Presentation at the ANS/ENS International Meeting
November 15, 2000

MANAGING THE ROVER/NERVA PROGRAM

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former (1960's)
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Director, Space Power and Nuclear Systems, NASA
Director, Space Nuclear Systems Division, AEC
NASA Associate Administrator for Organization and Management

I list all these titles to indicate that part of my background that relates to and makes me somewhat eligible to speak on this subject and to be a part of this important Panel. This (Slide 1) is the joint AEC-NASA Space Nuclear Propulsion Office (SNPO) organization that I headed and that is the basis for much of my discussion. And it also indicates the program direction responsibility I had within NASA for the Reactor In Flight Test (RIFT) system which was planned as the vehicle stage to flight test our first nuclear rocket. Then, later (Slide 2), I also took over the radioisotope work in the AEC. I want to emphasize that these organization charts convey only a very small part of the tremendously strong technical and management capability that was actively drawn on in accomplishing our nuclear rocket program. I'll discuss that later. But I guess this is why I've been called on by Dave Black, our Chairman, to discuss the management concepts and systems we used in the nuclear rocket program and I thank him very much for inviting me to do that.

This chart (Slide 3) shows the original planned sequence of our program starting with the Los Alamos KIWI reactors, including their detailed fuels materials and critical assembly and control work, the NERVA engine development, and our plan to conduct a flight test of this Reactor In-Flight Test stage on the Saturn launch vehicle. As is apparent, since we never flew a nuclear rocket, this flight test development was cancelled later in the program and I'll explain that later. Also, as my organization charts indicated, Los Alamos moved from their 1000 plus megawatt KIWI reactors to their higher power developments in the Phoebus reactors and there were many other parts to the program and many organizations involved.

These various activities and this Panel's responsibility brings back many memories of the outstanding accomplishments made in that Rover/ NERVA Nuclear Rocket Program by an outstanding TEAM of people and organizations working together closely -- and I emphasize TEAM. Although many of the individuals who participated are no longer with us, I can tell you that those who are still here seek opportunities to be and work together. In fact, we just had a Rover Reunion in September, arranged by Los Alamos people, in Las Vegas near our Jackass Flats test site at the Nuclear Rocket Development Station. Yes, Jackass Flats is where we did our reactor and engine testing but it is not descriptive of nor named for the people working on the program there.

Here are just a few of the people who were involved in these various activities (Slide 4). As our biographies indicate, Dave worked with Westinghouse on its nuclear rocket reactor development and Stan Gunn was from Rocketdyne, involved in the major work they did on pumps and nozzles for the KIWI reactor tests. Very importantly, that Rocketdyne hydrogen pump development provided the pump for the J-2 hydrogen oxygen rocket engine. In this picture of the NERVA engine model, we have Howie Schmidt, formerly of the Air Force- AEC Aircraft Nuclear Propulsion Office and then heading the NERVA work in the SNPO Headquarter's office, Sid Krasik, an outstanding technical leader in the Westinghouse work on the NERVA reactor, Les Corrington from our SNPO Cleveland Extension, Bill House and Charlie Trent from Aerojet General who led the NERVA engine system work, and me. And here (Slide 5), after the major KIWI-B4E test that was a great and important success are some of the outstanding and key people from Los Alamos who did so much in leading the early research and technology development work that led to the KIWI designs and tests and the higher power Phoebus reactor work. Here is Norris Bradbury, the Director of the Los Alamos Lab, Raemer Schreiber, the head of the nuclear propulsion work, Rod Spence, Keith Boyer, Frank Durham, Bert Knight, and there were many other individuals and organizations in the program. I go through these as examples to indicate that ours was a very broad and enthusiastically committed TEAM of people and organizations joining their great capabilities in the areas required to achieve the objectives of the program. In fact, when I first saw this model (Slide 4) of the NERVA engine, I directed that the Aerojet General insignia be removed from it and all other models or pictures to convey clearly to everyone that this was not a single organization's, but rather a multi-organizational, activity and program and objective. Indeed, as I'll indicate later, this need to assure that all elements of the organization work in an integrated way across all of the required functions is one of our management principles that I'll discuss shortly.

The three of us on this panel and those others who are still around would eagerly jump on board any realistic effort to retrieve some of those past accomplishments and work to apply them to meeting future, defined space mission objectives requiring nuclear propulsion for their accomplishment. In fact, my view -- and I am convinced that of the others who worked on the program -- is that the accomplishments we made, the performance we achieved in that very broad program provides the clear technological system basis for safe nuclear thermal rocket operation required for major deep space missions that have been discussed, proposed, considered for decades. We achieved full system operation for over an hour and ran fuel elements that exceeded the 10 hour 60 cycle operating capability that the program set. And we developed and demonstrated the capability to achieve a wide range of thermal power and thrust with the high specific impulse that future missions may require.

Let's move on to those advanced missions with the assured propulsion capability that is provided and that was demonstrated by that Rover/NERVA technological base and in accordance with the basic principle we established forty years ago **that nuclear energy is used only when it makes it realistically possible to achieve the objectives of desired**

space missions. Yes, human travel to Mars is made realistically and safely possible with that nuclear rocket system. Let's do it.

With that introduction and pitch, let me now turn more specifically to my assignment on this Panel -- the organization, the management system, basic concepts, and process we established to manage the nation's nuclear rocket program. First, I should emphasize the major management principles (Slide 6) that we followed as we defined our overall approach and as we proceeded through this program. I applied these principles, perhaps somewhat automatically without any clear and deliberate effort, based on the experience I had and based on the influence of outstanding managers under whom I worked that gave me a sense of how to manage even before I was asked to head the Rover program. I believe these principles still apply and should be used today even though I also believe that, too often in various government activities, they are now being disregarded and even violated. My listing of these principles should not be viewed as defining any order of importance; they are all important.

Management Principles

1. Any organization responsible for a major scientific and technological program must assure that it has high internal scientific and technological as well as significant management capability in the areas involved in fulfilling its responsibility. If it doesn't have such capability, then it must be established in some way. The SNPO extensions that I'll discuss later indicate how we built our capability.

2. Assignment of major parts of the work on the program to other organizations must be done in an objectively solid process weighted heavily on the proven experience and knowledge and availability of the required capability. Really look for the best.

3. Assignment of major parts of the required work to other organizations does not and cannot relieve the central program organization from its assigned overall responsibility for assuring that the program is effectively carried out and its objectives are met. That responsibility cannot be given away. You can't blame others.

4. All elements of the program operation must work in an integrated way across the various required functions and the various organizations involved in executing those functions, including the overall management organization. No part of the organization is independent of the others. They must know what each is doing. I've already referred to this in our TEAM approach.

5. The program leader and the overall management organization must have visibility into the activities of the various parties assigned to carry out the various functions of the program through encouragement of open discussion of perceived issues, concerns, questions by and among the parties involved. Anyone's uneasiness must be freely expressed and heard.

6. It is essential that Federal agencies that may have a special development responsibility -- as, for instance, the old Atomic Energy Commission's or the Department of Energy's current authority under the Atomic Energy Act for nuclear energy systems -- should carry out their work in close association with the potential users, like NASA and DOD, of that technology for systems and missions under their responsibility.

In a simplified summary of these various principles, the organization must operate as a TEAM with full awareness of objectives and activities underway in all parts of the program and its potential uses and with mutual respect and openness across all the elements of the organization. In the end, the measure of our success would be the actual achievement of the objectives we set to provide a proven capability for deep space flight.

I emphasize these principles because they did provide the basis for our operations. Just as I referred to the outstanding technological achievements in our program that I am convinced make it possible to accomplish future difficult space missions with high assurance, I believe these management principles and concepts that we applied are also required to achieve those objectives. I emphasize them also because I have serious concern that they are being disregarded too often today, as I mentioned earlier. Internal capability in several organizations I know of has declined significantly. In fact, government is not attracting the bright young capability it used to. Too often, delegation of authority/responsibility is made to outside organizations with the implication that the central organization has relinquished some of its responsibility. The operating arms of the program organization are often discouraged from raising valid concerns or questions they may have for fear that the program and their role may be severely reduced. Fundamentally, we need to get back to running our programs with a clear goal of assuring their success rather than a willingness to accept failure because of technology uncertainties, arbitrarily set cost limits, inadequate component and system development testing. I am sure that your experience can identify violations of the principles that I've enunciated here.

By enunciating these principles, I am also raising the critical question of how can we reestablish the high standing of government employment that existed when I was a young punk in that service with the clear commitment to achieve the objectives we set. Frankly, I don't have the answers but it's a problem we must all address. Good examples and clear leadership through all levels of government is obviously essential but we must also show that there is a valid progression of opportunity within and even after government employment. I certainly benefitted from such opportunities.

THE ESTABLISHMENT OF THE JOINT AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

It is important to recognize that our NASA role and organizational structure in this program did not start from scratch. In fact, nuclear rocket research actually started in 1955, 3 years before NASA was established, under the management of the AEC-Army

Air Corps Aircraft Nuclear Propulsion Office (Slide 7) with both the Los Alamos and Lawrence Livermore Laboratories of the AEC involved. At that time, the objective was mainly nuclear ICBM propulsion. In 1957, the DOD dropped the nuclear ICBM objective. Then, when NASA was established in October, 1958, the Air Force responsibility for the nuclear rocket system work was transferred to NASA by Executive Order. That started the effort to establish a joint office of NASA and the Atomic Energy Commission. That joint office concept had been well established in the Navy nuclear submarine program and in the Army Air Corps nuclear aircraft program. It grew largely out of the 1946 Atomic Energy Act's assignment of civilian control over military and civilian nuclear energy development to the Atomic Energy Commission. That is still the situation with the Atomic Energy Act authority assigned to the Department of Energy. So the AEC and DOE bear responsibility for government reactor development and the user agencies like NASA and DOD provide the development of the non-nuclear components and full nuclear propulsion and power systems.

However, although I started working closely with the AEC-Air Force office and Los Alamos, it took some time to get a joint AEC-NASA office established. Extensive discussions involving the Administrator of NASA T. Keith Glennan, the Chairman of the AEC, and, very importantly, key members of the most powerful House-Senate Joint Committee on Atomic Energy finally led to a Memorandum of Understanding on August 31, 1960 announcing the joint AEC-NASA Office to manage the program. That office was shortly later named the Space Nuclear Propulsion Office, SNPO. I was named its Manager and Milton Klein, who had been Assistant Technical Manager at the AEC's Chicago Operations Office, was named the Deputy Manager. A small team of about 15 to 20 very capable people from NASA, the AEC and officers from the AEC-Air Force Office, formed the Headquarters staff of the office. To be sure that the organization had the capability it required, we established three Extensions of the SNPO (Slide 8). One was in Albuquerque to provide direct liason with the AEC's Albuquerque Operations Office that had management oversight of Los Alamos; a second in Nevada to provide management support for onsite activities and direct contacts and communications at the Nuclear Rocket Development Station with the AEC's Nevada Operations Office and directly with the facility and the reactor testing requirements; and the third in Cleveland for management of our engine contract work drawing on the close technical support of the NASA Lewis Laboratory with its experience and continuing work on hydrogen pumps, hydrogen cooled nozzles, and other components needed for nuclear rocket engines.

That provided our SNPO with the broad capability we needed to conform with the first management principle I listed earlier. In fact, here are some of the actions (Slide 9) that we accomplished very soon after SNPO was established, in addition to RIFT actions that we took within the NASA program itself. Obviously, the first things we had to do were to get our major contractors, identified here in this Slide, selected and to move forward on the start of the NERVA engine development and design and on building the full facility base we would need for our high hydrogen volume nuclear rocket reactor and engine tests including the necessary remote maintenance and disassembly (E-MAD) capability

for our engine systems. Here is the layout (Slide 10) of the entire NRDS showing the locations of the reactor Test Cells A in which the first KIWI reactors were run and then the addition of Test Cell C which provided a liquid hydrogen capability for our reactor tests with the Engine Test Stand (Slide 11) providing the first full, downfiring engine capability we needed for our NERVA engine tests. It is clear, however, that requirements for such reactor and engine testing are certainly different now than they were in the 1960's and early 70's. Though we exhausted, with careful monitoring, the high temperature nuclear heated hydrogen directly into the atmosphere, any testing of such systems today would require the prevention of even any low level potential radioactive emissions. As a result advanced concepts to retain that exhaust jet in the test facilities have been proposed and continue to be examined to make the necessary development testing acceptable. It certainly does, however, add to the difficulty of developing a full nuclear rocket system for space missions.

REACTOR AND ENGINE TEST EXPERIENCE

The next slide (12) presents the sequence of reactor and engine tests that were conducted through the program. It is important to reemphasize the more basic and extensive fuels materials, fuel element research, critical assembly, hydrogen pump and hydrogen cooled nozzle work and testing and other reactor and engine component and system development that was conducted prior to such reactor and engine testing and through the entire program. Nevertheless problems showed up. I won't go through all of these. But let me start with the KIWI-B4A test (Slide 13) that all of us expected to be the culmination of Los Alamos's KIWI program and would provide the basis for the NERVA reactor design. However, the high expectations for that November 30, 1962 test were quickly turned off when the test started and flashes of light in the nozzle exhaust indicated core damage as the power increased over about 250 megawatts.

A week later, on December 8th, (Slide 14) President John F. Kennedy flew out to the Nevada Test Site to visit the Nuclear Rocket Development Site after he and Vice President Lyndon B. Johnson had visited Los Alamos the previous day where they and their entourage were briefed on the nuclear rocket program. Included in the visits were Glenn Seaborg, Jerry Wiesner, Bob Seamans, McGeorge Bundy, Pierre Salinger, Harold Brown, Jim Ramey and others. At Los Alamos, Senator Clinton Anderson and Congressman Morris were also present and Senator Cannon and other Nevada members of the Congress were present at the Test Site. On the right side of this slide is Milton Klein, the Deputy Manager of the SNPO. At the time of the President's visit, the KIWI-B4A reactor had been moved to the MAD building but it had not yet been disassembled so we did not yet know what problem had actually occurred, although we did tell him and the group that there had been a problem in the test. On disassembly, it was found that almost all of the fuel elements had been broken as a result of severe vibrations that had been experienced through the entire core.

In the beginning of January, several of us met in our SNPO offices with Dr. Bradbury, Dr. Schreiber and some of their key people, with representatives from NASA's Langley ,

Lewis and Marshall. I expressed my decision (and I made it without confirming it with my bosses first) that we would have no further hot testing of the full reactor until we had gone through thorough work to identify the causes of the failures and to develop well defined solutions to those problems. Dr. Bradbury objected, saying that I would kill the program if there was no contiunued reactor testing. I responded that contrary to his position, there was no question we would kill the program if reactors continued to have major failures. He still objected and said they could make some undefined quick fix but I rejected any undefined, unproven "quick" fix. You'll all recognize that my view was we had to do the job right.

I'm pleased to say my decision prevailed and a comprehensive collaborative program was developed among the groups involved, obviously including reactor design analysis and extensive component, subsystem, and vibration testing by Los Alamos and Westinghouse. I then proposed that we run a cold flow non-fueled and, therefore, non-fissioning reactor test of the KIWI-B4A with ample instrumentation to confirm vibrations as the cause of the failures and, hopefully, to get further information to identify their source. That cold flow test was run on May 15, 1963 and it clearly confirmed a faulty design feature that resulted in interstitial flows that induced vibrations in the fuel elements and their failure. Incidentally, two days later, Norris Bradbury wrote to me saying that my "insistence on a repeat KIWI B-4A cold flow" had "resulted in a damned interesting experiment! Perhaps we've all learned something!" Basically, (Slide 15) Los Alamos had placed a peripheral flow seal at the inlet of the reactor so the low exit pressure permitted the core to expand outward and allowed interstitial or interfuel element flow to induce vibrations. It was totally a non-nuclear flow induced problem. Westinghouse had been concerned about the need to bundle the core to avoid interstitial flow and corrosion effects so they had placed the seal at the exit end of the core and were working on increased lateral support of the system. Based on those results and with thorough analysis and testing, Los Alamos and Westinghouse worked together to design corrections to the problems that were identified which we incorporated in another cold flow test. There were no vibrations.

With those confirming results, I approved moving forward with a redesign of the reactor for return to hot testing. About that time in 1963, NASA and the AEC were preparing their FY 1965 budget requests. In a budget meeting I had with the Commission, sitting across their big conference table from them, they made clear that they wanted to request funds to flight test the RIFT stage even though our resolution of the KIWI-B4A problems was not conclusively proven. Instead, we in SNPO proposed that we continue with a comprehensive ground development program that would establish a sound and proven basis for readiness to commit to flight systems and missions. But the Commission's decision was to try for the flight test budget. When NASA Administrator Webb and AEC Chairman Seaborg met with President Johnson and on the budget, he rejected the flight test. I was called over to the White House to prepare a memo from the Administrator and Chairman to the President presenting the ground test program and its budget which was accepted. That was when the RIFT stage effort was cancelled.

We then proceeded to test the KIWI-B4D reactor, first in cold flow early in 1964, and then, in May, the hot test was run. However, A leak in the jet nozzle led to a fire and curtailed the test after about a minute. However, we followed that test, near the end of July, with the KIWI-B4E (Slide 16) test which was our redesign based on all the year and a half of analysis, component design and testing , cold flow testing. There was high confidence about that design which was confirmed in the 8 minute full power (900 megawatt) test followed by a 2.5 minute restart and on its disassembly with no problems indicated. It was the success of that test that generated the obvious satisfaction shown in my earlier Slide 5. That satisfaction is also indicated in the (Slide 17) Jackass Flats postcards I sent to my wife and daughters.

That KIWI-B4E test completed the Los Alamos KIWI reactor work which was then extended by Westinghouse and Aerojet to the NERVA reactor, breadboard NRX engine, and full engine system testing while Los Alamos moved on to their Phoebus reactor work aimed at achieving higher powers and temperatures. These NRX breadboard engine tests (Slide 18) were run repetitvely for a total of about 30 minutes at power levels greater than 1000 megawatts. And the NRX-A6 reactor test achieved an operating time of over an hour at a power of 1100 megawatts, equivalent to over 50,000 pounds of thrust and the powered time required for the deep space missions being contemplated for nuclear propulsion application. And later we had a test of the full NERVA engine set up in the ETS-1 downfiring facility which was also operated successfully. The Los Alamos Phoebus tests (Slide 19) extended our power level to over 4000 megawatts, or more than the 200,000 pound thrust level.

CONCLUSION

Unfortunately, as many commentators at the time and historians of the space program have written, the technology of nuclear rocket propulsion was fully demonstrated as ready for flight mission applications, but the deep space missions whose accomplishment depended on nuclear propulsion applications were not part of the U.S. space program nor were any such missions planned. In addition, budget pressures led to the shutdown of the program in 1972. As I indicated early in this discussion, the increased interest in missions to Mars regenerates awareness of the importance of nuclear rocket propulsion, especially as the only proven nuclear propulsion system for accomplishing such missions safely and with high assurance of success. Those of us here and others who worked on the program would be ready to participate in rebuilding the knowledge base that was established and applying it to accomplish the human missions to Mars after instrumented missions explore that environment to define the human exploration objectives more fully. As I said before, **LET'S DO IT!**

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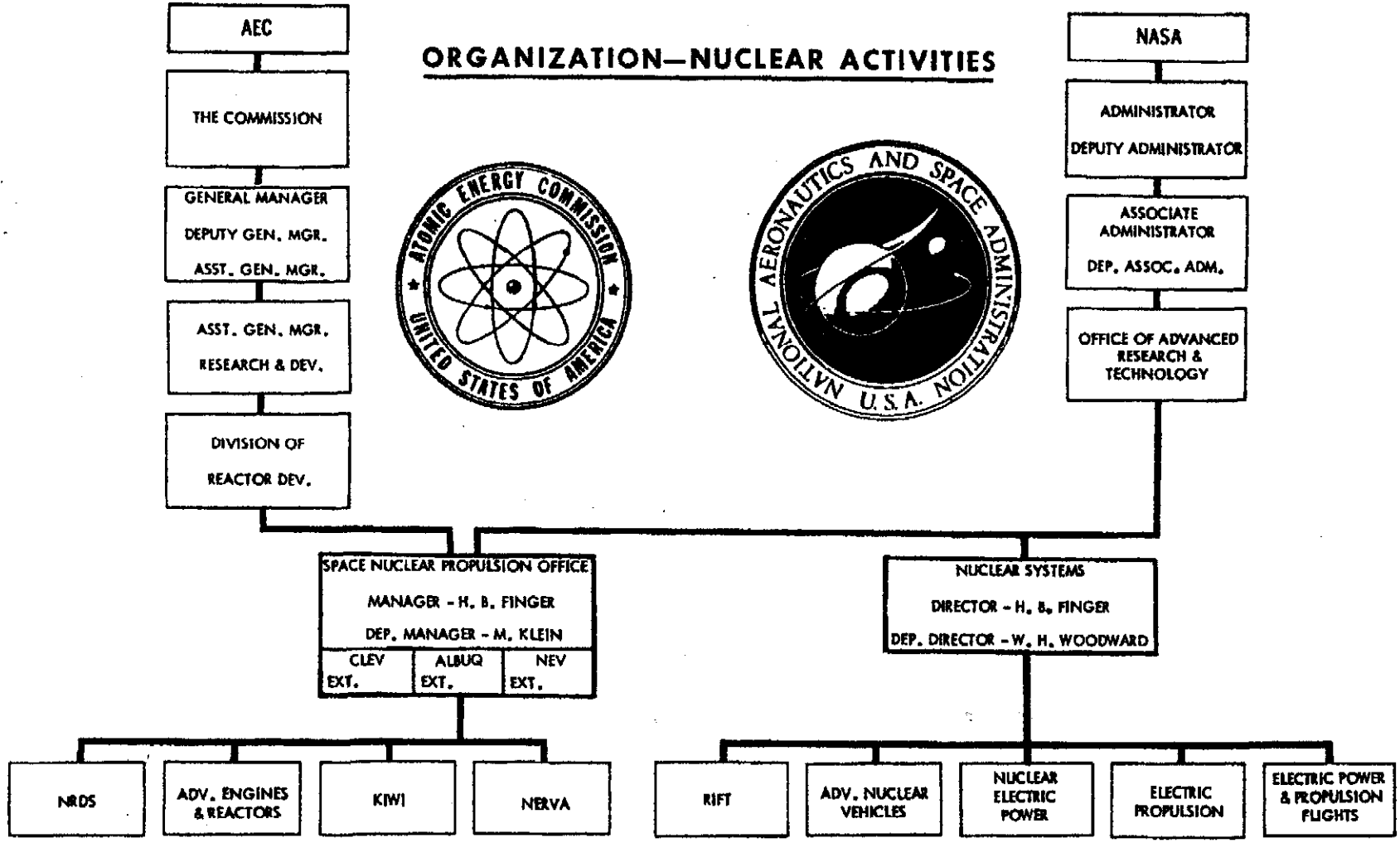
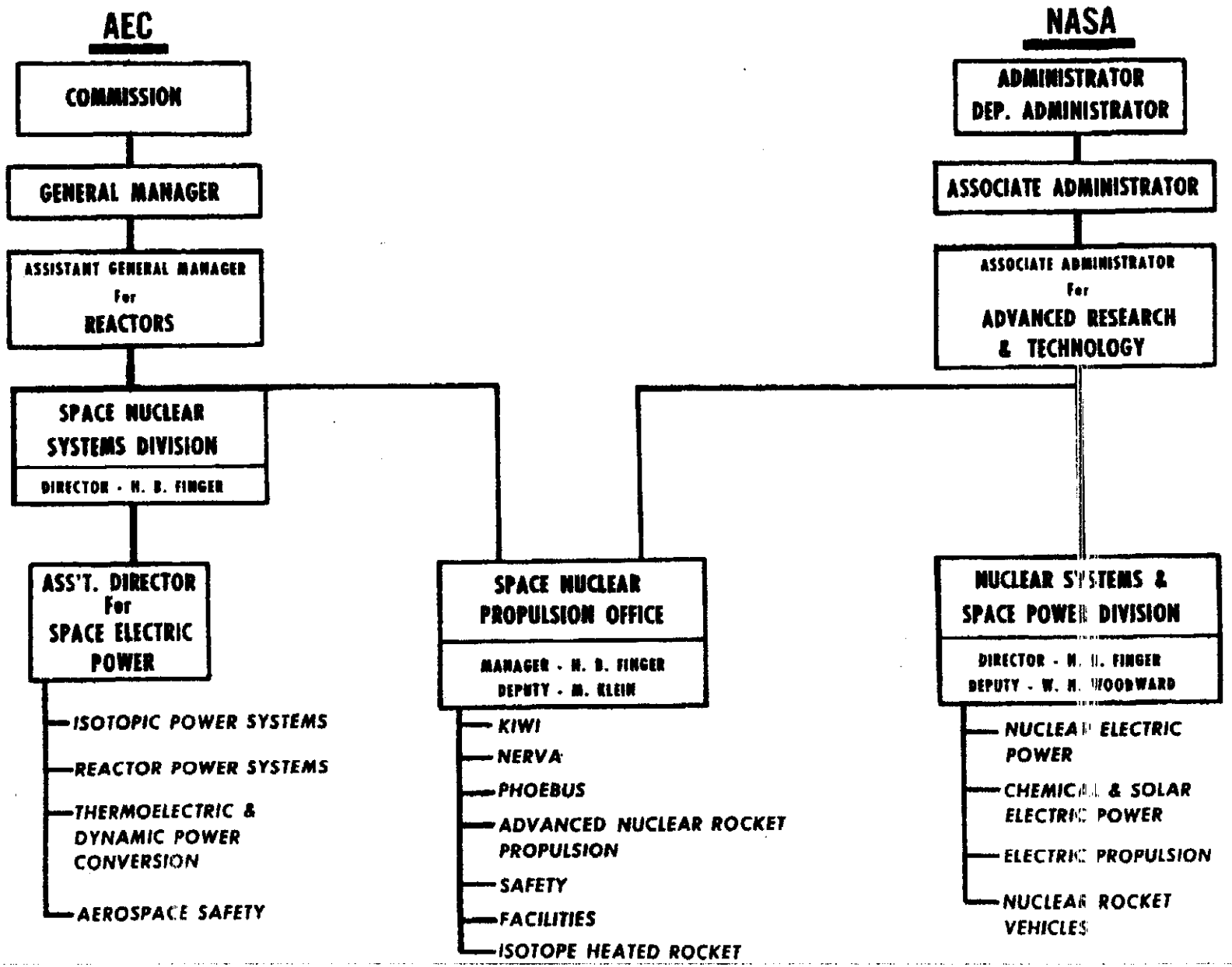
ORGANIZATION—NUCLEAR ACTIVITIES



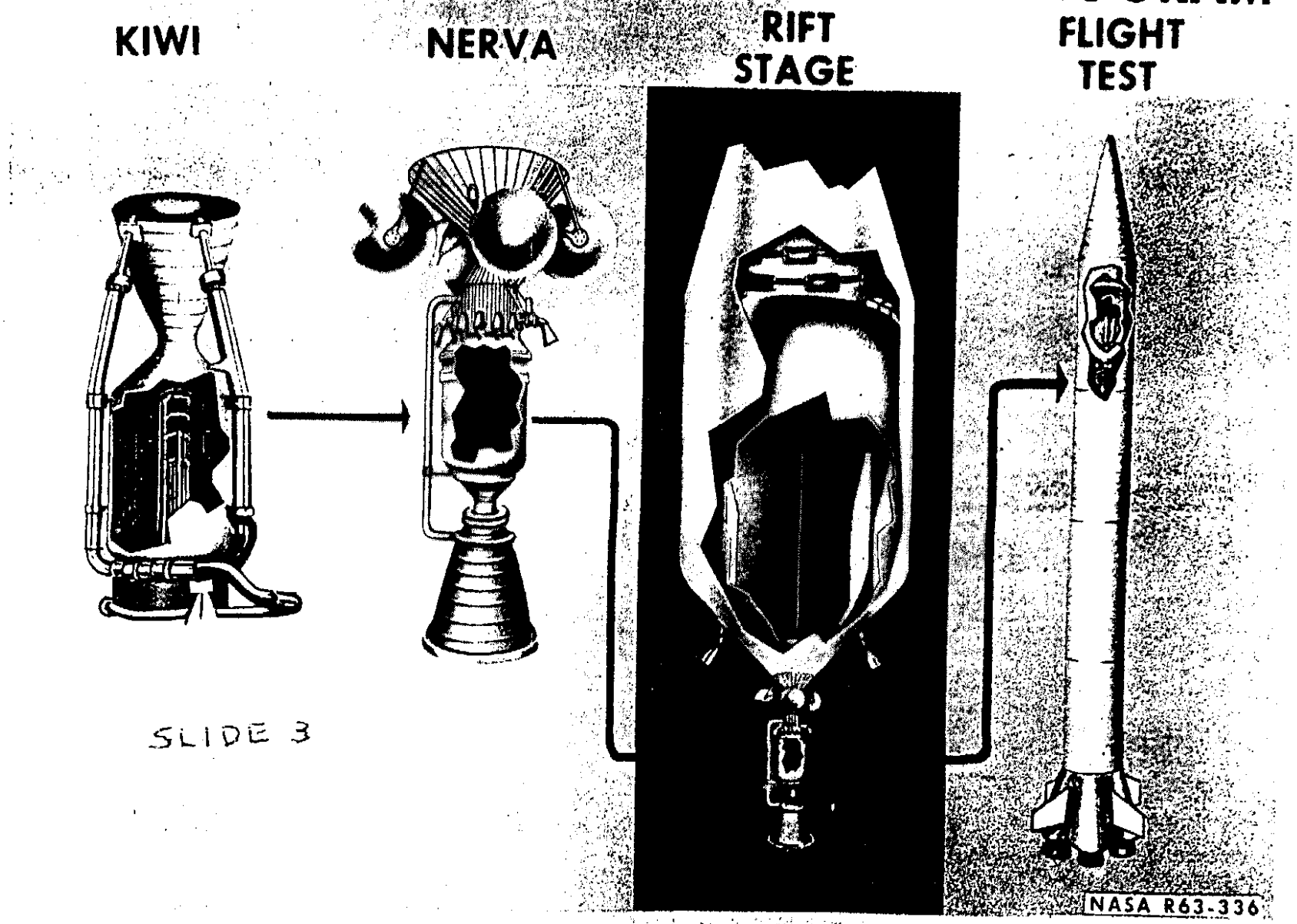
SLIDE 1

ORGANIZATION OF SPACE NUCLEAR SYSTEMS PROGRAMS

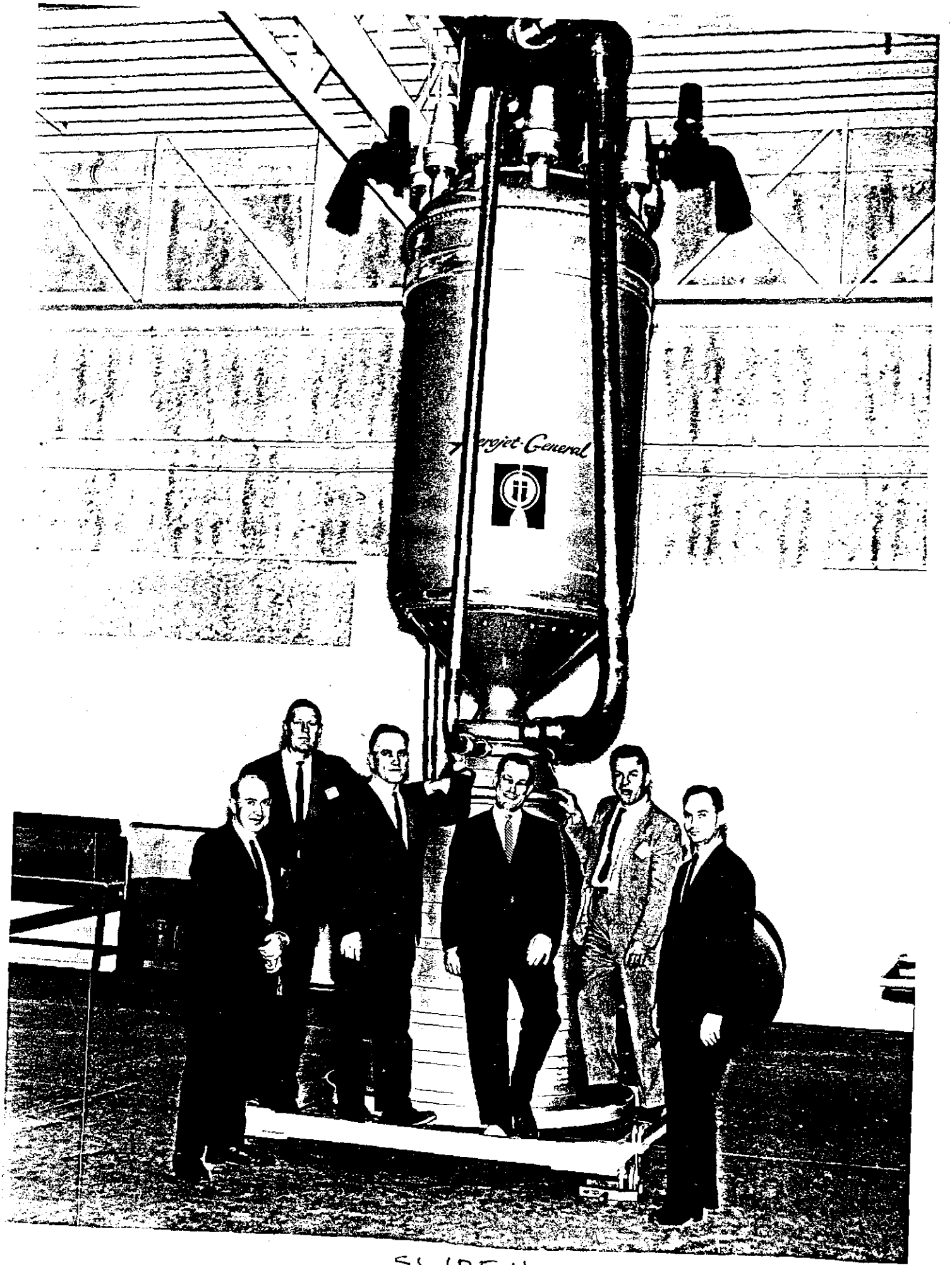


SLIDE 2

MAJOR STEPS IN NUCLEAR ROCKET PROGRAM



SLIDE 3



SLIDE 4

SLIDE 5

Slide 6

MANAGEMENT PRINCIPLES

1. Responsible organization must have high internal scientific, technological, management capability.

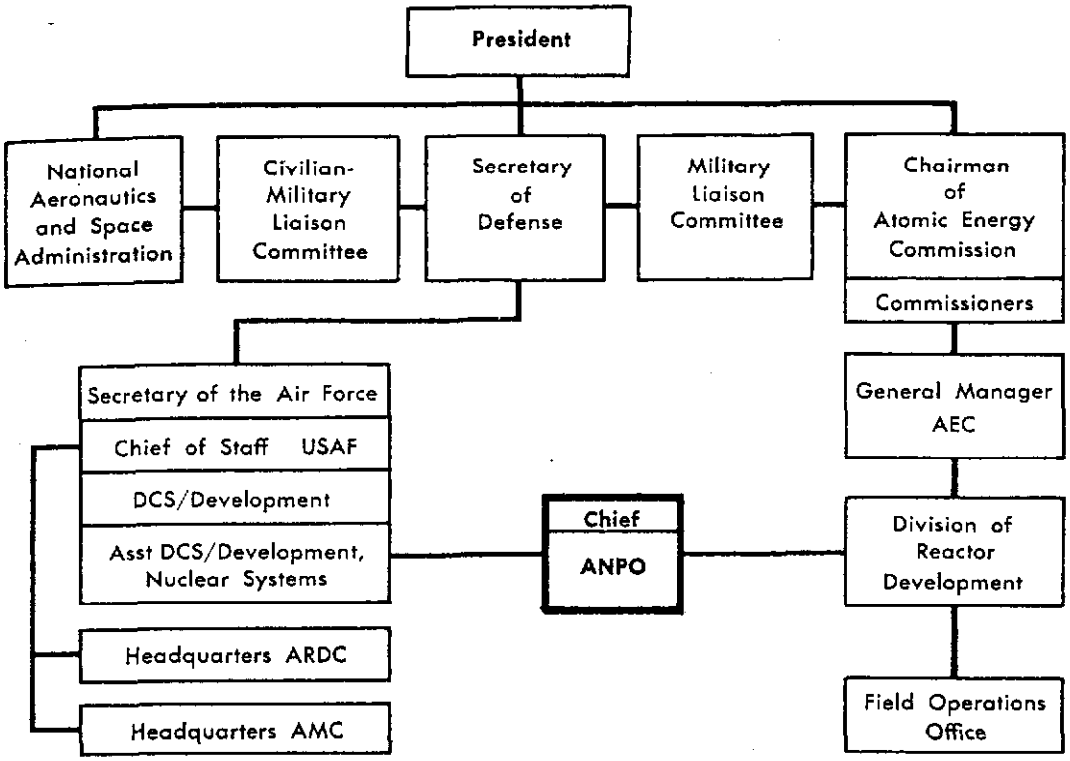
2. Assignment of work to other organizations requires objective evaluation to select the best.

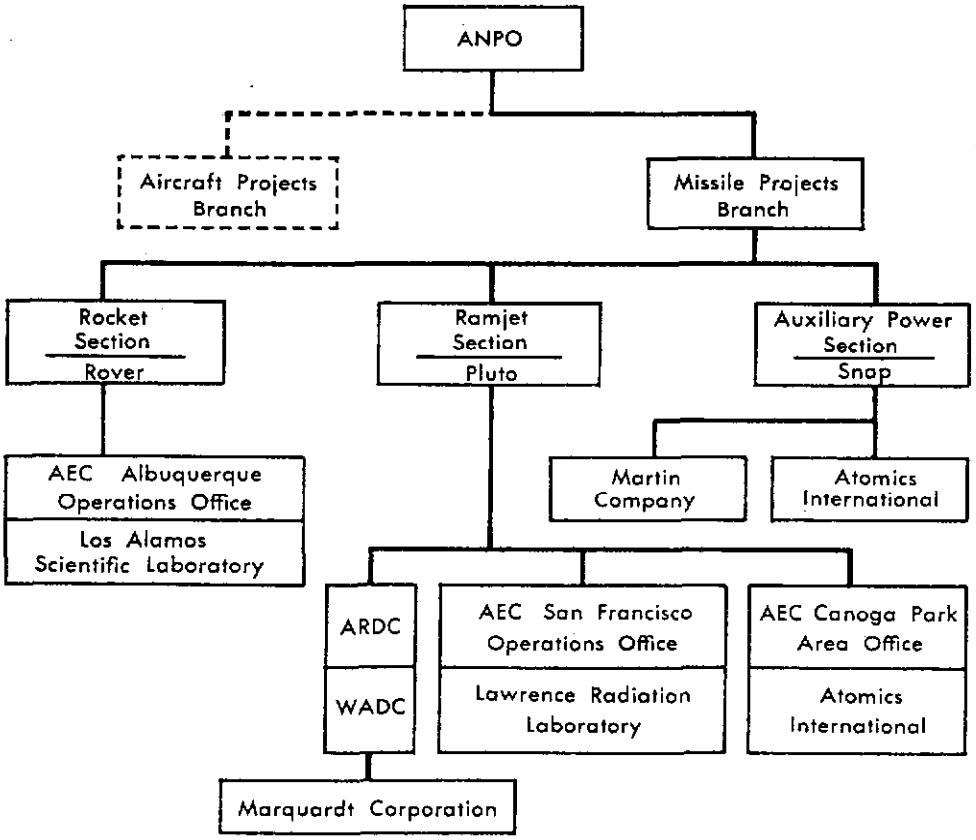
3. Assignment of work to others does not relieve the central organization of its responsibility.

4. All elements of the program must work in an integrated, collaborative way across all functions.

5. The program leader and management organization must encourage open communication and discussion of any issues, concerns, questions, uneasiness among all involved functional organizations and personnel.

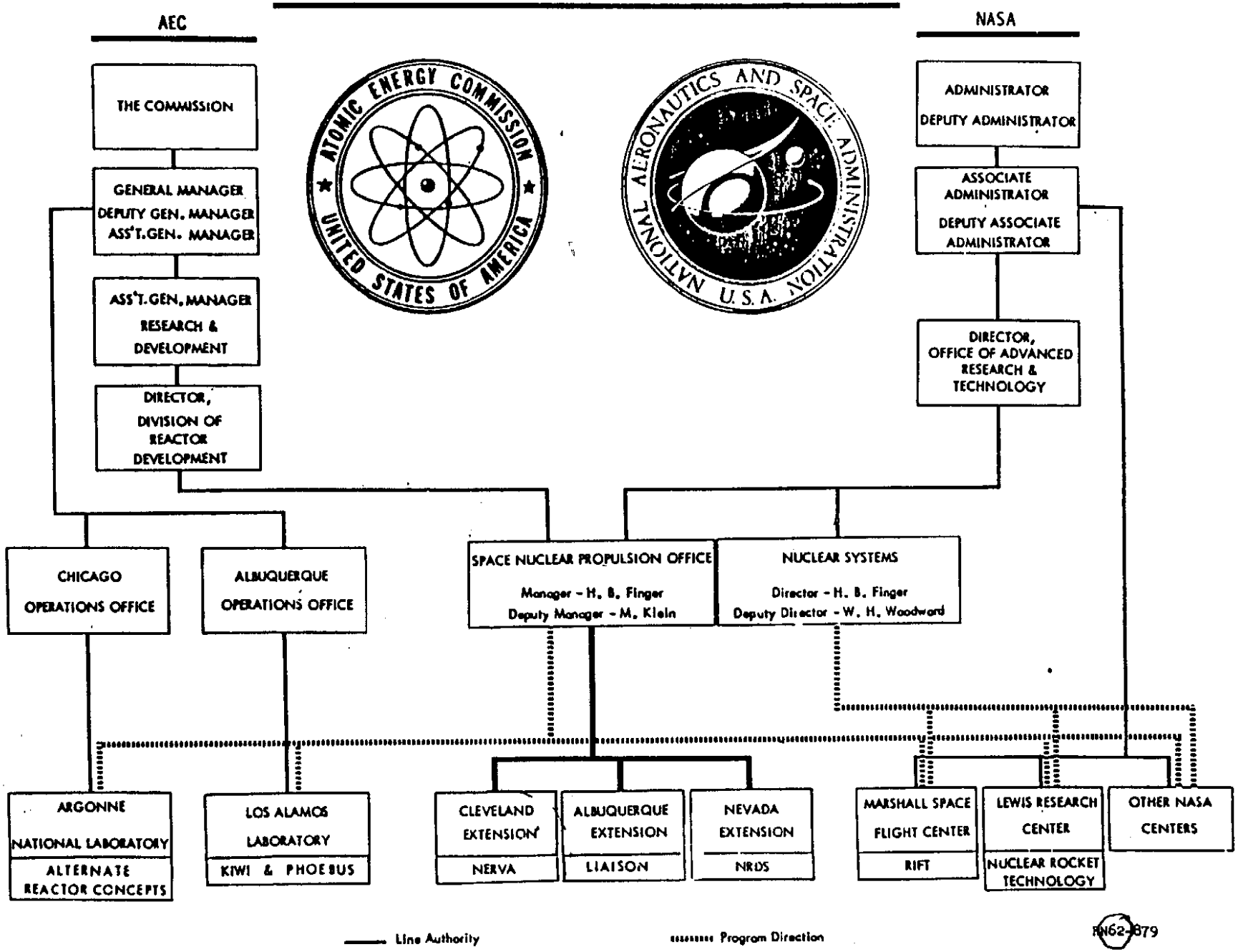
6. Close association among the various involved and responsible agencies -- developers and users -- is essential to achieve objectives.


President
National Aeronautics and Space Administration
Civilian-Military Liaison Committee
Secretary of Defense
Military Liaison Committee
Chairman of Atomic Energy Commission
Commissioners
Secretary of the Air Force
Chief of Staff USAF
DCS/Development
Asst DCS/Development, Nuclear Systems
Headquarters ARDC
Headquarters AMC
Chief
ANPO
General Manager AEC
Division of Reactor Development
Field Operations Office


ANPO
Aircraft Projects Branch
Missile Projects Branch
Rocket Section
Rover
Ramjet Section
Pluto
Auxiliary Power Section
Snap
AEC Albuquerque Operations Office
Los Alamos Scientific Laboratory
Martin Company
Atomics International
ARDC
WADC
AEC San Francisco Operations Office
Lawrence Radiation Laboratory
AEC Canoga Park Area Office
Atomics International
Marquardt Corporation

SLIDE 7

NUCLEAR ROCKET PROGRAM ORGANIZATION



SLIDE 8

3

EARLY PROGRAM ACTIONS

1. August 31, 1960: AEC-NASA Space Nuclear Propulsion Office established.

2. September, 1960: Contracts with Convair, Douglas, Lockheed, Martin on flight testing nuclear rockets (RIFT).

3. December, 1960: Contract with Parsons team on master plan for required Nuclear Rocket Engine Development Facilities.

4. February, 1961: Issued RFP for NERVA contractor. Proposals due April 3.

5. June 7, 1961: Aerojet General- Westinghouse Team selected for NERVA contract.
   July 10, 1961: NERVA contract signed.

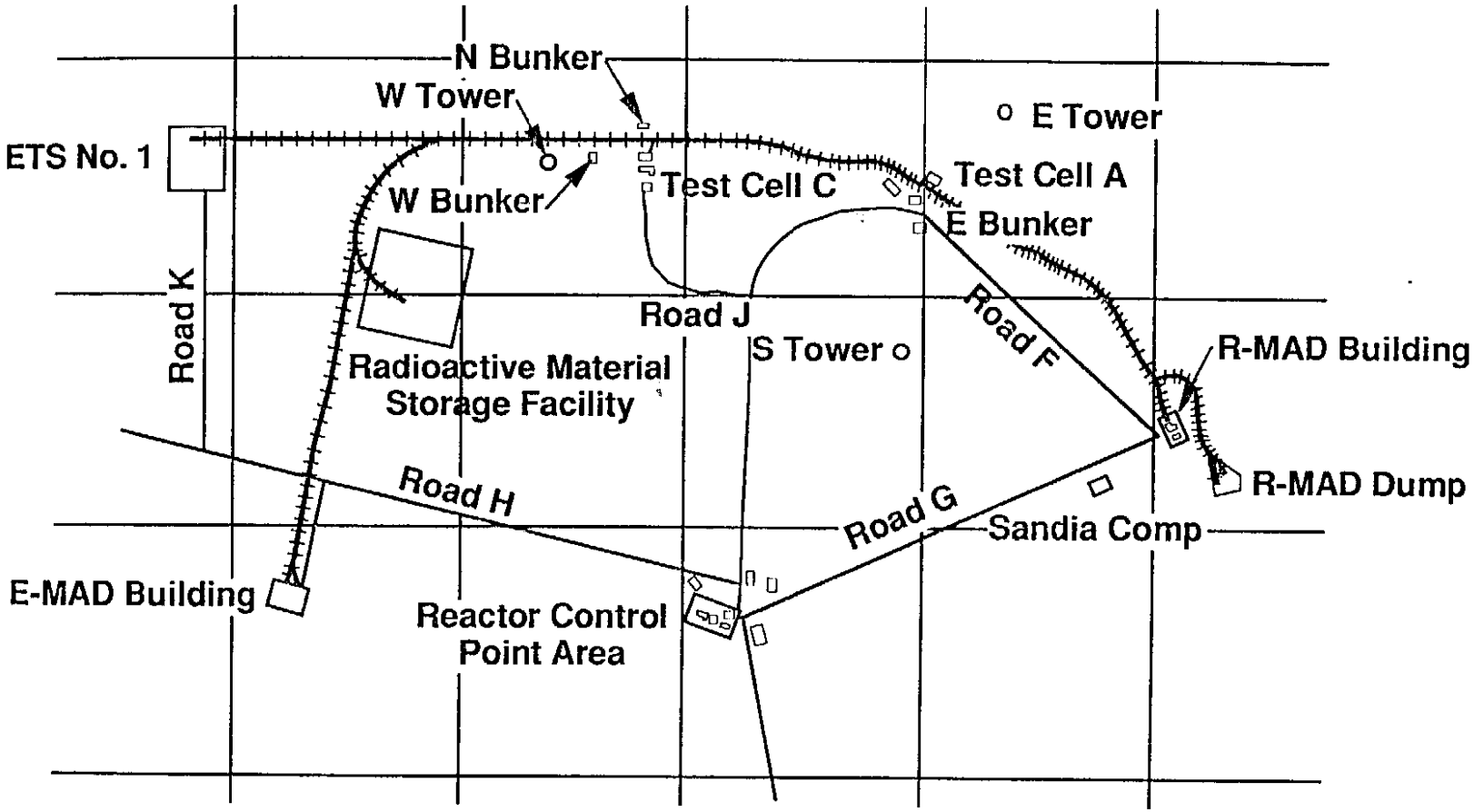
6. July, 1961: RIFT studies extended.

7. August, 1961: Contract with Vitro to design Engine MAD Building. Construction started in 1962.

8. July 11, 1962: RIFT development contract awarded to Lockheed.

SLIDE 9

Nuclear Rocket Development Station
Site 400, Nevada Test Site



SLIDE 10

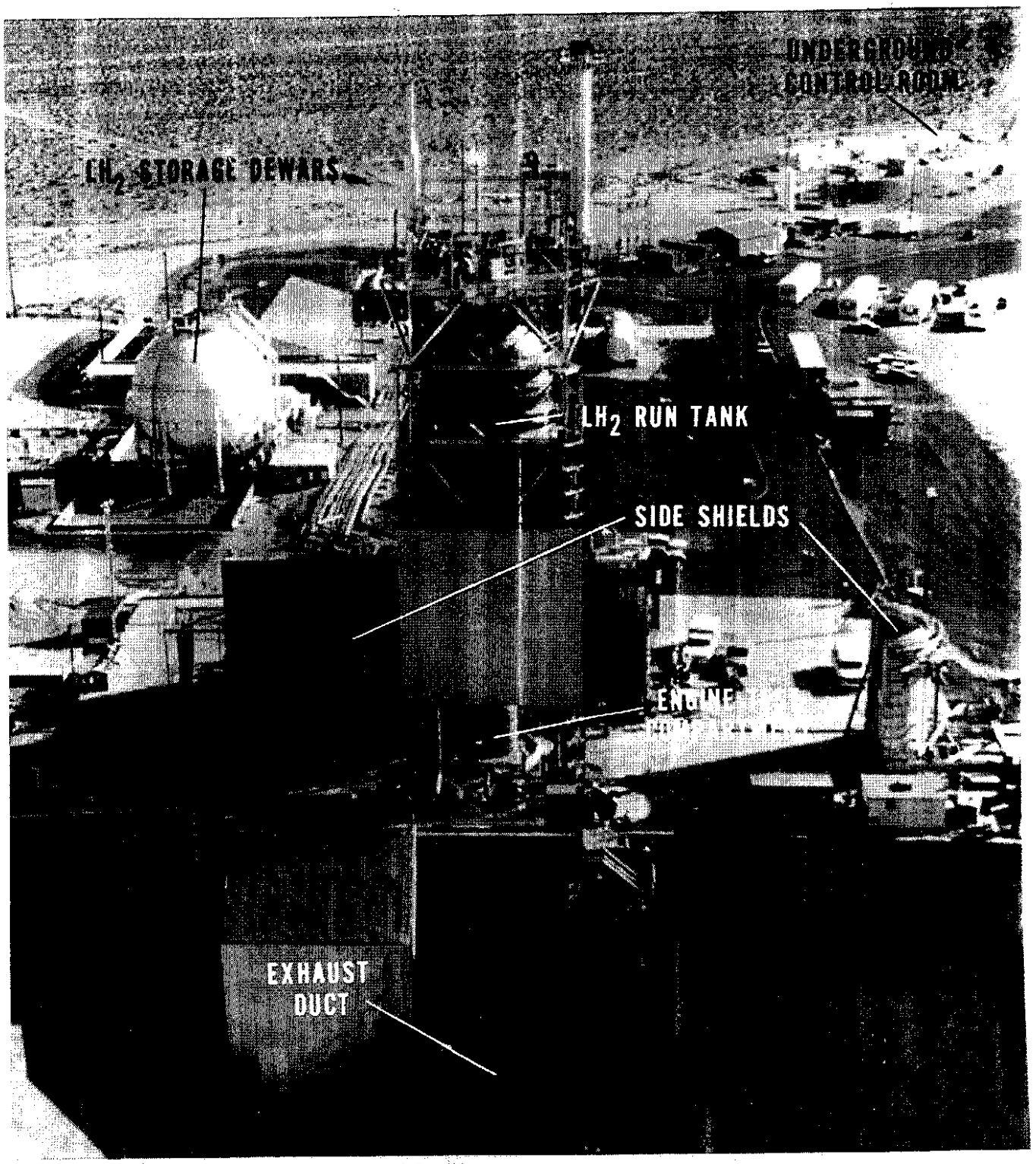
Rockwell International
Rocketdyne Division

90c-8-73
M730

ENGINE TEST STAND NO. 1

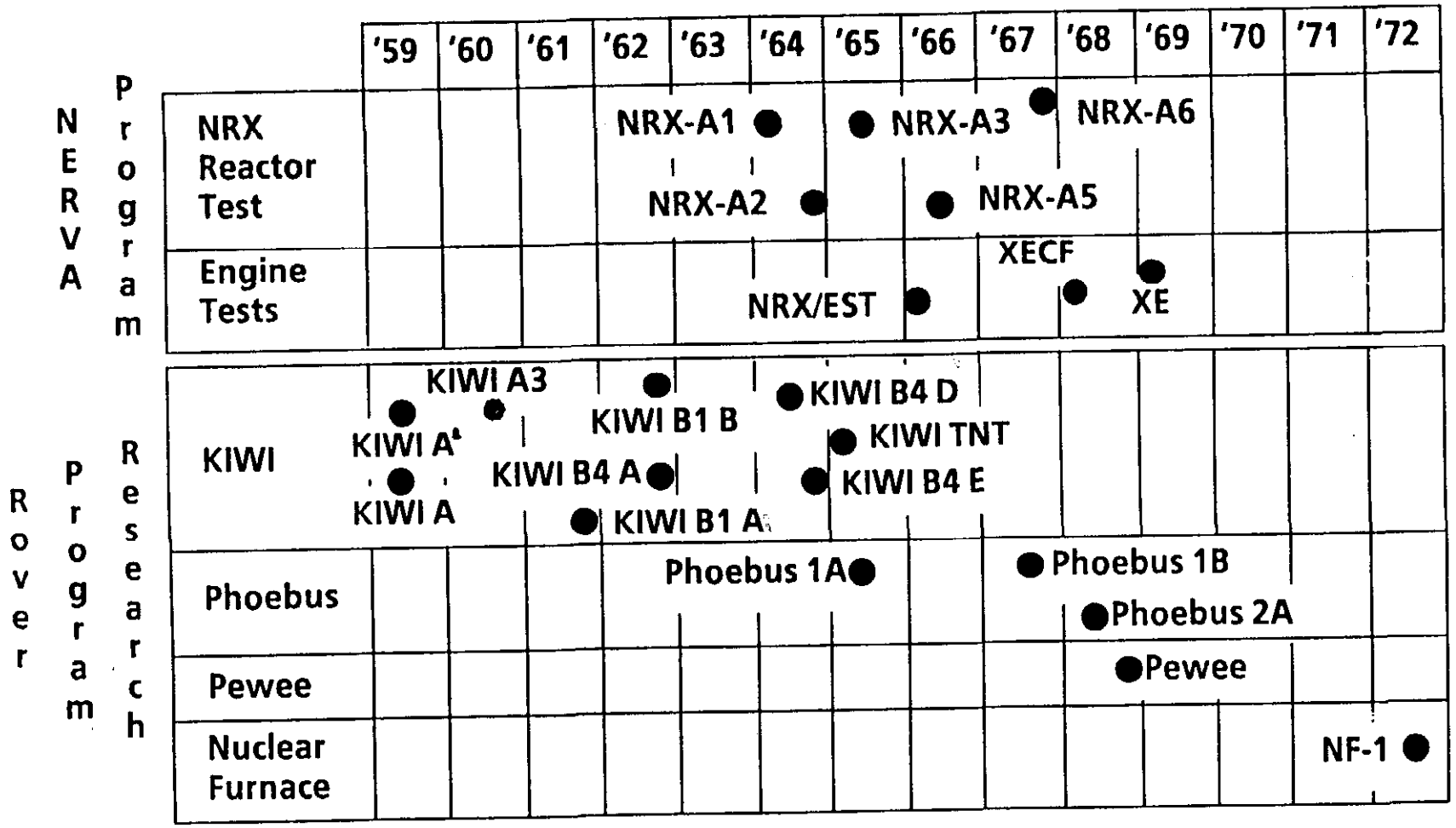
NUCLEAR ROCKET DEVELOPMENT STATION

SLIDE 11

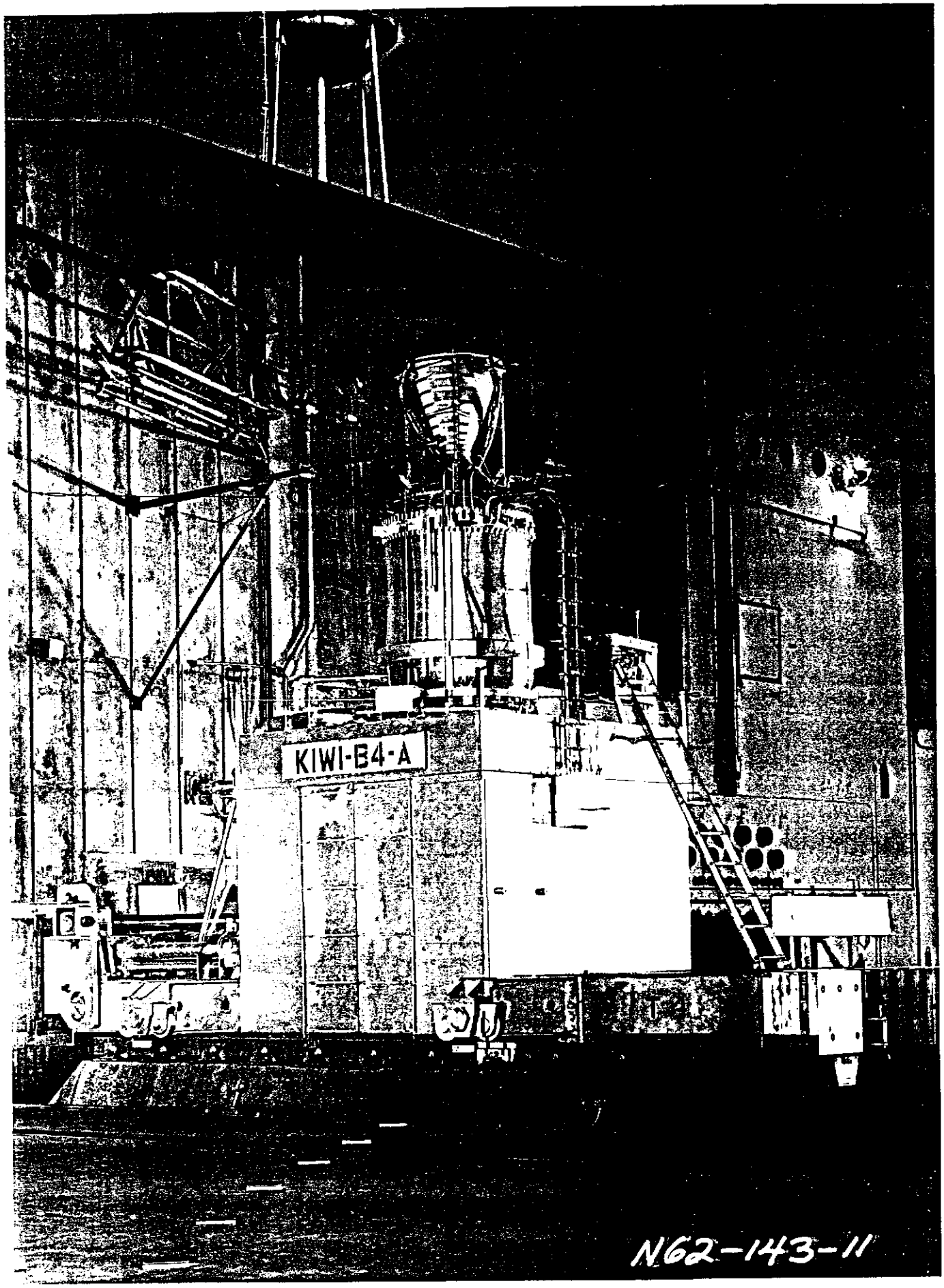


NASA NPO67-1572
REV. 1-15-69

NERVA/Rover Reactor System Test Sequence



SLIDE 12



SLIDE 13

SLIDE 14

KIWI B-4

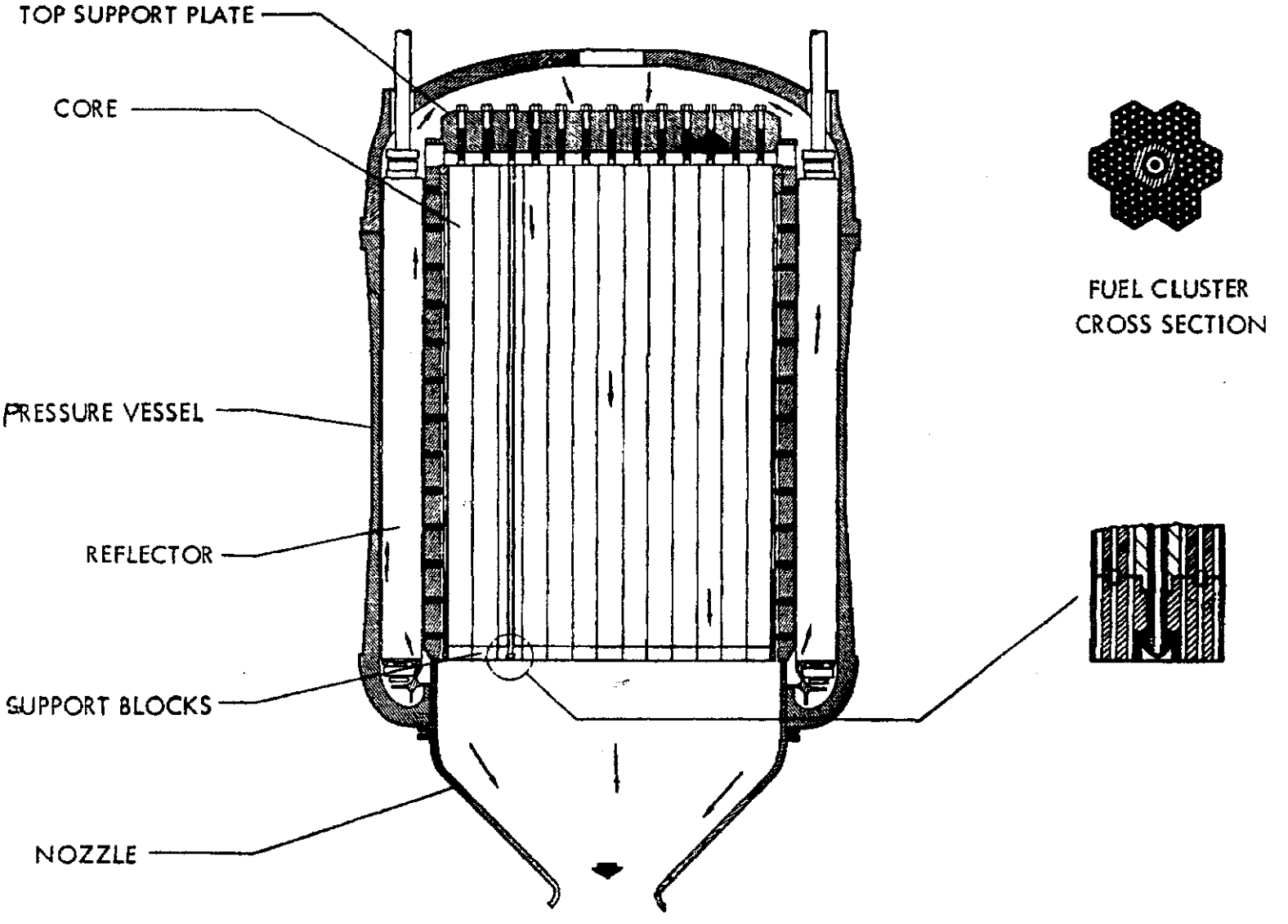
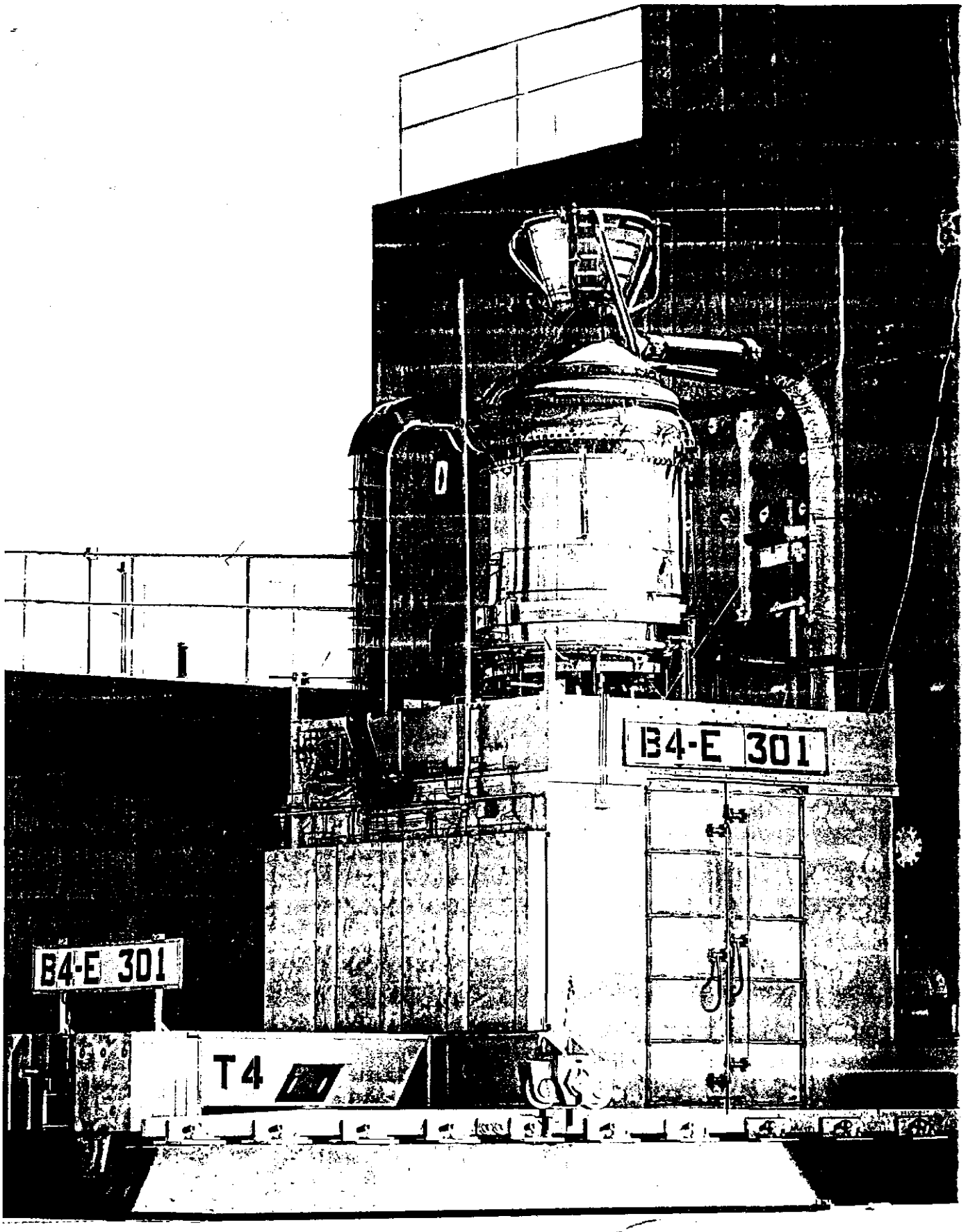


Figure 15



SLIDE 16

SLIDE 17

JACKASS FLATS NEVADA

It looks like we
accomplished
what we ~~accom~~ wanted

We all hope this
is the beginning
of a long string
of successes.
Love ~~Harry~~ Daddy

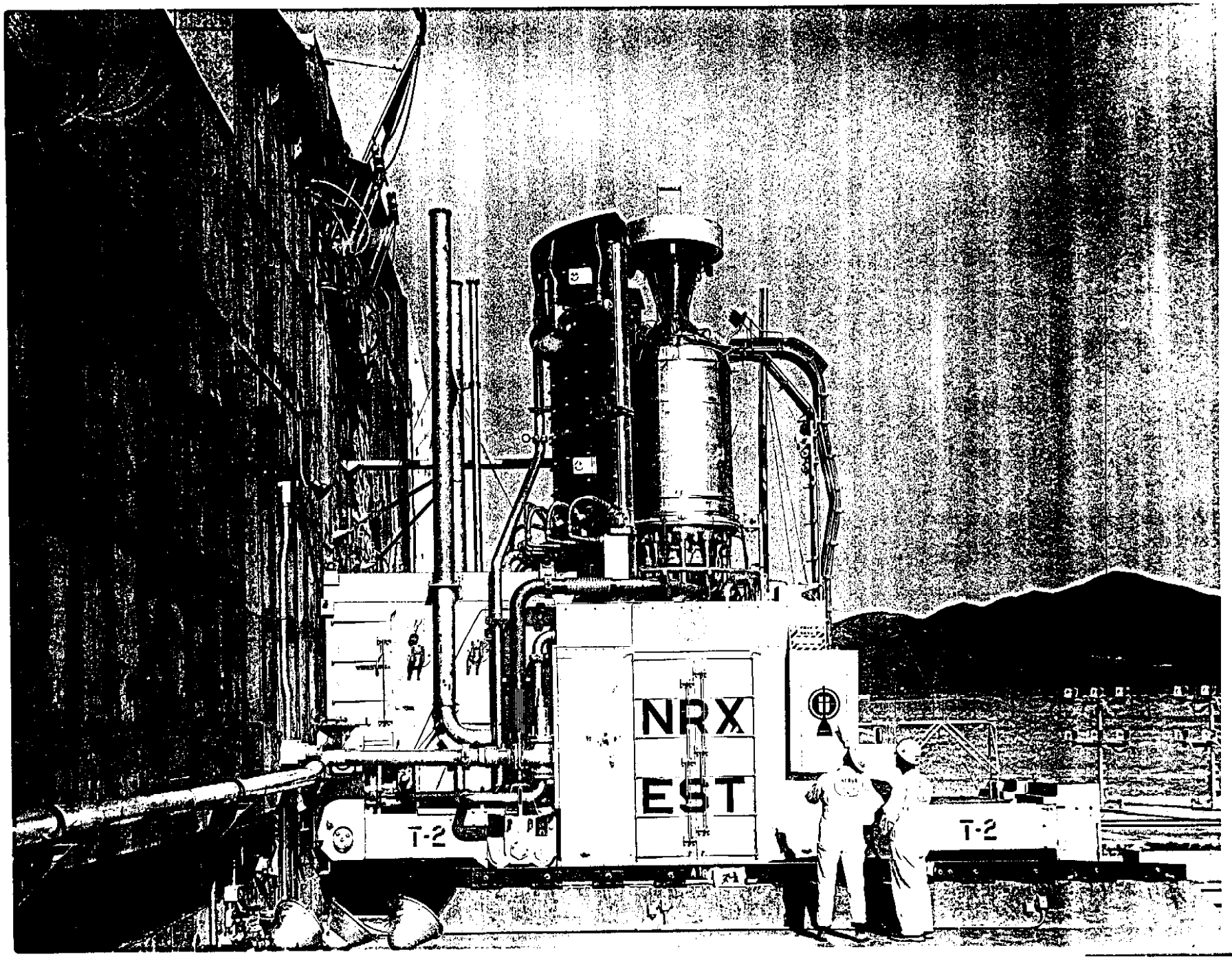
Mrs. H. B. Finger
& Daughters
6908 Millwood Rd
Bethesda,
Md.

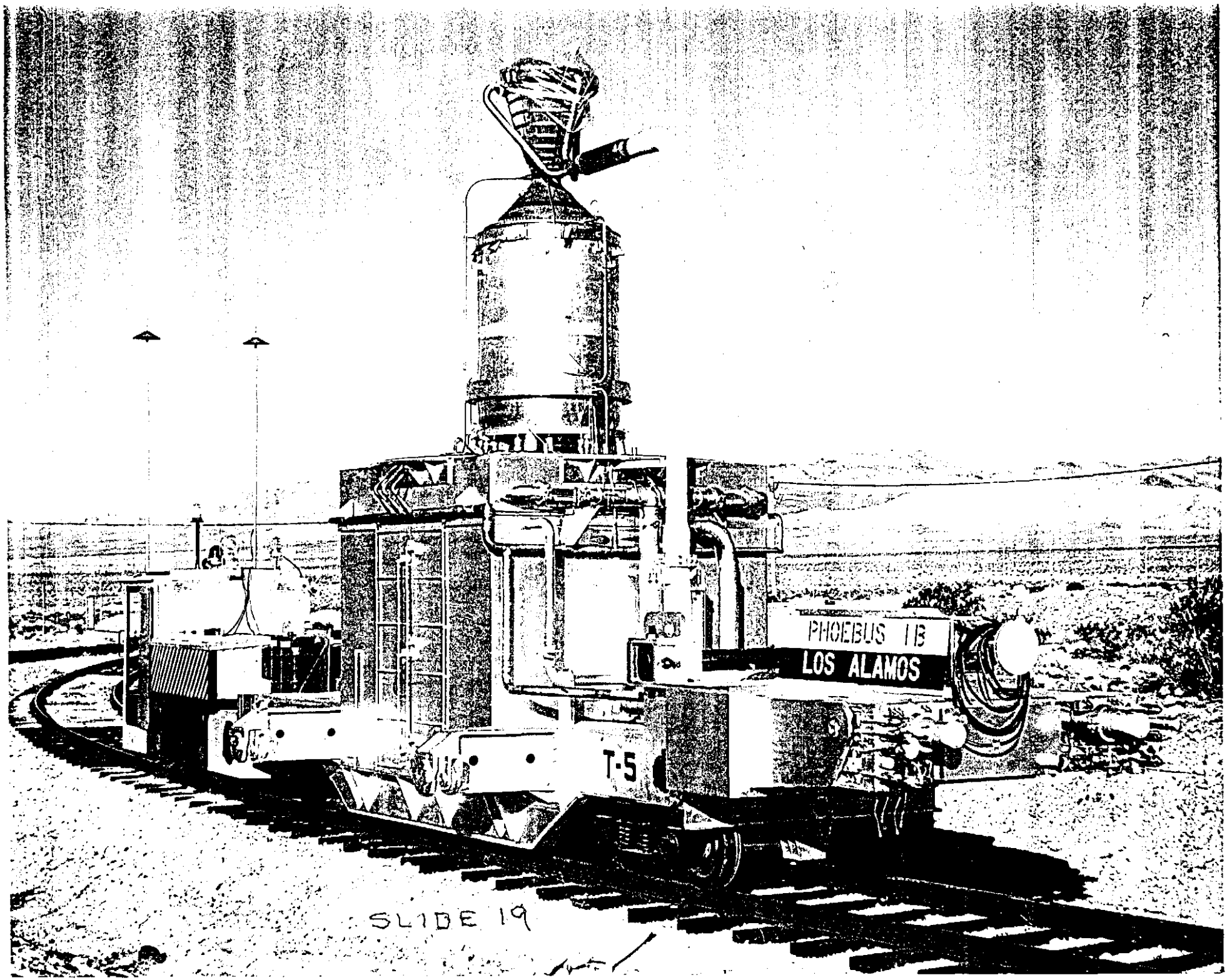
May 22

Everything
looks
fine.
I am really
pleased
Love & Kisses
Harry

Mrs H B Finger,
Bobbie Ellie Sandie
6908 Millwood Rd
Bethesda, Md
20034

SLIDE 18





SLIDE 19