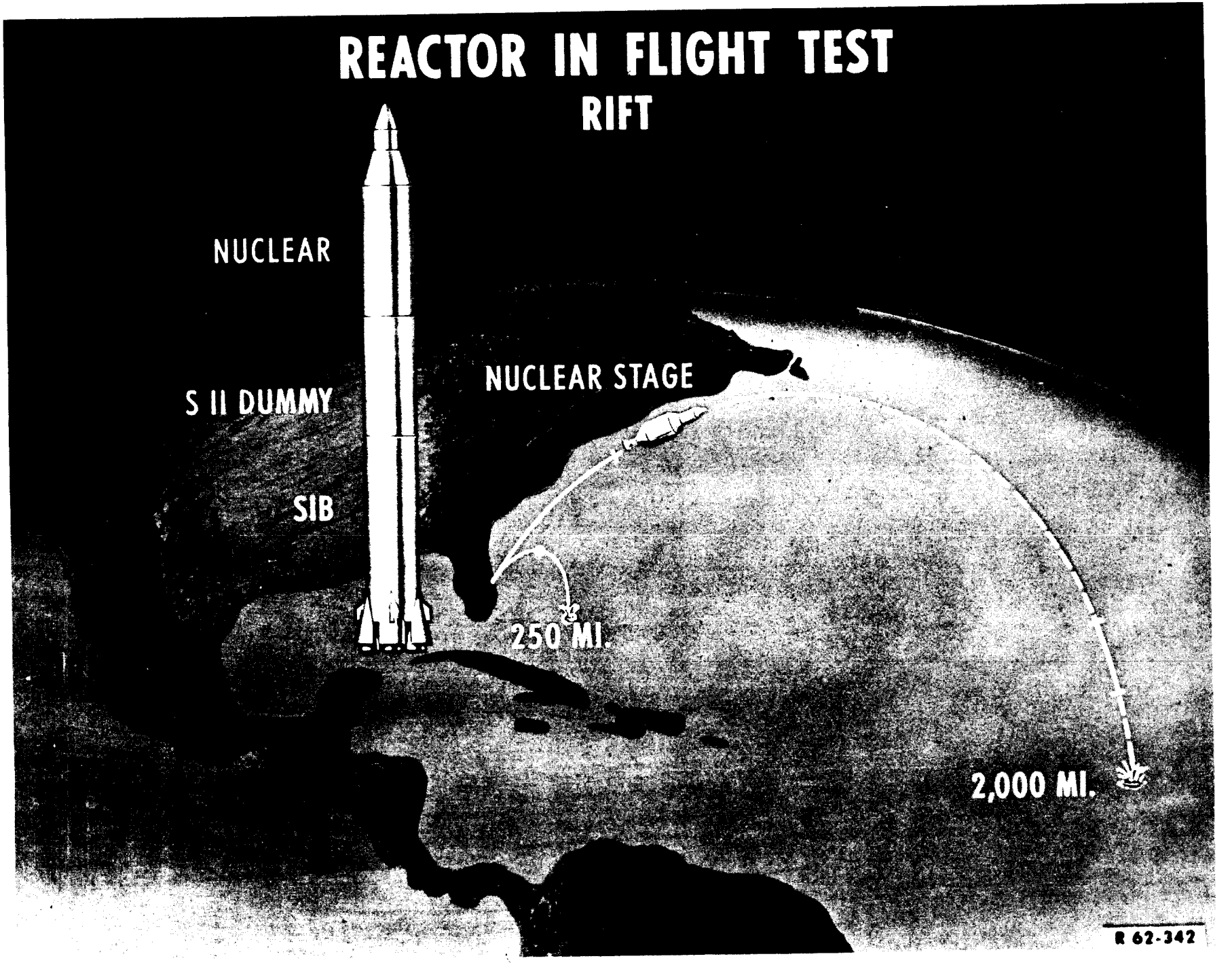
R 62-340


KIWI B-1A
R 62-341

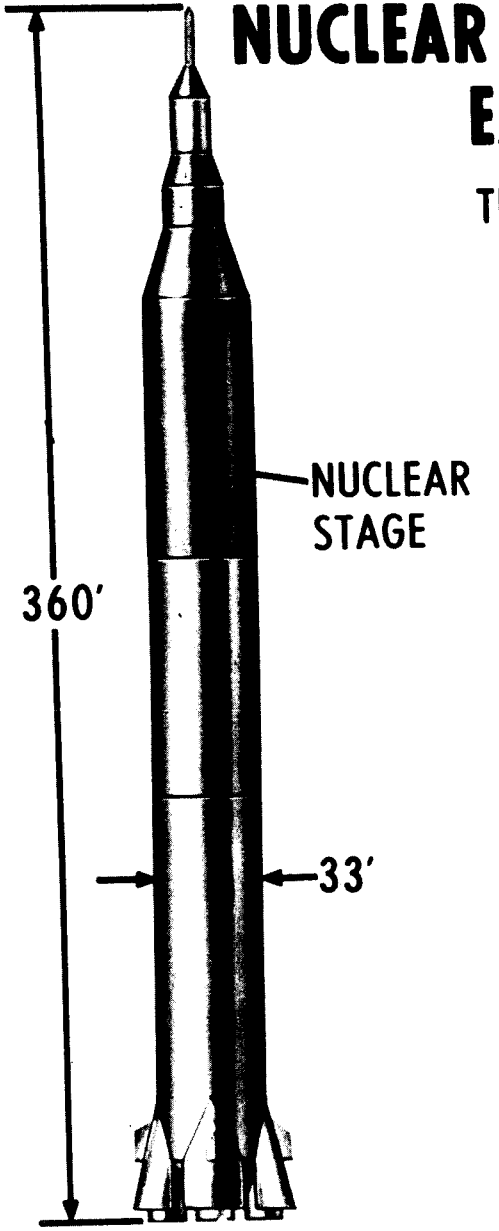
NERVA ENGINE PRELIMINARY DESIGN

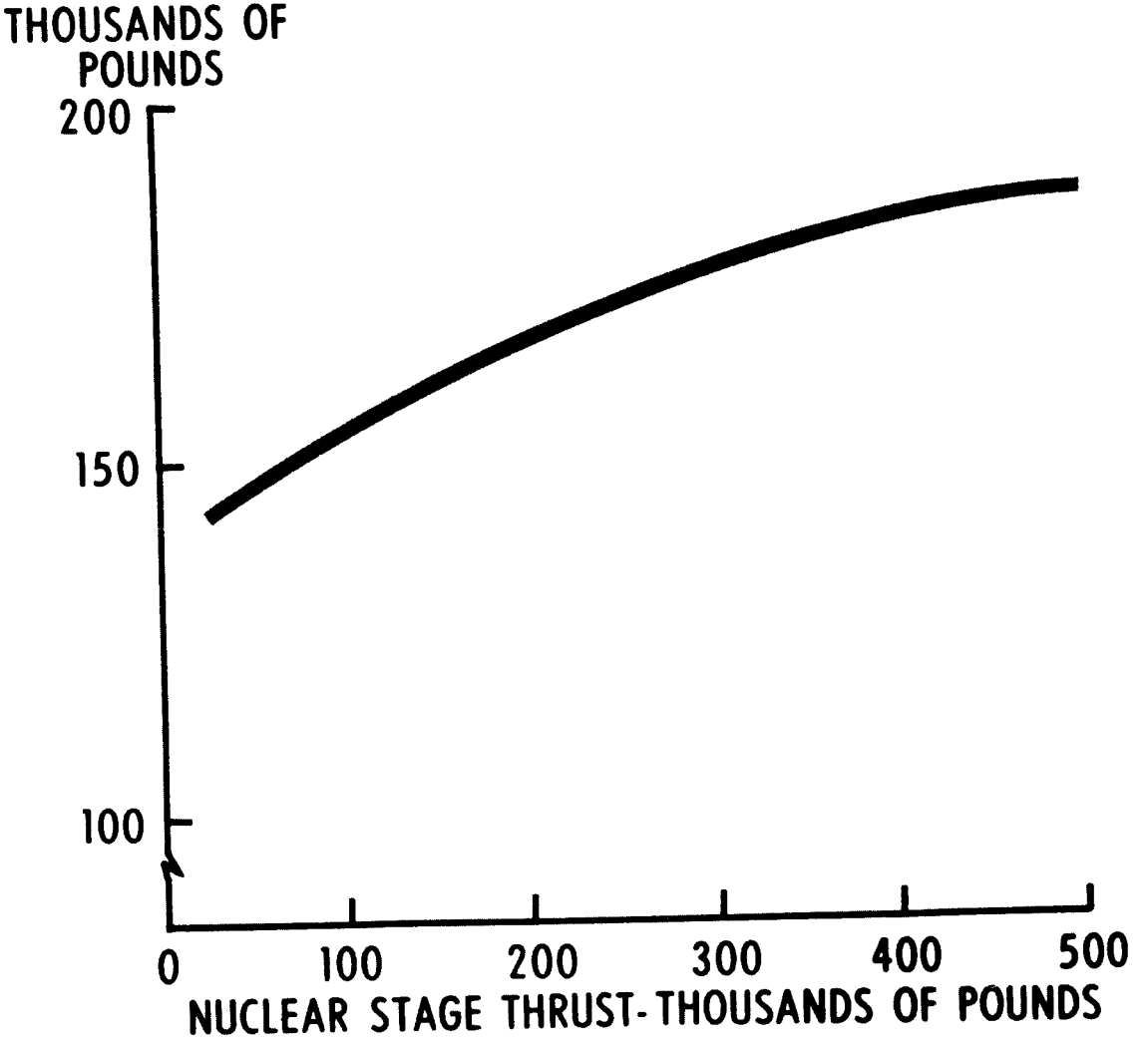


R 62-395


REACTOR IN FLIGHT TEST
RIFT
NUCLEAR
S II DUMMY
SIB
NUCLEAR STAGE
250 MI.
2,000 MI.
R 62-342

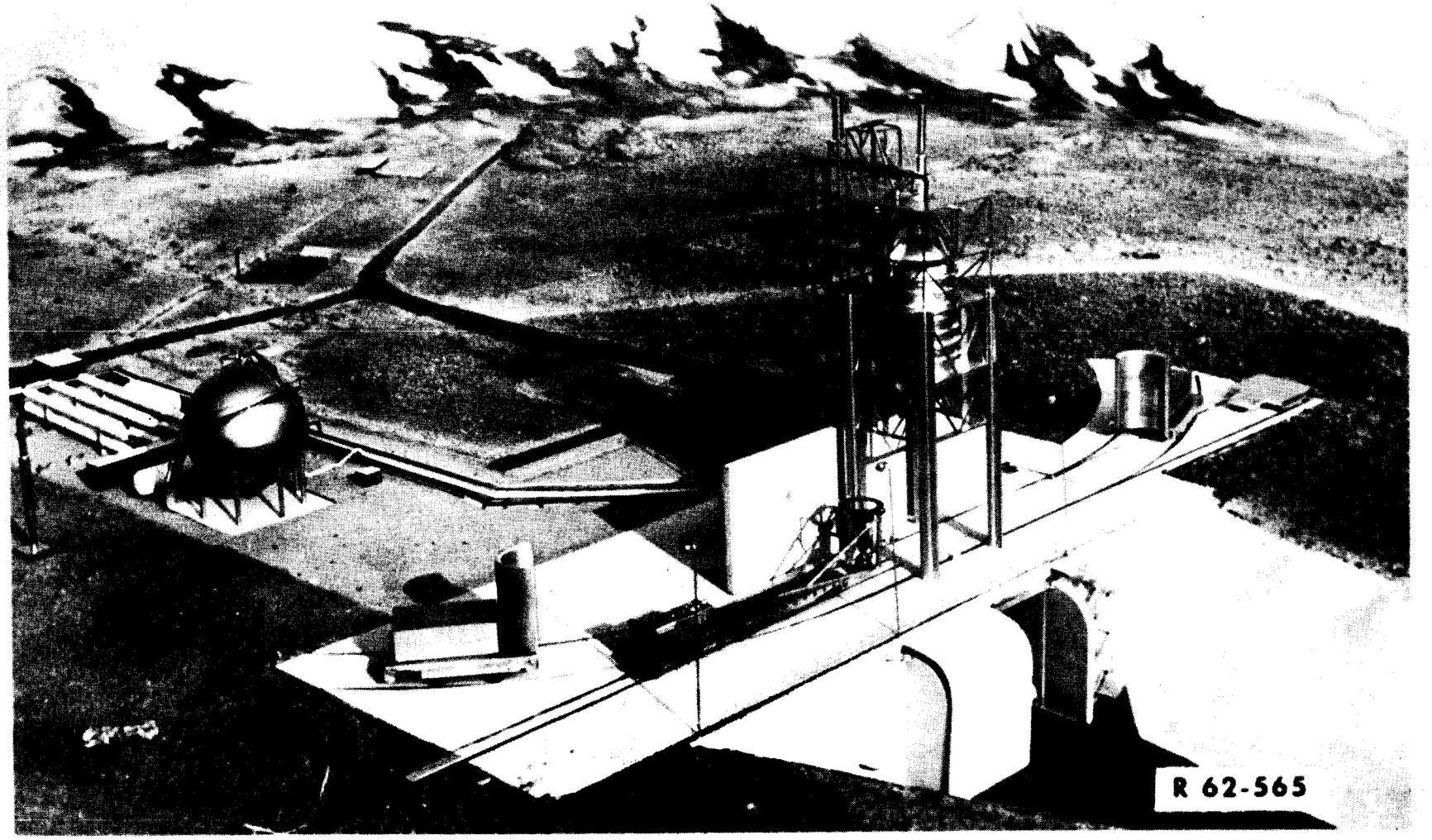
NUCLEAR STAGE ON ADVANCED SATURN EARTH ESCAPE PAYLOAD



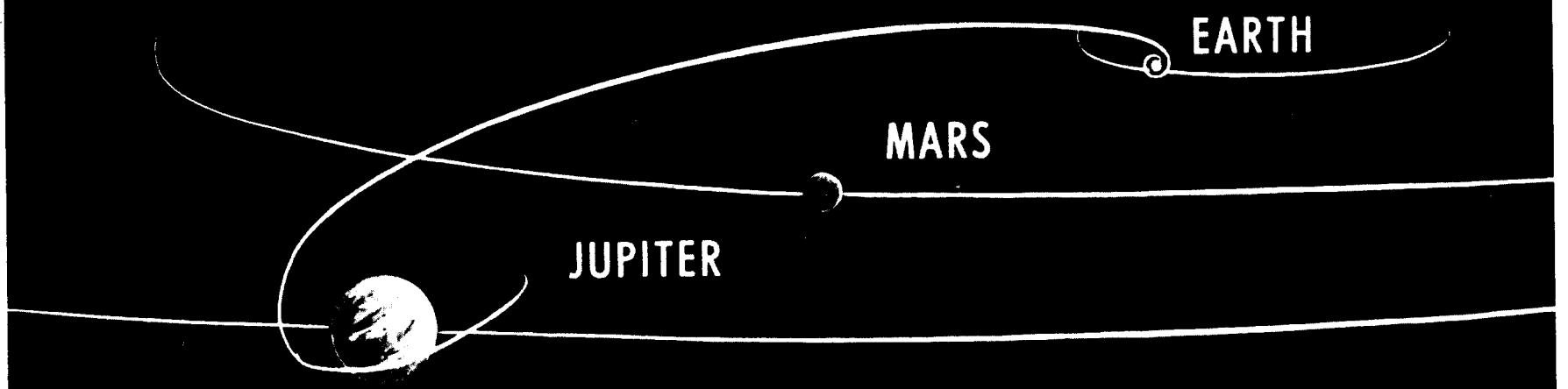


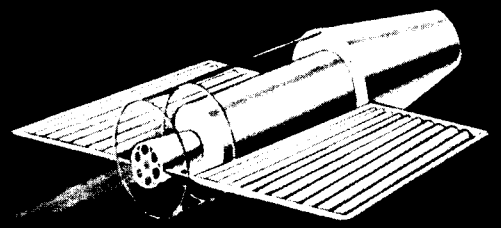
R 62-343A

NUCLEAR ENGINE TEST STAND
NRDS



ELECTRIC PROPULSION OBJECTIVES



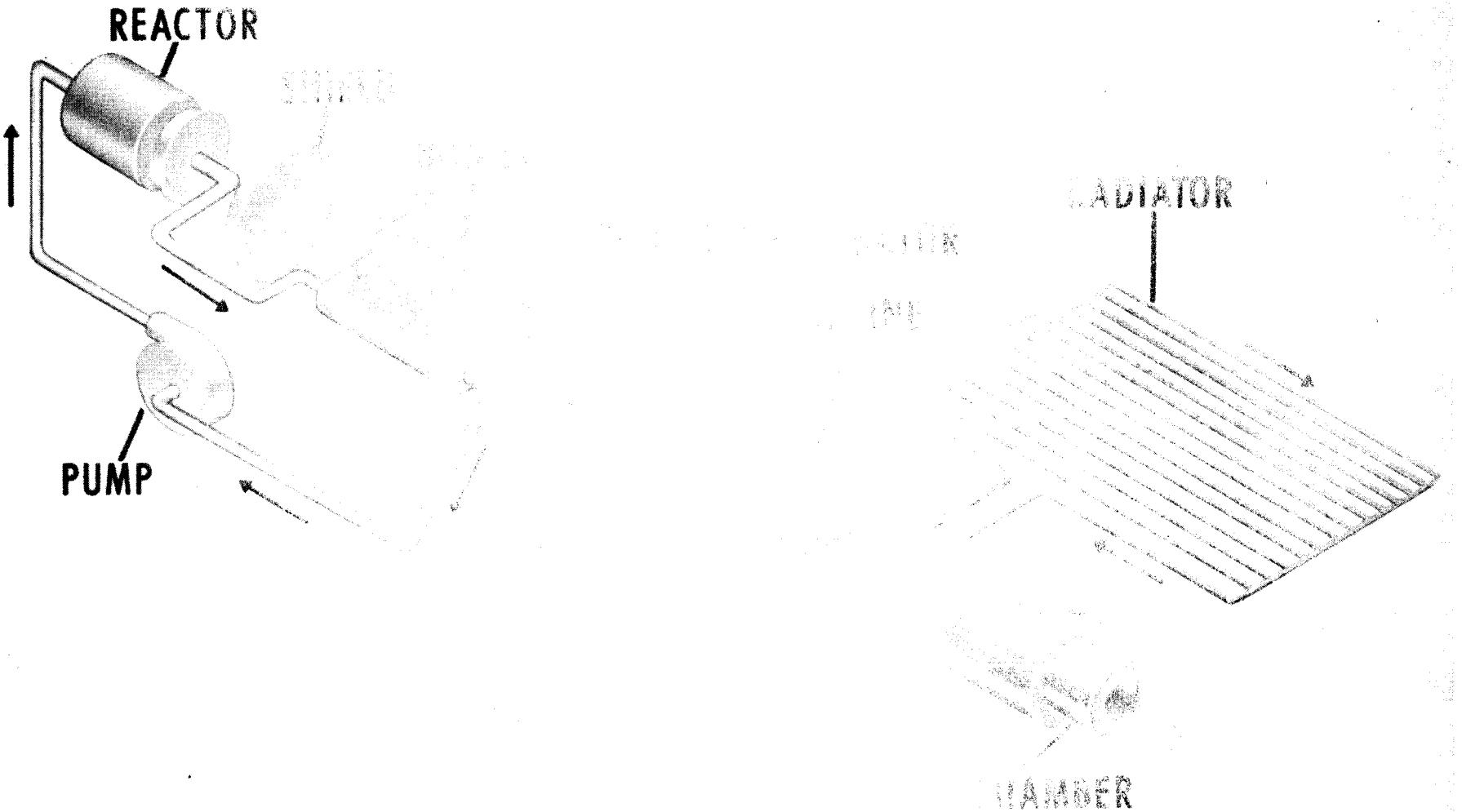


OBJECTIVES

- LONG LIFE - OVER 1 YEAR
- LIGHT WEIGHT - ~ 10 LBS./KWe

R 62-347

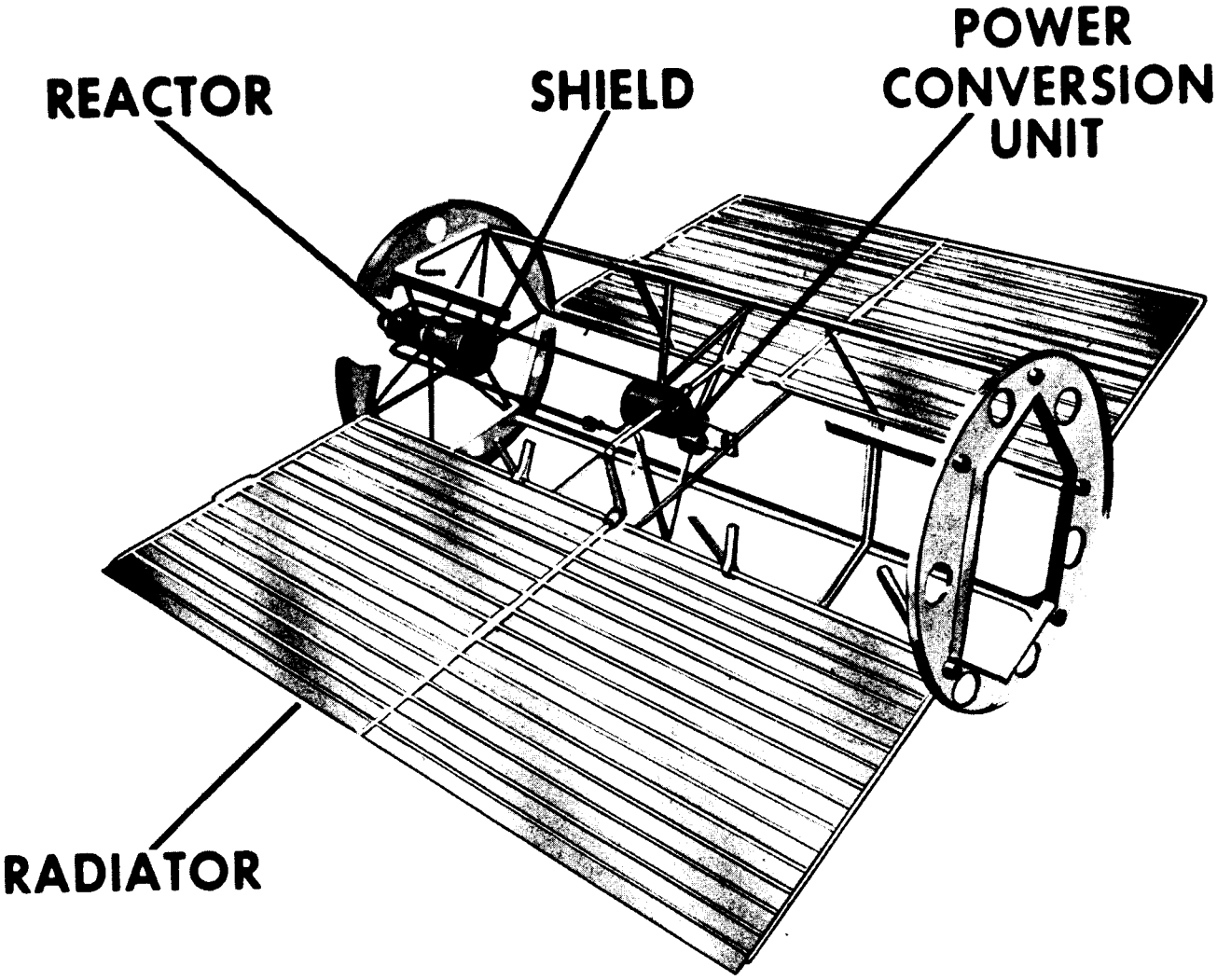
NUCLEAR-ELECTRIC POWER AND PROPULSION SYSTEM



R 62-348

REV 4-12

SNAP 8 ELECTRICAL GENERATING SYSTEM



R 62-349

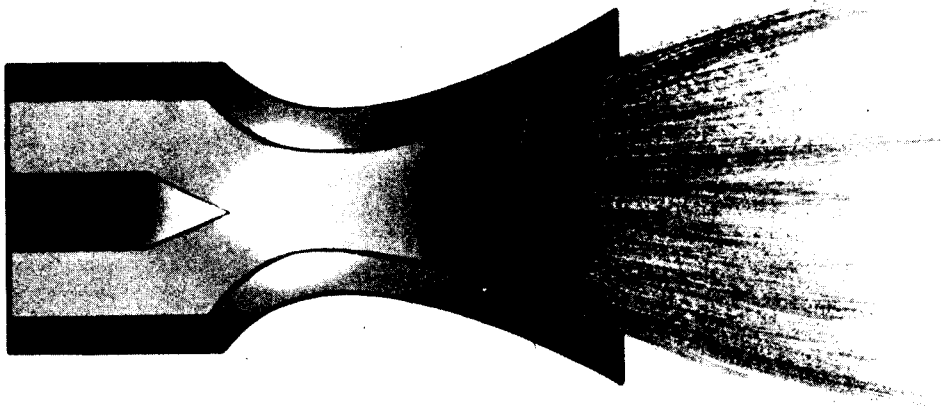
60KW ELECTRIC PROPULSION AND POWER MISSIONS
CENTAUR BOOSTER

MISSIONS	SCIENTIFIC PAYLOAD	PAYLOAD PLUS POWER SYSTEM
24 HOUR EQUATORIAL SATELLITE	4200 LBS.	7200 LBS.
MARS SATELLITE	1600 LBS.	4600 LBS.

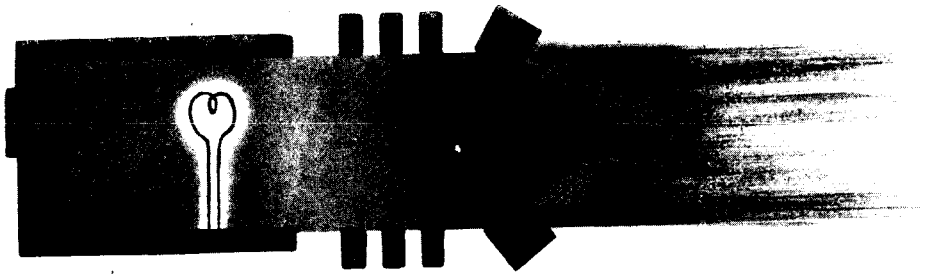
R 62-350

ELECTRIC THRUST CHAMBER PROGRAM

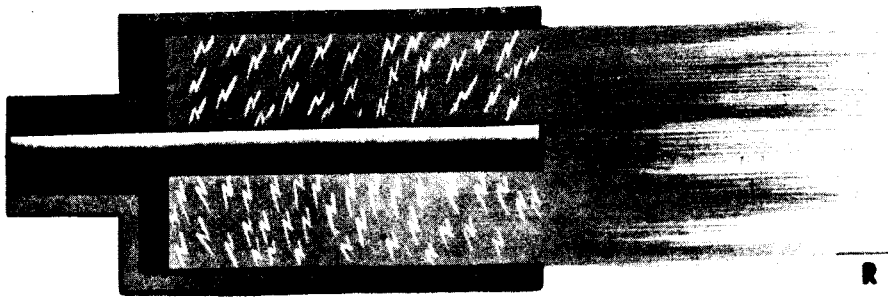
ARC JET



ION ENGINE

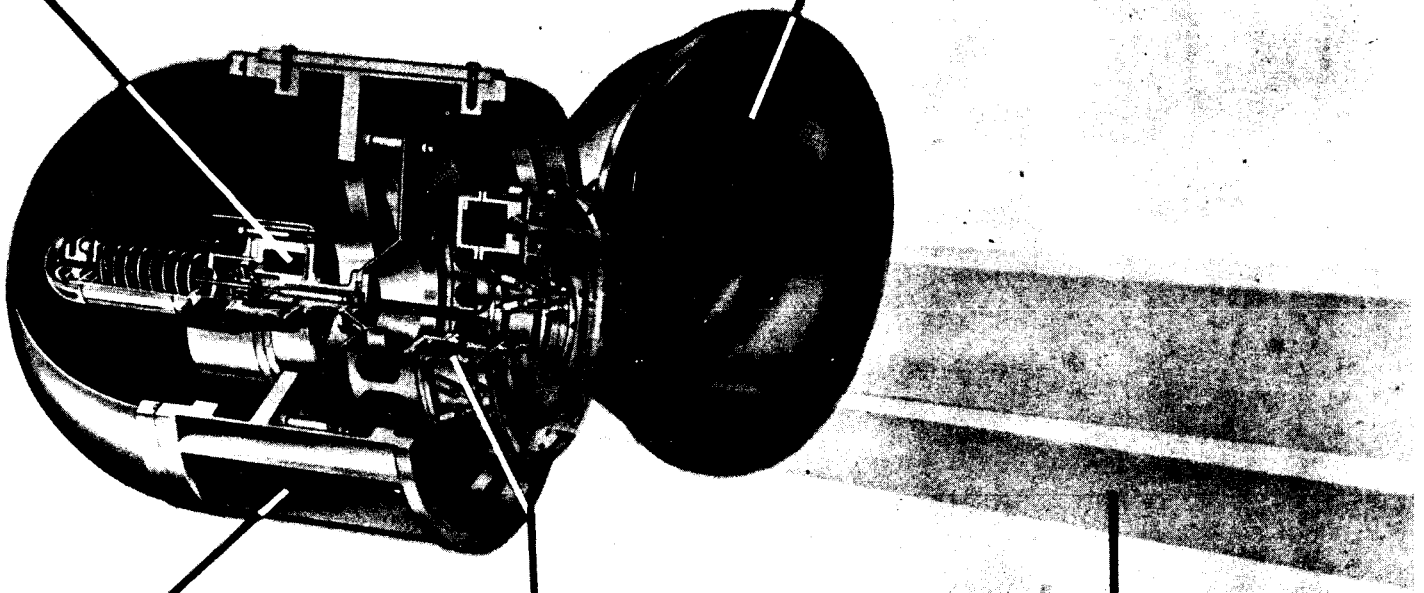


PLASMA JET



R 62-351

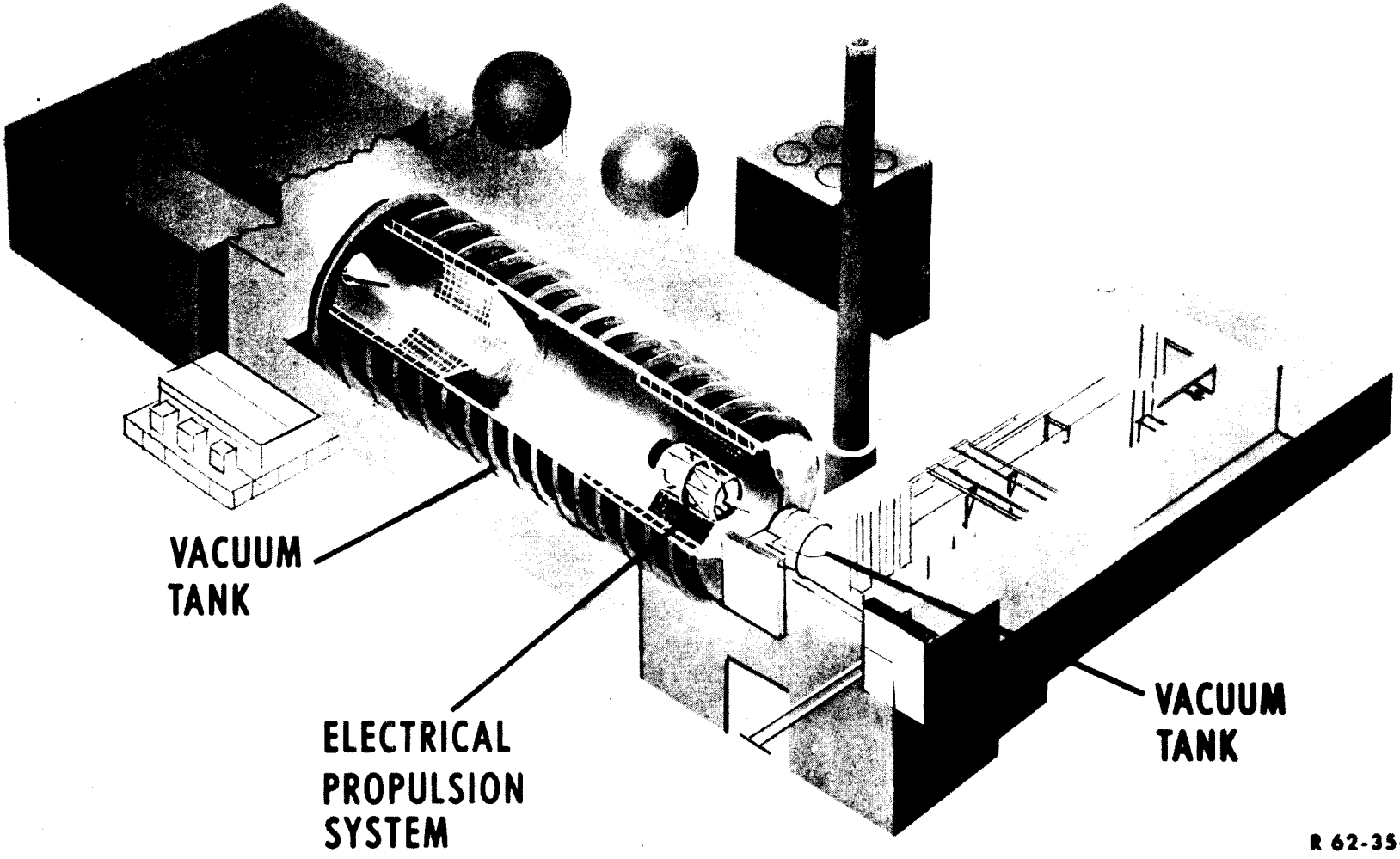
FLIGHT TEST ION ENGINE



R62-353

PROPOSED SPACE PROPULSION RESEARCH FACILITY

NASA LEWIS RESEARCH CENTER



R 62-354