

GPO PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy (HC) 3.00

Microfiche (MF) .65

(Long printed version of
(presentation at:
(Fifth Symposium on Advanced
(Propulsion Concepts, IIT
(Research Institute, Chicago, Ill.
(4/10/68

ff 653 July 65

NERVA PROGRAM STATUS
Robert W. Schroeder, Chief
Space Nuclear Propulsion Office
Cleveland Extension

I will describe the origins of the NERVA Program, the major tests conducted to date, and our current future projections. Before presenting this chronological review, however, I believe that it will be appropriate to describe briefly the nuclear rocket cycle and discuss the advantages that it has when compared to chemical rocket propulsion. Clarification of some terms may also be in order.

Chemical rockets (whether of the solid or liquid type) carry fuels and oxidizers which are ignited, burned, and exhausted through the nozzle. Ignoring accessory power requirements, nozzle efficiencies, and some secondary factors, it can be shown that the specific impulse is directly proportionate to the exit velocity, which, in turn, is proportionate to the square root of the initial enthalpy in the nozzle chamber, upstream of the throat. This initial enthalpy is entirely dependent on the initial temperature and the heat capacity or specific heat of the combustion products. With chemical rockets, therefore, the specific impulse obtainable is governed by the temperatures that can be produced by the fuels and oxidizers used or the temperatures that can be endured by the structure, together with the specific heat of the combustion products. Because of limitations on temperatures that can be achieved and specific heats that can be achieved, the specific impulse of chemical rockets is limited generally to approximately 400 seconds.

In the case of a nuclear rocket engine, thrust is also obtained by ejecting a fluid aft at high velocity. However, the most fundamental single difference when compared to a chemical rocket engine is that the fluid to be ejected aft, which we call "propellant", is not the energy source. The energy source is the nuclear reactor which produces fission energy which heats the propellant. The temperatures that can be achieved are limited only by material considerations, not by the energy content of combustibles. Of even greater importance, we are no longer constrained by the specific heat of the combustion products but are free to select a propellant having maximum specific heat. To obtain maximum specific heat, hydrogen is chosen as the propellant. As will be described later, the hydrogen is carried as a cryogenic liquid, passes through the reactor as a reactor coolant, and then passes through the nozzle as a propellant. Because of the

N68-21402
(ACCESSION NUMBER)
22 (PAGES)
MX60977 (NASA CR OR TMX OR AD NUMBER)
(THRU)
(CODE)
(CATEGORY)

FACILITY FORM 602

high specific heat of hydrogen, and the chamber temperatures that we are able to achieve (currently well in excess of 4,000° R), specific impulses of approximately 825 seconds are obtainable. It will be noted that this is approximately twice the specific impulse obtainable with chemical rocket engines. A gain of a factor of two is, of course, a very major gain and implies that the fuel or propellant that must be carried to achieve a certain impulse can be reduced by a factor of two. This, in turn, reduces the size and weight of required tankage, the size and weight of the engines required to propel the total tank mass, etc., permitting corresponding gains in payload or corresponding reductions in the size and cost of the vehicle for a specified payload.

As indicated in the foregoing discussion, the nuclear rocket engine enables us to achieve a gain of approximately a factor of two in specific impulse, and this is the primary justification for development of nuclear rocket engines. The discussions relative to savings in propellant weight, tank weight, engine size, etc., tend to set the stage for more specific discussions of mission capabilities. I will not discuss mission capabilities in any detail, as the subject is quite complex and as mission objectives and requirements have been, and will continue to be, subject to reassessment. However, the nuclear rocket engine appears to be very advantageous for earth orbital missions, lunar missions, and planetary missions. There are, of course, many detailed studies regarding various missions and many dissertations have been prepared on this intriguing subject. These studies of missions are essential but they tend to obscure the fact that the nuclear rocket engine constitutes a major advance in propulsion capability that can be used in many ways, including missions not yet visualized as well as those that have been studied. Development cycles for aeronautical or space engines inherently are long and the history of engine development over the past several decades establishes that the missions for which advanced engines are used ultimately seldom are definable during the early development stages.

Having discussed very briefly the national motivation for development of nuclear rocket engines, I will now outline the work that has been done to date, discuss our current activities, and will indicate our current objectives.

The NERVA Program currently includes two different but related and overlapping phases; the so-called "Technology Program" and the "NERVA Engine Program". There were prior phases, but in the following discussion these prior phases and the "Technology Program" will

be discussed collectively, as sharp distinctions are unnecessary. Most of our current effort is applied to the "Technology Program" which is scheduled for completion within the next year or so. The objectives of the Technology Program are to develop the underlying technology in the areas of reactor design and development, non-nuclear component design and development, and to evaluate interactions between the engine components, such as the reactor, the nozzle, the turbopump, and the control system, by means of integrated system tests. These objectives often involve, as prerequisites, more fundamental work in the areas of material development, radiation effects work, and fundamental safety work. The Technology Program also entails development of fabrication processes and reduction to practice of fabrication concepts. Very major efforts have been applied toward fuel element production, for example, with the objective of mass production of fuel elements with consistent characteristics at reasonable costs and reasonable yield ratios. Similarly, major efforts have been applied toward production of regeneratively-cooled nozzles with large numbers of thin walled coolant tubes having reproducible characteristics and consistently sound bonding. An attempt will be made to summarize the achievements to date of the Technology Program by discussing work done on the reactor and several of the major non-nuclear components and by reviewing the results of an integrated system test.

REACTOR DEVELOPMENT

The NRX series of reactors under development by Westinghouse, as part of the Technology Program, is based on prior work done by Los Alamos under the Los Alamos Kiwi Program. This 1100 megawatt series is under development, not as a flight prototype, but to enable us to advance the overall technology and to permit demonstrations of significant reactor durations at power densities and temperatures in the region of interest. This series has also been used to demonstrate startup and shutdown characteristics, control characteristics, and, by means of a special test that will be described, interactions between the reactor and the engine components interconnected in the proper functional relationship.

Figure (1) shows a diagrammatic sketch of the NERVA reactor. Inasmuch as fuel element temperatures substantially above 4000° R are required, with hydrogen flow rates of about seventy pounds per second, and because of the known affinity of carbon for hydrogen, the development of suitable fuel elements and solutions to the fuel element corrosion problem are areas to which considerable attention has been devoted.

FULL SCALE REACTOR TESTING

The NERVA team has to date conducted tests on six full scale reactors, the first of which included an unfueled core, i.e., a core without uranium. In the time period immediately preceding the first NERVA full scale test, Los Alamos conducted a test of the Kiwi B-4A reactor and severe fuel element damage and breakage were caused by a flow induced vibration. The causes of the vibration were not immediately understood, and a series of analyses and laboratory evaluations were initiated by both Los Alamos and Westinghouse. These investigations led to a fuller understanding of the problem and to the conclusion that fuel element breakage from this cause could be eliminated by proper control of bundling forces and interstitial pressure distribution. Los Alamos then conducted cold flow tests on a redesigned Kiwi type reactor and Westinghouse conducted laboratory flow tests and full scale cold flow tests during the early portion of 1964. These tests confirmed that this problem had been solved. Later in 1964, in September and October, the first NERVA power reactor, NRX-A2, was operated successfully at the NRDS. In this experiment the reactor was tested at several intermediate power levels and then was brought up to full power and temperature and held there for about two minutes. The reactor then was shut down and later restarted for a series of lower power tests for performance mapping purposes. When this reactor was disassembled for examination, it was found to be in very good condition with the exception of some corrosion of fuel elements.

By the time the second NERVA fueled reactor had been assembled, the fuel elements were considerably improved from a corrosion standpoint. This reactor (NRX-A3) was tested under a variety of conditions, including full power and temperature for about sixteen minutes and additional time at various low power conditions. Three restarts were demonstrated, one of which was a fixed control drum startup. When this reactor was disassembled, it was also in very good condition, again with the exception of some corrosion of the fuel elements. Several other observations made during the NRX-A3 testing are worthy of note. One inadvertent shutdown, caused by a flow control system malfunction, was exceptionally severe as flow to the reactor was terminated while the reactor was operating at full power. This caused a scram and an abrupt temperature transient. Analyses and limited observations of the test article indicated that significant damage was not incurred and it was decided to restart the machine and resume operations. This restart was achieved on May 20, 1965.

Concurrent with the reactor development, major efforts were devoted to the design and development of non-nuclear system components. It was felt that much could be learned regarding system interactions were an early test of an integrated system to be conducted with the components installed in their proper functional relationship. Accordingly, it was decided to change the NRX-A4 reactor, which initially had been intended as another reactor in the reactor development series, to a combined reactor test-system test. This was designated NRX/EST. It involved an upward firing configuration on a test car somewhat similar to that of the previous reactor test configurations. However, it included an engine-type turbopump configuration with the turbine driven by engine exhaust drawn from the nozzle bleed port and suitably diluted by cold hydrogen. This functionally represented the ultimate engine configuration, although the geometric location of components did not simulate the engine configuration in detail. Figure (2) illustrates the standpiping system associated with reactor tests and Figure (3) illustrates the NRX/EST configuration. Figure (4) shows the test article installed on the test car and connected to the facility.

The NRX/EST test series was conducted successfully at the Nuclear Rocket Development Station between December 8, 1965, and March 25, 1966. The most significant operations were as follows:

1. The first operation of a nuclear rocket engine system with the major engine components connected in a flight functional relationship.
2. Demonstration of system stability under a number of different control modes while operating over a broad area of the engine performance map.
3. Demonstration of the multiple restart capabilities of the engine system.
4. Demonstration of the endurance capabilities of the reactor and other engine components by operation at nominal rated conditions for approximately thirty minutes and at or above 1700° R chamber temperature conditions for approximately one hundred minutes.

In general, performance of the reactor and engine system were in accordance with pretest predictions. Reactor parameters, such as temperatures, temperature distribution, pressures, pressure drops, and engine system performance were reproducible from one test to

another. The last test was terminated when significant core reactivity loss was indicated by the control drum position.

The planned test series called for the use of the facility turbopump and associated systems for one or more of the full power tests in order to meet the reactor objective of thirty minutes of full power operations. Since the engine system performed satisfactorily, it was not necessary to change over to the "reactor only" configuration (use of facility turbopump). All experimental plans of the NRX/EST test series were performed using the engine system. The integrated power for the test series as determined from the nuclear instrumentation was approximately 3.7×10^6 megawatt seconds. This is to be compared to the integrated power of 1.8×10^6 megawatt seconds for the NRX-A3 reactor and integrated power of 3.8×10^5 megawatt seconds for the NRX-A2.

The next test in this series, the NRX-A5 test, was conducted between May 26, 1966, and June 23, 1966, inclusive. This was not an engine systems test and included the use of the facility pump in the same manner as the NRX-A2 and NRX-A3 reactors. The major purpose of this test was to obtain further information regarding reactor integrity and fuel corrosion under essentially stable steady-state power conditions. The most significant operations and accomplishments of this test series were as follows:

1. The test assembly operated for about thirty minutes at near rated conditions.
2. Operation of the new 8 decade neutronic system was demonstrated. For the EP-1 and EP-4, neutronic detectors were located on the test car under the test article and used as a neutronic system feedback.
3. Checked out and operated the reactor at rated conditions using a temperature control system without the neutronics/power control as an inner loop.
4. Demonstrated the acceptability of a startup from low power to near rated conditions with the drums in a fixed position.
5. Performed the initial criticality of the reactor after all poison wires were removed.

In summary, the overall project atmosphere in the spring of 1966 encouraged a high level of confidence. This compared most favorably with the 1962 status when the reactor was inoperable because of a structural vibration, premature failures of nozzles were encountered, the pump capability had not been demonstrated, and various adverse system interactions and control problems were postulated. Successful demonstrations, however, are often the precursor of even more ambitious objectives. Although the reactor and engine component operating durations of thirty minutes that had been demonstrated are adequate for many of the postulated missions, in order to increase the rigor of the demonstration and to thereby add to our confidence level for flight usage, reactor duration objectives of sixty minutes were advanced. The available evidence indicated that the corrosion characteristics of the fuel elements tested to date in reactors would not be adequate for this duration. Consequently, it was decided to defer further full scale NERVA reactor testing pending further laboratory assessment of the design and production variables influencing fuel element behavior. Accordingly, a fuel element assessment and accelerated development program was initiated at WANL.

An accelerated electrical test program was instituted in which hydrogen was flowed through the elements at flow rates and temperatures simulating reactor behavior, utilizing electrical resistance heating in lieu of neutronic power generation. By means of these tests, various combinations of matrices and coatings were explored, the effects of permeability were evaluated, as were the effects of varying interstitial pressures. Similarly, effects of processing variables were evaluated. The evaluations after each test included incremental weight loss data, measured at various axial stations, as well as detailed macroscopic and microscopic examinations of matrices and coatings. This program was fruitful and led to better understandings of fuel element behavior.

Fuel elements of varying behavior were observed during prior reactor tests and one objective of the assessment program was to adjust the electrical test parameters so as to better discriminate between "good" and "poor" elements by testing sister elements from batches used in reactor tests and then correlating electrical test behavior with reactor test behavior. It was found possible to tailor the electrical test so as to discriminate qualitatively between "good" and "poor" elements. Using this adjusted electrical test as a screening device, it was found that changes in coating processing and coating profile would give significantly improved performance under electrical test conditions.

The NRX-A6 fuel element specifications were modified accordingly and more rigorous acceptance tests were then designed to qualify each batch for reactor usage. These developments permitted release of the NRX-A6 fuel elements early in 1967. Although the majority of elements in the NRX-A6 reactor consists of this currently standard production type, a number of other elements with different matrix/coating combinations are incorporated in test sections for evaluation. Each of these experimental types, has, however, been required to pass the NRX-A6 electrical qualification test before incorporation into the reactor.

The test of the NRX-A6 reactor was completed on December 15, 1967, at the Nuclear Rocket Development Station. The test featured a startup ramp with two short intermediate power holds for quick data review and control setting adjustment, followed by a one hour endurance run at rated power and temperature. Side-by-side tests of XE engine control drum actuators and of instrumentation transducers were also conducted in the NRX-A6 radiation field. The test was completed without incident; and the overall amount of reactor corrosion encountered, as indicated by control drum motion, was significantly less than anticipated. Data obtained during this test currently are being analyzed, and the reactor is being disassembled for careful observation and assessment of the condition of its various components. Observations to date are as follows:

1. Figure(5) identifies the three separate tests that were run, together with their primary objectives. It will be noted that all objectives were met and that the reactor operated above design temperature and power for sixty minutes, at which point it was still operating satisfactorily and was shut down in accordance with the preestablished plan.
2. Figure(6) compares the five live reactors tested during the NRX reactor program. It will be noted that in slightly more than three years the demonstrated reactor duration increased from two minutes to sixty minutes. Further, the NRX-A6 post-test condition was superior to that of the NRX-A2 in most important respects. It will also be noted that the average power and average chamber temperature maintained during the NRX-A6 test were higher than those maintained during

preceding tests. The table indicates that both NRX-A4 and NRX-A5 operated for about thirty minutes, suggesting a developmental plateau. However, both of these reactors were designed and built during the same time period such that the NRX-A4 test results could not be factored into the NRX-A5 test article. These reactors were built essentially concurrently, as the first was intended for engineering system tests with many restarts and much part-load performance, whereas the latter was intended to demonstrate endurance under steady-state conditions.

Detailed analyses of the NRX-A6 fuel elements are still in process but current indications are that the fuel element overall condition is quite good and that fuel element performance, as assessed during reactor post-mortem, correlates well with the electrical tests used for qualifying purposes.

The NRX-A6 test has also demonstrated satisfactory operation for one hour at design power and temperature of a number of non-nuclear components, including the regeneratively-cooled nozzle, the pressure vessel, and instrumentation and control components. Reactor exit gas thermocouples, which had been of some concern prior to the test, operated satisfactorily. A side-by-side test of an engine candidate control drum actuator, in which the actuator was operated while exposed to a high neutronic flux, was completed successfully.

The NRX-A6 reactor endurance test, the last reactor endurance test scheduled as part of the Technology Program, exceeded our most optimistic expectations and the data obtained from this test established an excellent baseline for further evolution of the NERVA reactor

NON-NUCLEAR COMPONENT DEVELOPMENT

In parallel with this reactor effort, major efforts were being exerted by Aerojet in Sacramento relative to development of non-nuclear components.

NERVA TECHNOLOGY NOZZLE

Initial work was performed on a nozzle concept involving circular cross-section stainless steel tubes and an aluminum jacket.

A number of problems were encountered that we will not take time to discuss in detail. This design was superseded by the design currently used consisting of a structural forging made of Type 347 stainless steel with formed U tubes of the same material fitted into and brazed to machined slots in the forging. A photograph of this nozzle is shown in Figure (7).

The first development test of this nozzle was conducted in March, 1964, and formal qualification of the nozzle was completed in September, 1966.

The qualification tests consisted of demonstrating the performance of the nozzle hot bleed port and nozzle throat and tube walls. Ten chemical simulation tests were conducted with the bleed port in which the maximum turbine inlet temperature and maximum bleed port wall temperatures predicted for the nuclear rocket engine testing were exceeded. In addition, ten chemical simulation tests were conducted with the nozzle in which the maximum throat heat flux and maximum tube wall temperatures exceeded those predicted for nuclear engine testing. Of perhaps even greater significance, however, this type of nozzle has been used on each of the NRX reactor tests conducted to date without difficulty. During the NRX/EST engine system test, the hot bleed port was incorporated and utilized to supply hot gas to the turbine in the same manner as will be employed on the engine. This nozzle configuration, therefore, has demonstrated its suitability for the intended purpose and production techniques have been established enabling us to manufacture this type nozzle repeatedly with predictable performance characteristics.

TURBOPUMP ASSEMBLY

The technology turbopump assembly consists of a single stage centrifugal pump driven by a two-stage axial flow turbine, as indicated by Figure (8).

The liquid hydrogen flow rate is about 75 pounds per second with a pressure rise of about 1000 psi, requiring a turbine power of approximately 8000 horsepower. Because of the close physical coupling required between the pump and the turbine, and because of the low temperature of the pumped liquid hydrogen (-420° F), the bearings of the turbopump cannot be lubricated in the conventional sense. Instead they are cooled with a constant stream of liquid hydrogen. This inability to lubricate presents severe problems in the development of bearings. In addition to this bearing lubrication problem there is a problem associated with very high nuclear

radiation levels from the reactor. This puts very stringent limits on the material than can be used for various applications, such as ball and roller bearing cages. The development of suitable bearings has been the most difficult problem in the turbopump to date. In attacking this problem, we developed an electrically driven bearing tester that is capable of testing the complete bearing assembly with the bearing properly loaded in both the radial and axial directions and with the proper flow rate of liquid hydrogen for cooling. Using this bearing tester in the radiation field of a test reactor, we have been able to develop bearings that are suitable for use in turbopumps for engine system tests for reasonable operating periods. However, we feel that we must continue this development effort to provide for turbopumps that will be suitable for many repeated tests of ground test engines.

Development of the technology turbopump was initiated in the third quarter of 1962 but the current configuration was selected in the first quarter of 1964. An external view of this is shown by Figure(9).

The first hot gas test with this configuration occurred in April, 1965. Qualification tests were completed in February, 1966, consisting of:

- (a) Demonstration of forty minutes operation at design condition on each of three separate turbopump assemblies.
- (b) Demonstration of ten percent overspeed capability for thirty seconds.
- (c) Demonstration of adequate stall margin.

This turbopump assembly operated satisfactorily during the NRX/EST test. As indicated earlier, this turbopump was originally intended for use during the NRX/EST test only for the engine system tests, with the intention of switching over to the facility pump for the reactor endurance test. However, the turbopump and other system components operated so satisfactorily during the engine system test that it was decided to continue their operation during the reactor endurance test. Accordingly, the pump operated for the best part of an hour, including thirty minutes at or near design conditions. At one point the pump delivered 130 percent design flow. The turbopump assembly has been developed satisfactorily, therefore, for the technology conditions. All turbopumps for the XE-engine program have been accepted and delivered.

OTHER COMPONENTS

Other major non-nuclear components for the technology reactors and engines have been developed, qualified, and used on various full scale tests; these include the turbine power control valve, propellant shutoff valve, the pressure vessel, instrumentation systems, and control systems.

TECHNOLOGY ENGINE PROGRAM

We have thus far discussed reactor development and non-nuclear component development associated with the Technology Program. These components will be combined and operated in a downward firing attitude and with altitude exhaust during the forthcoming XE-1 and XE-2 test series. A schematic of the X-engine, listing the main propellant feed system components is shown in Figure (10).

These tests will give us further information regarding system interactions, the endurance capability of various components, and operating information in a downward firing attitude with the engine exposed to altitude exhaust. These operations will also teach us much regarding problems associated with operation of complex engines in equally complex engine test facilities.

CONCLUDING REMARKS

Considerable progress has been made toward establishing the basic technology that will be required for further nuclear-rocket-engine development. Six technology-type reactors have been demonstrated with continuous burn times as long as one hour; non-nuclear component development has progressed to a comparable degree; and a complete engine system has been operated for extended periods over extreme portions of the operating map.

The so-called technology-type reactors and engines have been assigned a nominal rating of 1100 MW thermal power with a chamber temperature of 4090° R. Plans currently are being formulated to develop through PFRT (Preliminary Flight Rating Test) an upgraded model with a nominal rating of 1560 MW thermal power with a chamber temperature of 4500° R. With a flight-type nozzle this will permit a vacuum thrust of 75,000 lbs. and a vacuum specific impulse of approximately 825 seconds. The increase in power capability will be achieved by design refinements and by some increase in power density. The increase in chamber temperature will come in part from reducing reactor bypass streams that have in the past diluted the

chamber temperature and in part from some increase in fuel element discharge temperature. The specific impulse is on the basis of 4500° R chamber temperature but also entails improvements in pump and turbine efficiencies, as well as reductions in parasitic pressure losses and optimization of the nozzle configuration.

Present plans call for establishing the overall system design and preliminary design reviews of major components during this calendar year, followed by detailed design and release for fabrication of component test articles. Subsequent to initial development tests, critical design reviews will be held and fabrication of qualification test articles will be permitted. Qualification tests of the major components, including the reactor, the turbopump assembly, the nozzle, the pressure vessel, valves and lines, etc., will be conducted as a prerequisite to engine development testing and PFRT.

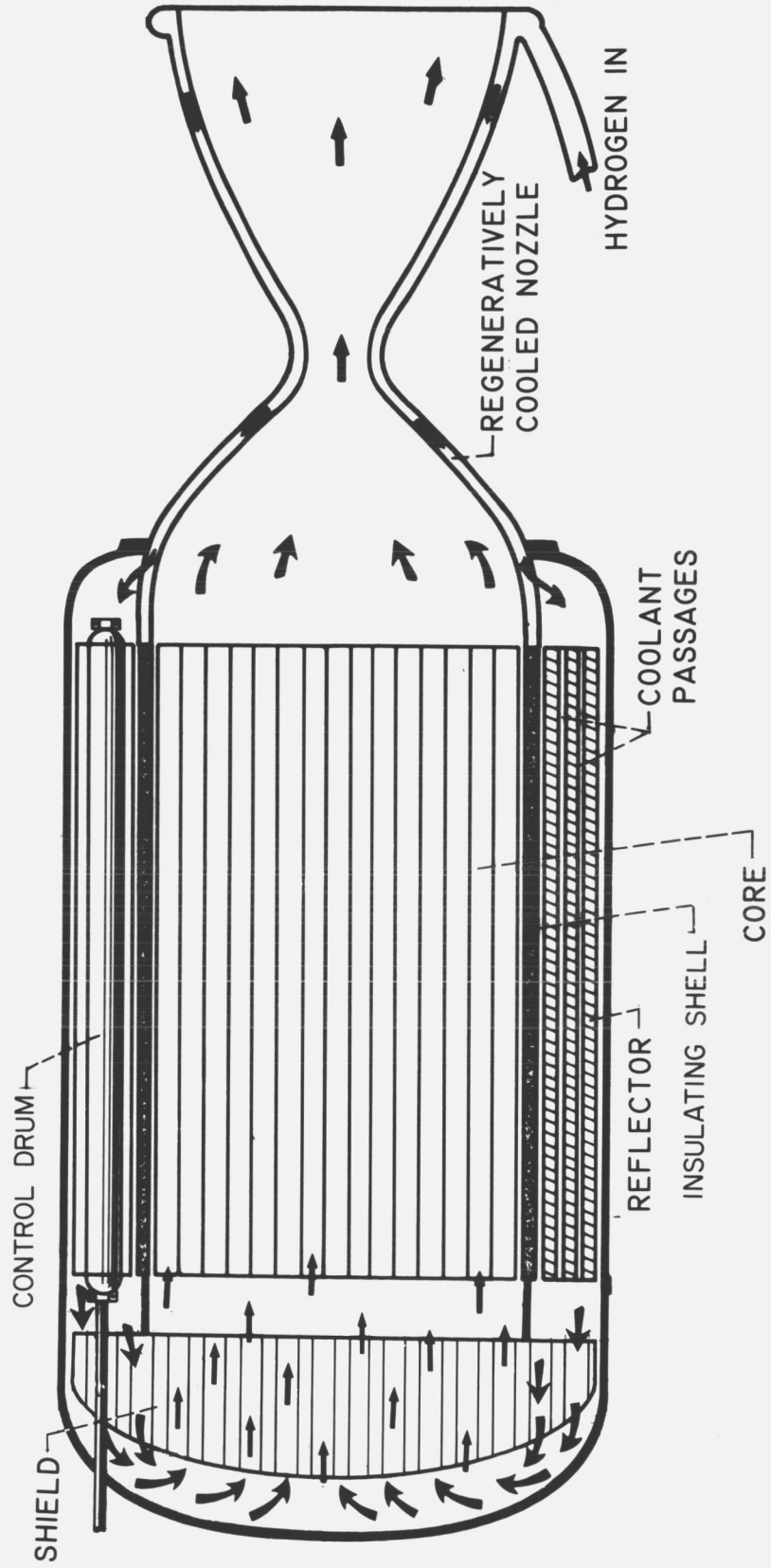
The full-scale engine development and PFRT will be done largely on test stand ETS-1 after certain modifications to it. Plans also include an additional stand for ground testing the engine/prototype vehicle tank combination. If funding proves adequate, engine PFRT should be completed by about 1975 and the 75,000 lbs. thrust engine should become available for initial flight usage shortly thereafter.

NERVA PROGRAM STATUS
Robert W. Schroeder, Chief
Space Nuclear Propulsion Office
Cleveland Extension

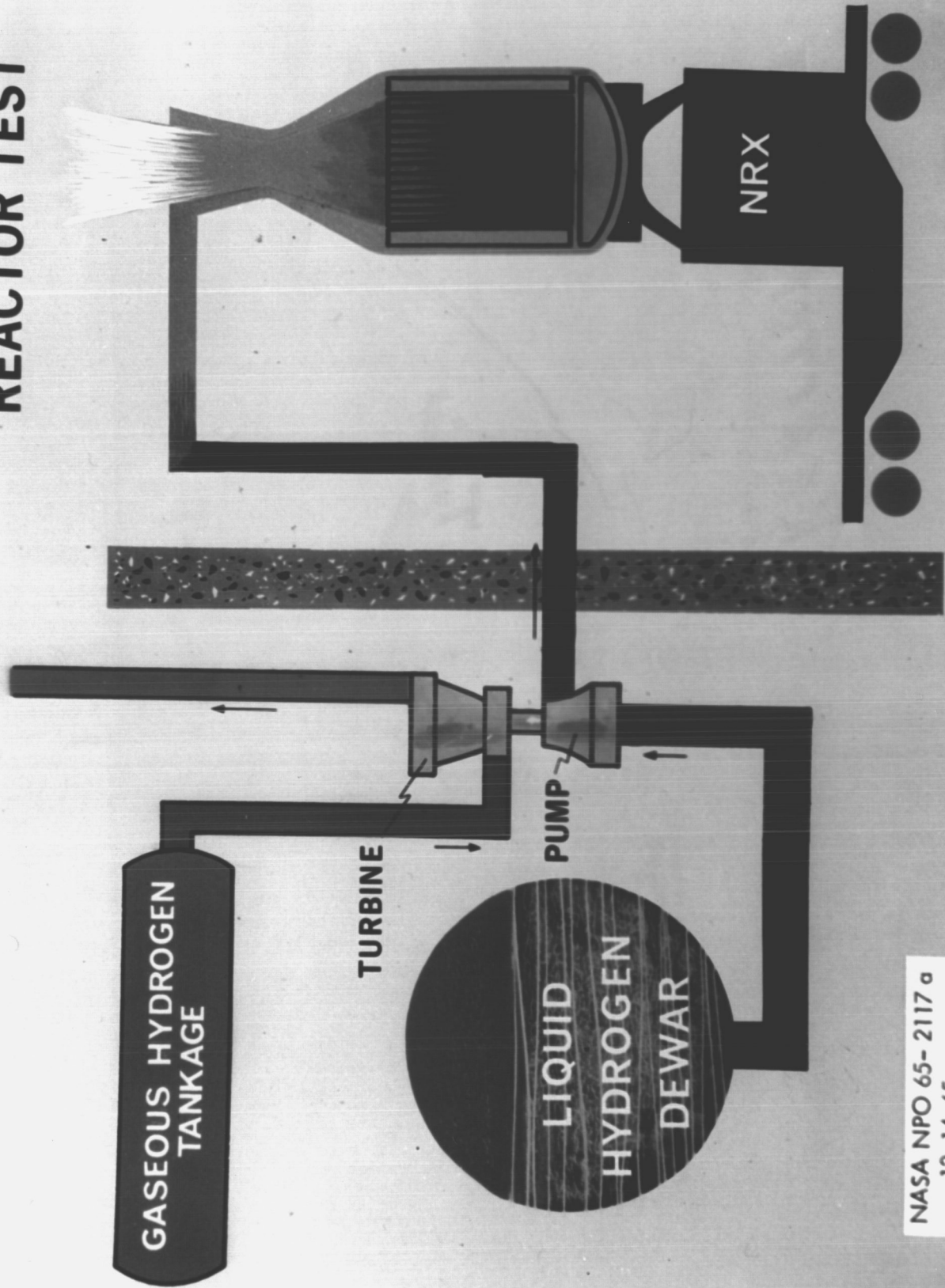
BIOGRAPHY

Robert W. Schroeder was born in New York City on December 2, 1917. He received a Bachelor of Mechanical Engineering Degree from the Polytechnic Institute of Brooklyn in 1939 and took graduate courses in aircraft engine structural design and motor fuels research at New York University and Stevens Institute of Technology, respectively. Subsequently, he devoted himself to aeronautical, nuclear, and aerospace activities and served as Chief, Power Plant Design Section, Glenn L. Martin Company; Chief of Design, Aircraft Reactor Experiment, Oak Ridge National Laboratory; Manager of Special Products, Griscom Russell Company; and Chief, Space Nuclear Propulsion Office, Cleveland Extension. In the latter capacity, he has served since March, 1962, with responsibilities for the technical, contractual, and administrative management of the NERVA Program and associated efforts and contracts in support of the NERVA Program.

NERVA REACTOR

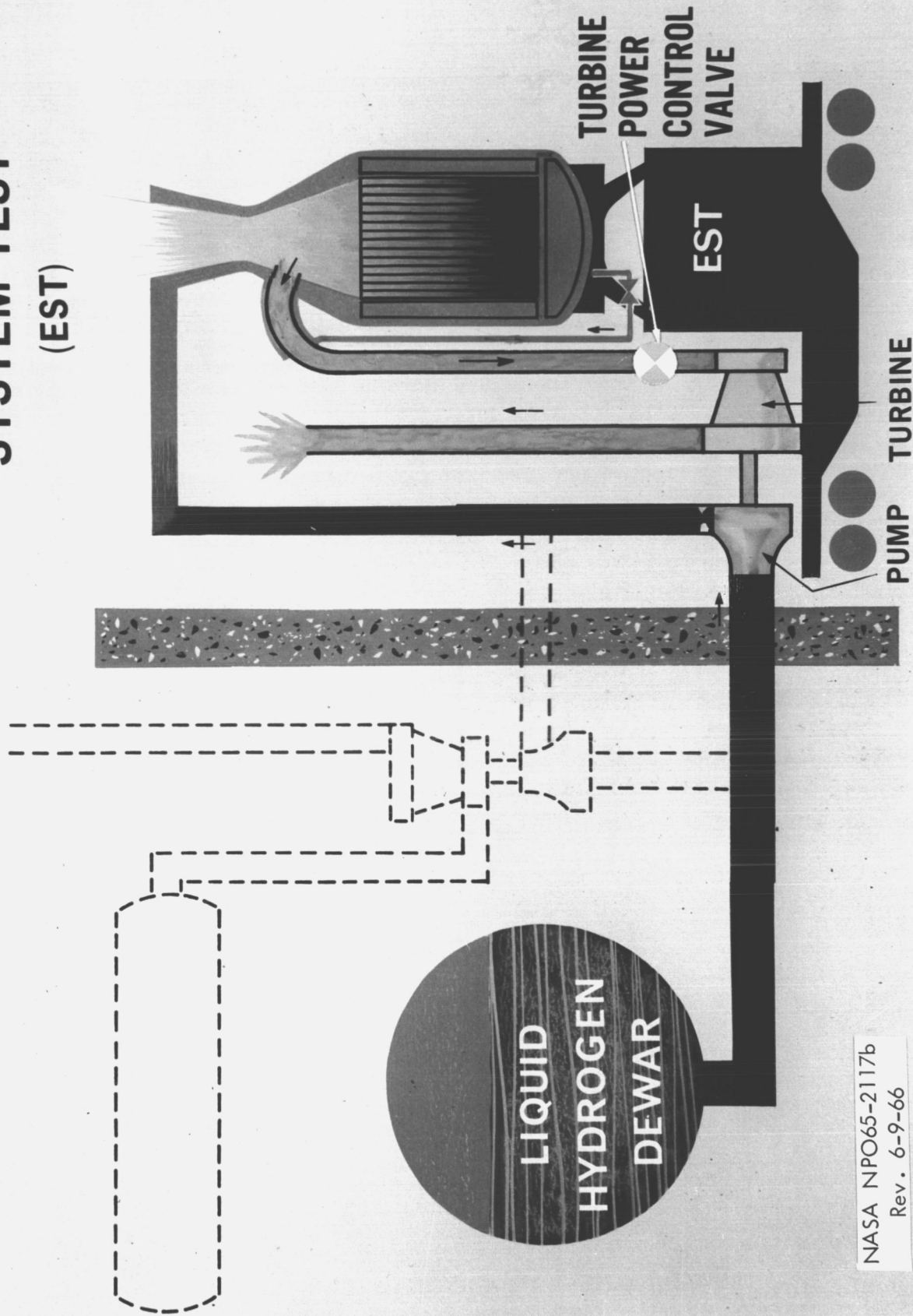


REACTOR TEST

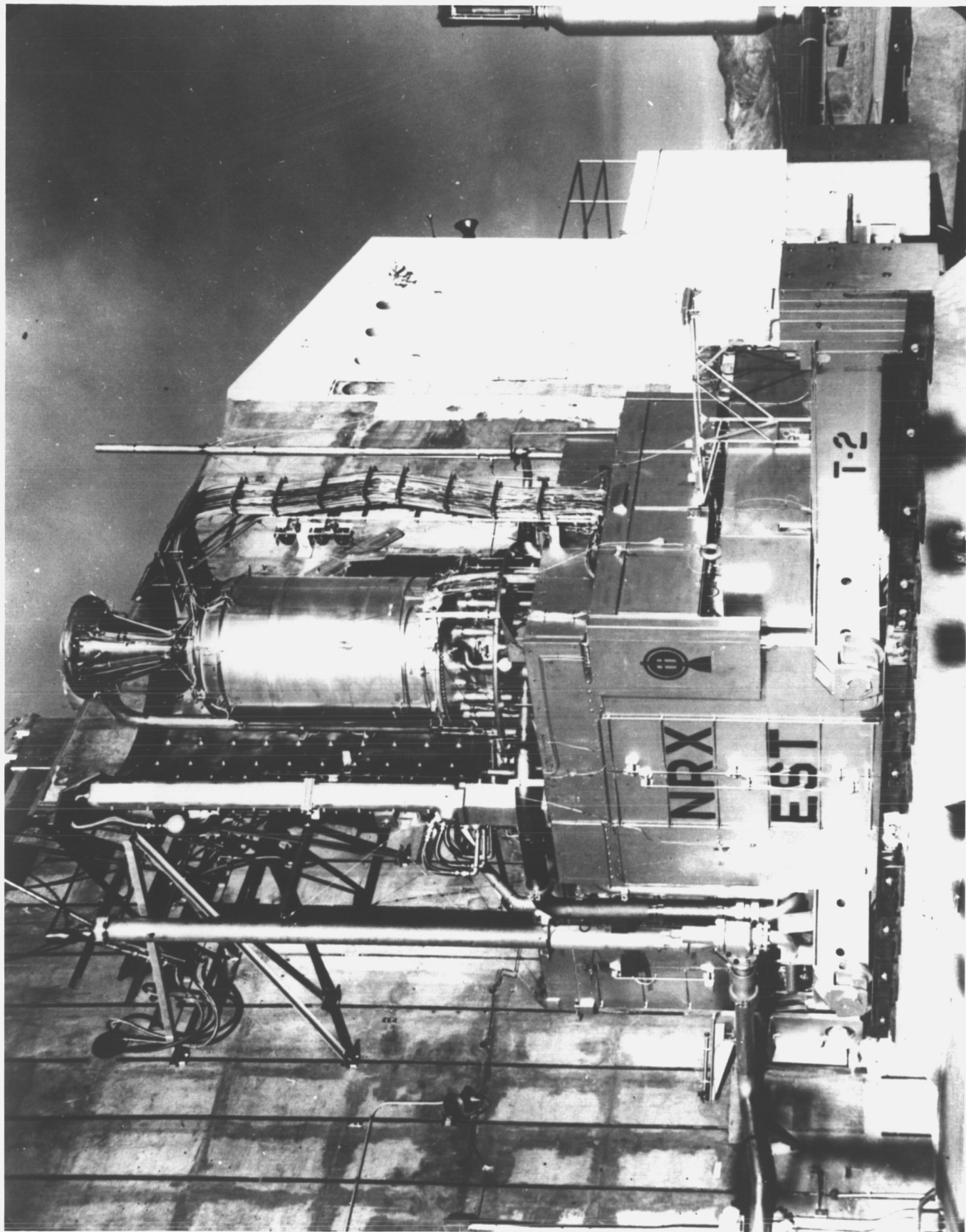


NASA NPO 65-2117 a
12-14-65

BREADBOARD ENGINE SYSTEM TEST (EST)



NASA (Figure (4))
CS-43493



NRX-A6 TEST OBJECTIVES SUMMARY

EP	TEST	PRIMARY OBJECTIVES	COMMENTS
I	<p>INITIAL CRITICALITY AND CONTROL DRUM CALIBRATION TEST</p> <p>NITROGEN FLOW TESTS</p> <p>NEUTRONICS CALIBRATION TESTS</p>	<p>TO ATTAIN CRITICALITY AND TO ENSURE THAT THE CONTROL DRUM WORTHS ARE ADEQUATE FOR POWER TESTING.</p> <p>TO PROVIDE ASSURANCE THAT THE INSTRUMENTATION IS READY FOR SUBSEQUENT TESTING AND TO PROVIDE A DEMONSTRATION OF THE STRUCTURAL INTEGRITY OF THE REFLECTOR SYSTEM.</p> <p>TO CALIBRATE THE NUCLEAR INSTRUMENTATION TO BE EMPLOYED FOR NUCLEAR POWER CONTROL.</p>	<p>ALL OBJECTIVES WERE MET</p>
II	<p>SYSTEM CHECKOUT</p>	<p>TO VERIFY PERFORMANCE OF ALL SYSTEMS AND SUB-SYSTEMS AND TO PROVIDE COORDINATION RUN FOR OPERATING PERSONNEL.</p>	<p>SYSTEM CHECKED OUT SATISFACTORILY.</p>
III, III-A	<p>POWER TEST</p>	<p>TO OPERATE AT RATED CONDITIONS FOR A TOTAL TIME OF 60 MINUTES.</p> <p>TO EVALUATE EFFECTS OF 60 MINUTES OF FULL POWER OPERATION ON THE STRUCTURAL INTEGRITY OF THE TEST ASSEMBLY.</p> <p>TO EVALUATE THE NRX-A6 STRUCTURAL DESIGN.</p> <p>TO EVALUATE THE NUCLEAR, THERMAL AND FLUID FLOW PERFORMANCE OF THE TEST ARTICLE.</p> <p>TO EVALUATE THE PERFORMANCE OF INSTRUMENTATION AND CONTROL SYSTEMS.</p>	<p>FIRST TEST TERMINATED AFTER 75 SECONDS AT 2000^{OR} HOLD BECAUSE OF SPURIOUS SCRAM. DURING SECOND TEST ALL OBJECTIVES WERE MET. REACTOR OPERATED ABOVE DESIGN TEMPERATURE AND POWER FOR SIXTY MINUTES.</p>

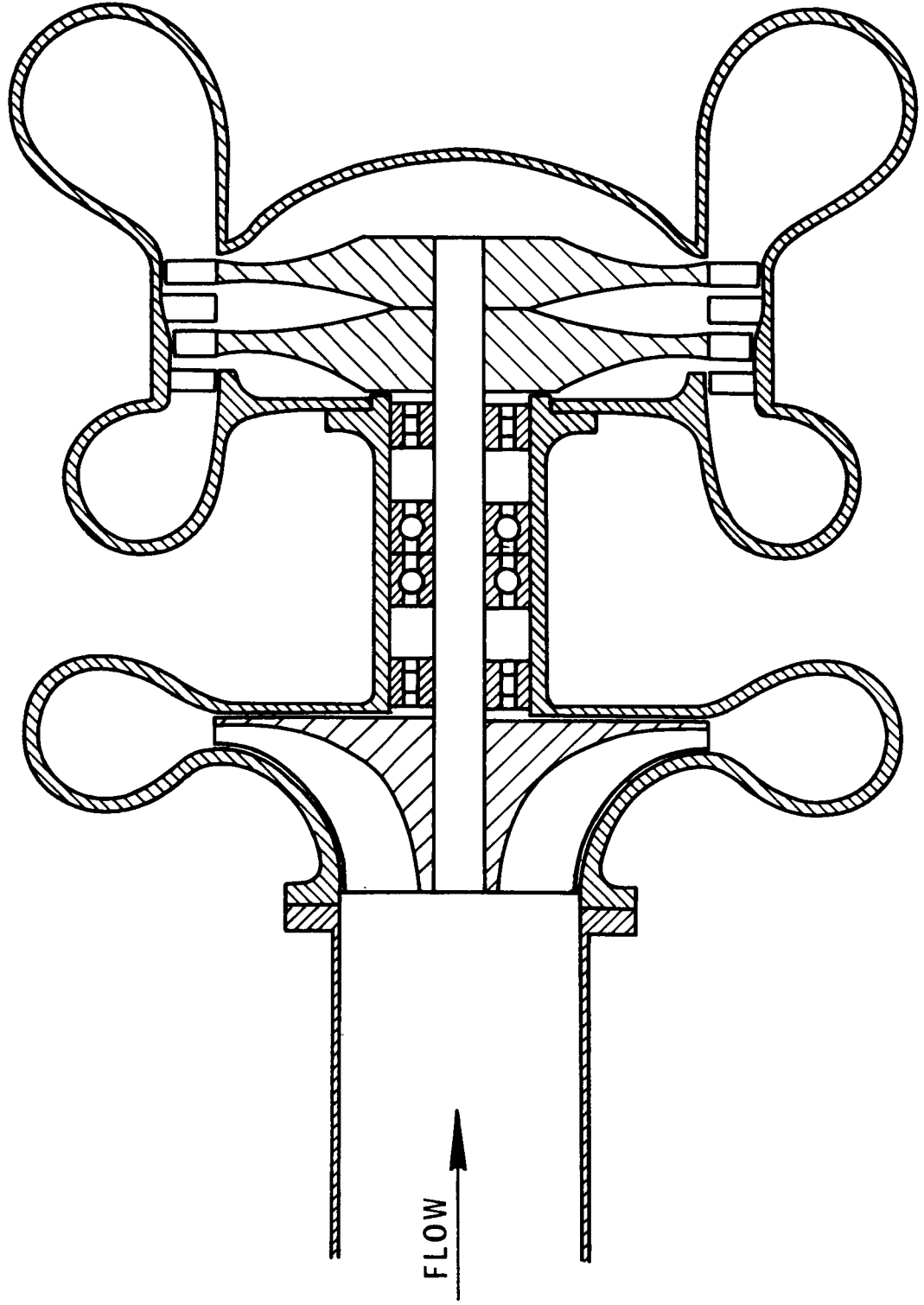
NRX REACTOR TEST COMPARISONS

REACTOR	NRX-A2	NRX-A3	NRX-A4	NRX-A5	NRX-A6
TEST COMPLETED	OCT 1964	MAY 1965	MAR 1966	JUNE 1966	DEC 1967
A. ENDURANCE RUN					
TIME AT FULL POWER-MINUTES	.8	16.6	30.1	30.1	62.9
AVERAGE POWER - MW	1000	1060	1100	1100	1150
AVERAGE CHAMBER TEMP. °R	3600	3860	3970	3980	4150
MAXIMUM CHAMBER TEMP. °R	3810	3900	4130	4150	4330
INTEGRATED POWER MW-SEC.	4.8x10 ⁴	1.1x10 ⁶	2.0x10 ⁶	2.0x10 ⁶	4.3x10 ⁶
B. TOTAL TEST SERIES					
TOTAL OPERATING TIME - MINUTES	26	71	115	37	72
NUMBER OF STARTS	2	3	11	2	2
INTEGRATED POWER MW-SEC.	3.8x10 ⁵	1.8x10 ⁶	3.7x10 ⁶	2.2x10 ⁶	4.5x10 ⁶
REACTIVITY LOSS \$.1	.9	3.2	2.1	.7

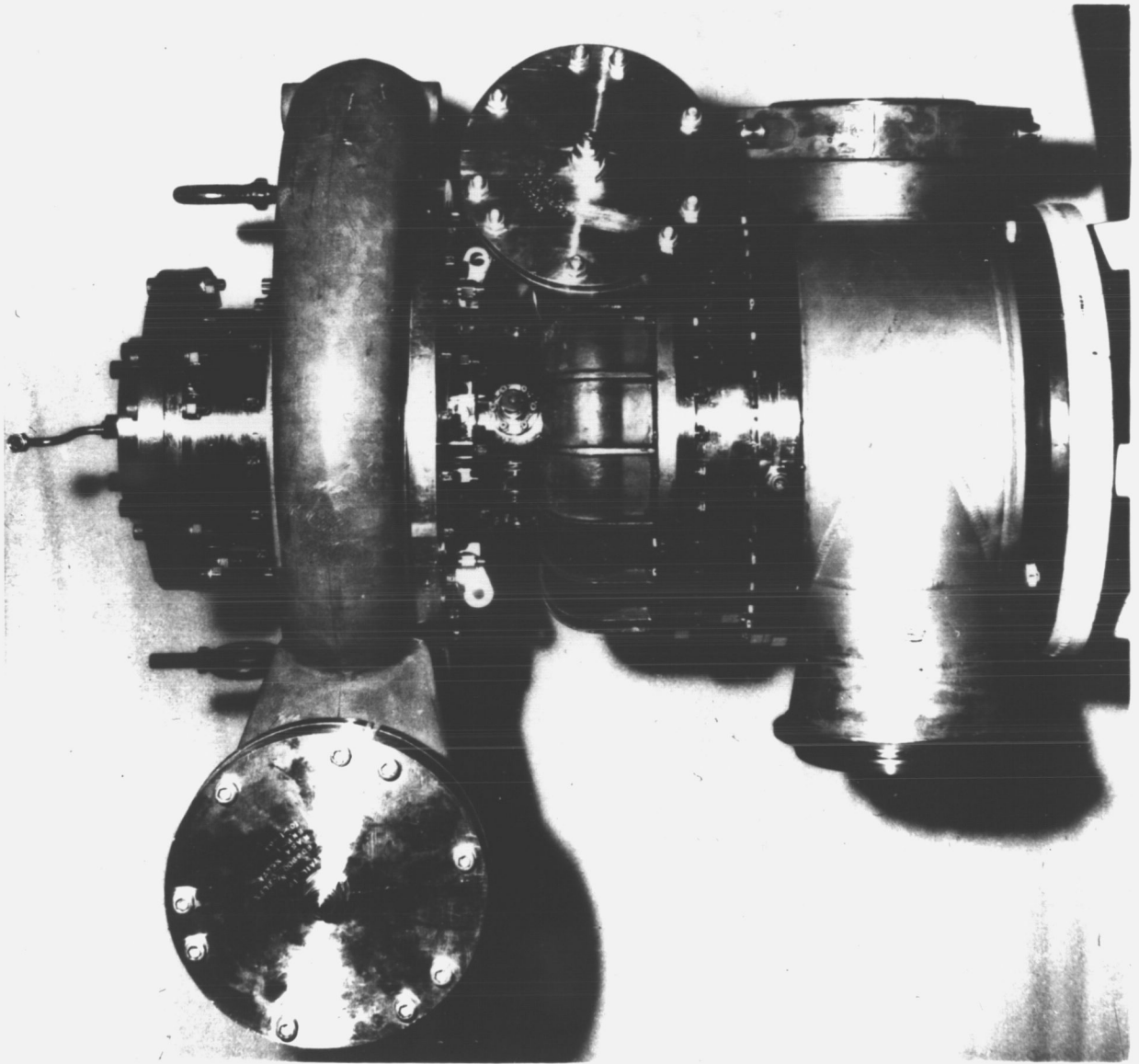
NASA (Figure (7))
CS-45792



DIAGRAMMATIC SKETCH OF NERVA TURBOPUMP



NERVA TURBO - PUMP



PROPELLANT FEED SYSTEM COMPONENTS X-ENGINE

