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Chapter 9

PROJECT ROVER: THE UNITED STATES NUCLEAR ROCKET PROGRAM*

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From 1900 onwards, space pioneers speculated that atomic energy could provide an inexhaustible source of energy which would make the exploration of space a reality. In the mid-1950s the United States initiated a nuclear rocket program called Project Rover which would last until 1972, cost over $1.5 billion, and have several potential missions. However, while the nuclear rocket had great potential, it never had a fully approved or defined mission and this in the final analysis caused its termination. This study analyzes the Rover program from technical, managerial, and political perspectives, examines how successes or failures in one of these areas affected the other, and evaluates whether the program was beneficial.

The idea to use atomic energy to propel a rocket for interplanetary space travel existed for over 40 years before the United States made a decision to develop a nuclear rocket. To be sure, this idea was most fanciful during the period 1900-1945 because the sciences of the atom and rocket were in their infancy. After the atomic bombs were dropped on Nagasaki and Hiroshima in 1945, some detailed engineering studies of a nuclear rocket were made. But by the end of the 1940s, there still was no serious interest in any country in nuclear rockets.

EARLY THOUGHTS ON ATOMIC ROCKETS

Starting around the turn of the century, a number of rocket and space pioneers speculated that atomic energy was the ultimate rocket fuel as it was an inexhaustible and would open up the door to interplanetary space travel. Robert Goddard, the American space pioneer, was perhaps the first to begin this speculation. As a college sophomore in 1906-07, he wrote a paper on the utilization of atomic energy. A gram of radium had the potential to lift 5,000 tons over 100 yards in height, Goddard noted, but its disintegration was so slow that years would pass before enough energy was released naturally to lift even a gram. Atomic disintegration had to be controlled and not occur spontaneously; but once achieved, the

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navigation of interplanetary space could begin. Goddard wrote on the subject in 1916, but afterwards concentrated on developing chemical rockets.

During the 1920s and 1930s, a number of space and rocket pioneers speculated on the use of atomic energy. They included Gaetano A. Crocco of Italy, K. E. Tsiolkovsky of Russia, Eugen Sänger, Hermann Oberth and Krafft A. Ehricke of Germany and P. E. Cleator of the United States. However, all of them essentially concluded that atomic energy was a rocket fuel of the future.

The development of the atomic bomb and the German V-2 rocket during World War II prepared the way for serious post-war thought of marrying the two sciences to produce a rocket capable of navigating through space. The first was by Leslie R. Shepherd and A. V. Cleaver of the United Kingdom who collaborated in 1947-48 to produce a remarkable series of papers, using only unclassified information, which were published in the *Journal of the British Interplanetary Society*. They surveyed the various nuclear propulsion systems, including the merits of solid and gaseous core reactors and the use of hydrogen as the working fluid. They concluded that future interplanetary space flight would require nuclear or ion propulsion, but at the moment, nuclear rockets were not technically feasible.

The second two-phase study was prepared by North American Aviation Company in 1946-47. The initial study investigated the technical aspects of using several structural materials and propellant working fluids. For example, with data obtained from preliminary calculations of liquid hydrogen, methane, and water, fairly accurate measurements of the size and weight of a graphite reactor were made and a conceptual design for a 10,000 mile intercontinental ballistic missile was produced. This led to an in-depth six-month study which looked at all conceivable difficulties attending an atomic-powered rocket with a range of 10,000 miles and a payload of 8,000 pounds. The study concluded that liquid hydrogen (LH) was the best working fluid because of its high specific impulse and that graphite was the best structural material for the reactor. However, on the basis of experiments, North American noted that hydrogen eroded graphite at a rapid rate--perhaps an appropriate analogy is a cube of sugar dissolving in a cup of coffee. Thus, North American postulated that feasibility of the nuclear rocket only could be established fully when a method of protecting graphite from hydrogen erosion had been developed. Upon completion of this study, however, further North American interest in nuclear rockets ceased.

ORIGINS OF PROJECT ROVER

In the early 1950s, the missile and nuclear weapon rivalry grew between the U.S. and Soviet Union. Both sides realized the potential intercontinental ballistic missiles (ICBM) would have for their nuclear arsenals, but each side pursued different courses to realize that potential. The Soviet Union, having exploded its first atomic bomb in 1949 and working on the more powerful thermonuclear bomb, focused its missile effort on developing large rockets capable of carrying its large and heavy nuclear weapons. The Soviet Union did not focus its immediate attention on making its nuclear weapons smaller and lighter. On the other hand, the U.S.

focused its atomic bomb development (and thermonuclear weapons development program) on making them smaller and lighter. Thus, a missile would not have to have a large boosting capability in order to deliver its payload. However, the principal U.S. ICBM in the early 1950s, the Atlas, encountered a number of technical difficulties and was characterized as a plumber's nightmare. At the same time, development work had not conclusively proved that U.S. nuclear weapons could be made smaller and lighter. It was in this atmosphere of technical uncertainty that serious interest in a nuclear rocket developed in U.S. government and national laboratory circles.

TECHNICAL ASPECTS OF THE NUCLEAR ROCKET

This interest was caused in large measure by an article which appeared in the December 1953 issue of the classified *Journal of Reactor Science and Technology*. Robert Bussard, a young scientist working in the Oak Ridge National Laboratory, reinvestigated some of the earlier studies, such as those by Shepherd-Cleaver and by North American Aviation. He concluded that a solid core, heat-exchanger nuclear rocket engine using hydrogen, methane, or ammonia as the working fluid would be superior to chemical systems for all but the smallest payloads (less than 1000 pounds) and the shortest ranges (less than 1000 miles). The margin of superiority of a nuclear rocket over its chemical counterparts became greater as the payloads became heavier and the distances longer.

This article generated considerable interest in government circles in Washington and in the nation's atomic laboratories. At the Atomic Energy Commission's (AEC) Los Alamos Scientific Laboratory in Los Alamos, New Mexico, several study groups started independent of each other to investigate the concept while at the Lawrence Livermore Laboratory in Livermore, California, a group called the Rover boys was formed to start work. During 1954, studies continued at both laboratories, but as they progressed the advantages of a single stage nuclear rocket over its chemical counterparts were not found to be as great as originally thought. Thus, prospects for the commitment of large amounts of money for development would not be forthcoming. Faced by this prospect, Los Alamos hit upon the idea of boosting a nuclear rocket with a chemical rocket lower stage. After theoretical calculations were made, the results were most important: a reasonably sized rocket but with a very large payload advantage. Clearly impressed with this military potential, the Air Force felt some justification existed for continuing nuclear rocket work. And throughout 1955, the Air Force worked within the Department of Defense (DoD) to formally establish a program which the two weapons laboratories had already informally established. In November 1955, the DoD sent a letter to the AEC requesting it to pursue further research into nuclear rockets.

During 1956, both Los Alamos and Livermore pursued their work aggressively as they were in competition as well, as they were most interested in this new concept. They conducted experiments on candidate reactor core materials and working fluids, developed designs for various nuclear rocket engines and airframes, and surveyed and developed designs for a test site in a remote desert in the state of

Nevada. In Washington, however, it was becoming apparent to decision-makers that a two-laboratory nuclear rocket program would be a very costly endeavor. As a consequence, the DoD undertook a high-level review of the nuclear rocket program to determine what mission it could fulfill. This review concluded that as the plumbing problems of the Atlas and other missiles were being solved and as there had been great progress in making nuclear weapons smaller and lighter, there was no plausible need for a nuclear rocket for ICBM applications. However, this review also concluded that a nuclear rocket had great potential for future space applications and that the program should be redirected and be pursued at a moderate level of effort toward the goal of demonstrating the feasibility of the concept. From a political perspective this change was most important. In Washington politics where there is continual fighting over money, it would be very easy to criticize any money spent on a nuclear rocket development program. However, it is not quite as easy to criticize a program which has as its goal the demonstration of feasibility of the concept.

This guidance was provided by the DoD to the AEC in January 1957. The AEC then reevaluated the programs of the two laboratories in the light of this guidance. Henceforth, all nuclear rocket work would be conducted at Los Alamos. Livermore was assigned the task of working on Project Pluto, a nuclear-powered ramjet. Ironically, although Livermore's nuclear rocket work was reassigned, their division nickname, Rover, became the code word for the project at Los Alamos.

To implement this new guidance, the group at Los Alamos, under the direction of Raemer Schreiber and Rod Spense, decided upon a basic reactor testing effort called the KIWI program. Named after the flightless New Zealand bird, KIWI was a two-phase effort, moving from the relatively easy to the more difficult steps in establishing feasibility. KIWI-A, the easier, was to determine the basic data both in reactor physics and materials and in testing procedures. KIWI-B, the more difficult, was to use liquid hydrogen (LH) as the working fluid. Progressing thus, the many unknowns of reactors reaching temperatures of over 2000^{o}C in a matter of seconds could be learned in a methodical, logical, but aggressive manner. Feasibility could be demonstrated with great assurance then.

KIWI-A had a design power level of 100 megawatts (MW). (One MW would provide 1000 pounds or 4.45 KN of thrust). It also had a reactor core 4 feet in diameter and 4 feet in length. The fuel elements were constructed out of flat plates and were called whims, a contraction of the words wheel and rim. These whims were curved and stacked upon each other in the cylindrical core. The working fluid was gaseous hydrogen. While design and fabrication of KIWI-A was underway, other Los Alamos personnel were at a site in the Nevada desert supervising the construction of the elaborate facilities needed to test the KIWI series of reactors. The test site as well as KIWI-A were completed and checked out in early 1959. In July, the first high-power, hot test occurred (Figure 1). Despite the fact that there was a failure of a key part in the reactor core which allowed hydrogen to escape without entering the core, KIWI-A was successfully tested at 70MW for over 5 minutes before being shut down. This test was highly important because it not only technically demonstrated the feasibility of the concept, but it also, as shall be made evident subsequently, was interpreted politically as evidence of a new and most promising energy source for rockets that needed to be developed immediately. There were several tests of other reactors in the KIWI-A series in 1960. KIWI-A and KIWI-A3 were tested to gain further experience in field testing procedures or investigate the performance of prototype fuel elements (Figure 2). However, the KIWI-A series were never viewed as prototypes upon which to build a design for a nuclear rocket engine.

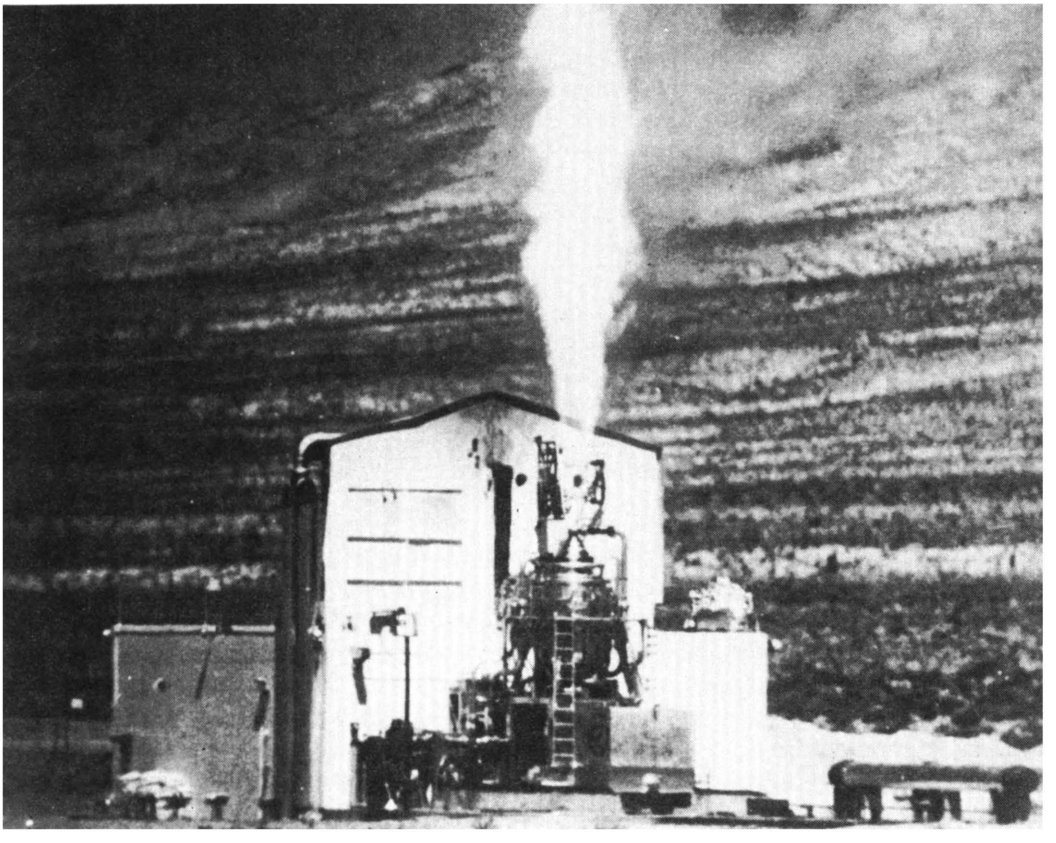

Figure 1 KIWI-A in full-power operation, on July 1, 1959. Photo from movie frame taken 500 yds away.

After KIWI-A, Los Alamos began serious work on the KIWI-B series of test reactors. These would be far more difficult and challenging than the KIWI-A series. They would have a 1000MW design power level, a drastically different reactor core design based ultimately on hexagonal fuel elements made of graphite-uranium mixture, and would use liquid hydrogen not only as the working fluid but also as the coolant for the rocket nozzle and reactor core. Furthermore, the KIWI-B series had more stringent target performance specifications, 1000 MW of power for 5 minutes.

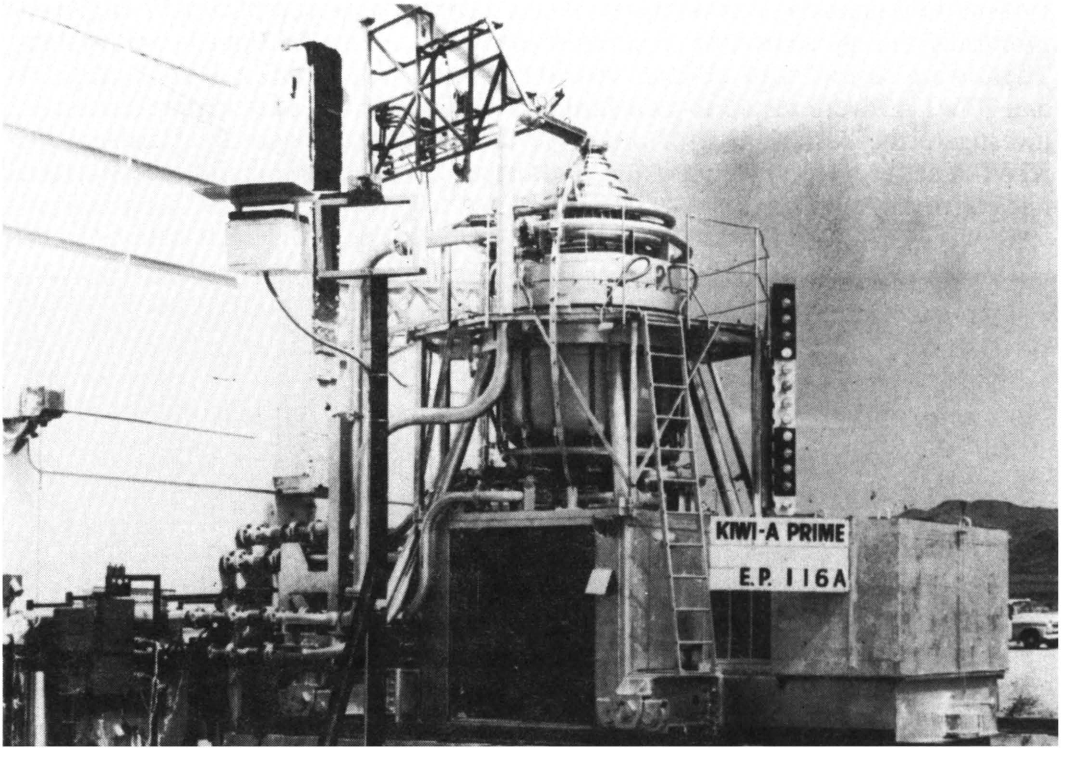

Figure 2 KIWI A Prime was operated at full power on 8 July 1960.

Using liquid hydrogen presented a vastly more complex series of technical problems than KIWI-A. For example, Los Alamos determined that over 50,000 gallons (227 meter^3) of liquid hydrogen would have to be pumped into the reactor in order to meet the target specification. They built two 28,000-gallon (127-meter^3) dewars along with the appropriate plumbing system at the test site to supply this working fluid to the reactor. This had never been done before. Next, the nozzle as well as the reactor core would be cooled with liquid hydrogen. This presented severe thermal problems. In addition to this, there were major worries whether 'slugs' of liquid hydrogen would enter the reactor core; as hydrogen is an excellent neutron moderator, there were concerns that these 'slugs' could cause serious reactor control problems. In other words, the power level of the reactor could not be maintained under control. Finally, as liquid hydrogen would enter the nozzle and reactor core at -253°C and, in the span of 5 feet, leave at a temperature of over 2000°C, there were severe thermal stress, thermal expansion, and structural integrity problems. To assist in solving some of these problems, several private industrial firms were brought into the program; foremost of these at this time was Rocketdyne which developed the nozzle and liquid-hydrogen pump.

It took about two years to redesign the test site to handle liquid hydrogen and about the same time to develop the new KIWI-B series of reactors. KIWI-B1B was the first reactor run on liquid hydrogen (in September 1962). It demonstrated that there were no problems with 'slugs' of liquid hydrogen entering the core. However, the B1B suffered structural problems and ejected a number of fuel elements from the core. This was not viewed as serious, as the design was held to be deficient structurally even before the test. Rather, it was thought more important to have a test on liquid hydrogen and learn about its handling properties.

The KIWI-B4A was viewed as the core design with great promise; it was thought that the B4A could go through a 5-minute full-power 1000MW test run without suffering any structural problems. The B4A was tested in November 1962 (Figure 3). Automatic programming brought the B4A up to low power and then to high power quickly; again the liquid hydrogen startup was successful. But paralleling the rapid increase in power was a rapid increase in the frequency of flashes of light from the nozzle. On reaching 500MW, the flashes were so spectacular and so frequent that the test was terminated and shut-down procedures begun. Quick disassembly confirmed that the flashes of light were reactor parts being ejected from the nozzle. Further disassembly and analysis revealed that over 90% of the reactor parts had been broken, mostly at the core's hot end. The test of KIWI-B4A had not only technical consequences, but also, most important, managerial and political consequences.

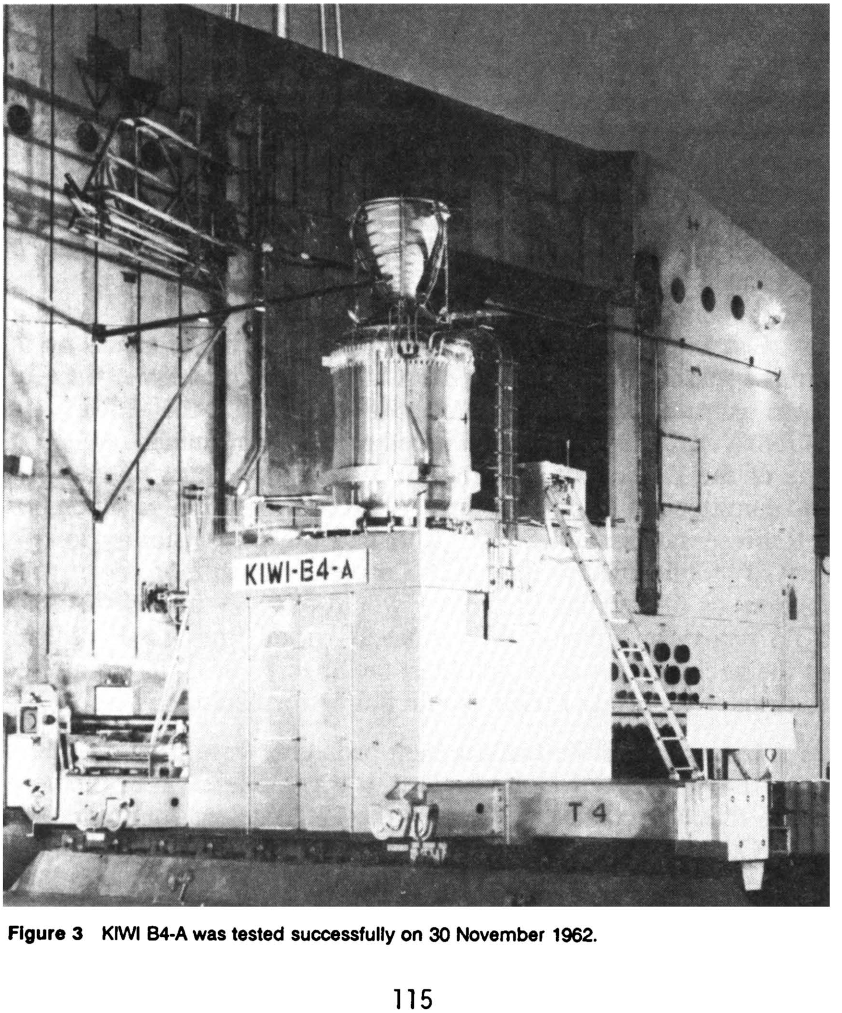

Figure 3 KIWI B4-A was tested successfully on 30 November 1962.

MANAGEMENT OF PROJECT ROVER

After the program was formally established in 1955, the Air Force was assigned responsibility for the non-nuclear aspect of a nuclear rocket. For example, it would be responsible for taking the reactor engine developed by the AEC and integrating it into the rocket vehicle. However, when NASA was created in 1958, the Air Force responsibilities were transferred to it. As can be expected, there were the normal bureaucratic problems of who would run the program--the developing agency or the using agency. These problems, however, only hid a more fundamental problem in that both agencies had different approaches to research and development. NASA favored a methodical, systematic approach to developing new technology, testing components rigorously before testing the entire system. Because many of NASA's developments would be used for manned airplane or space flight, dependability and reliability were emphasized. In this context, time was sacrificed in order to minimize risk. In contrast, the AEC had an aggressive approach to research and development, originating with the weapons development work in the 1940s and 1950s. Here rapid weapons development was paramount, with cost and risk sacrificed in order to save time. Thus, different approaches to technical problems were initiated and continued in parallel until one proved superior. Component and system testing, in developing a new technology, were conducted especially when there was a good opportunity for failure. Learning the unknown was more important than relearning the known. In this context, reliability and dependability were goals to achieve later in the development process.

In 1958 and 1959, this was not a serious problem, as the nuclear rocket had not been demonstrated to be feasible. However, after KIWI-A which demonstrated feasibility, this problem became more critical, particularly after NASA published several long-range planning documents for its future activities in space. The nuclear rocket was not mentioned, nor was it assigned missions 20 years or more in the future. This was troublesome to the AEC and infuriating to some of the Rover program's most staunch supporters in the Congress. At this time, the Congress of the U.S. was controlled by the Democrats who, after the Soviet Union had launched Sputnik in October 1957, continued to press for a much larger U.S. role in space. Some of the Democrats pressing for this larger role were also members of the Joint Committee on Atomic Energy (JCAE) (composed of members of the House of Representatives and Senate who had the responsibility to oversee the development of atomic energy). The JCAE sought a much more aggressive nuclear rocket program--as fast as the technology would allow. When NASA's long-range plans had no near-term mission for a nuclear rocket, the JCAE realized that it meant that the necessary funds to build test facilities, to bring in private industry, in essence, to develop a nuclear rocket, would not be forthcoming.

Under JCAE pressure the management problems were partially solved in 1960 when a joint AEC/NASA office was formed. It was modeled after the very successful joint office that was created to develop the U.S. nuclear submarines under Admiral Hyman G. Rickover. A controversy developed over who would be named to head this office, a NASA or an AEC man. Ultimately, NASA prevailed and Harold Finger from NASA's Lewis Research Center in Cleveland, Ohio, was named to head the office. Finger was schooled in the NASA development philosophy, but was not able to impose that philosophy upon the AEC until after the KIWI-B4A test in November 1962. Afterwards, Finger decided there would be no further hot tests until the cause of the core failure had been determined precisely and the solution to the problem tested repeatedly under cold test procedures before any hot testing would be resumed. Cold flow testing had a policy effect as it meant a hold on the other portions of the Rover program which were aimed at flight testing a nuclear rocket.

Nonetheless, throughout the first part of 1963, cold testing was done on another KIWI-B4A type reactor. On a heavily instrumented B4A was a specially designed camera which was inserted into the nozzle to take motion pictures of the cure during the test. In startup, as the pictures indicated, the gas flowing though the core caused severe vibrations which cracked the fuel elements. Some were ejected. Convinced, on the basis of the pictures and other data that vibration was the problem, corrective redesign of the KIWI-B4 series began. In August 1963, a redesigned KIWI-B4B was cold-flow tested and the test was completely successful. No fuel elements were cracked or ejected. Thus approval was given for the resumption of hot testing.

Beginning in January 1964, work began toward testing of the last two of the KIWI-B series of reactors, KIWI-B4D and B4E. In May, the B4D was hot-tested. Starting quickly and completely automatically, the B4D reached and maintained full power of 1000MW for about a minute until a leak in the nozzle forced termination of the test. Other than the nozzle failure, disassembly confirmed that the test was a complete success. The core was intact, no vibration had occurred. The core design was good. (Opinions still vary on whether the ban and subsequent cause and effect cold-flow testing procedure was warranted. Some adamantly maintain that a year and a half was lost in proving what Los Alamos had suspected originally as being the design fault. Little therefore was gained except interesting pictures. On the other hand, others staunchly hold that development steps followed prior to the ban on hot testing were too cavalier to produce an engine safe and reliable enough for man-rated flights. Little confidence in the soundness of an engineering design can be gained from failures).

The last of the KIWI series, the B4E had the same core design but featured an improved method of coating the fuel elements. Tested in August 1964, the B4E proved the most successful KIWI. Running for eight minutes at 900MW, the duration of the test was limited by the storage capacity of the liquid hydrogen dewars. Startup and control were smooth and stable. The core performed well with no flashes. The exit gas temperature was 2000°C, slightly lower than B4D. After shutdown, the B4E was not disassembled and analyzed. Rather it was decided that valuable information could be acquired on fuel element lifetimes by going beyond ten minutes in total reactor running time and on reactor restarts and reliability. The B4E was restarted and run at full power for two and one half minutes and then shut down. No problems were encountered. Subsequently disassembly and analysis revealed that the new fuel elements suffered only minimal corrosion and that the core remained intact. The reactor could have run much longer.

THE POLITICS OF THE ROVER PROGRAM

The Rover program was throughout its life a creature of partisan politics. It was strongly supported by the Joint Committee of Atomic Energy in the Congress, and in particular, by a few powerful Democratic senators who sat on the committee. These senators were also members of close friends of senators who were members of the 'inner sanctum' of the Senate, those senators who really wielded power. Senator Clinton P. Anderson, a Democrat from the state of New Mexico, was the Rover program's strongest supporter and if he was not a member of the 'inner sanctum' he was a close personal friend of the one person who was the head of it as well as the Senate, Senator Lyndon B. Johnson from Texas.

Anderson was unhappy in January 1957 when the DoD stated that were no missions planned for a nuclear rocket, but that it should be pursued at moderate level of effort to demonstrate the feasibility of the concept. However, at that time he had insufficient grounds upon which to press for a larger program. After the Soviet Union launched its Sputnik satellite in October 1957, the political climate in the U.S. dramatically changed. Now the Democrats raised the issue that the U.S. was losing the space race and they pressed for a much larger U.S. response. The Eisenhower Administration, however, did not feel that the space race represented a tangible threat to U.S. security. Nevertheless, it felt that it had to respond to the criticism of the Democrats. Throughout 1958, hearings were held in Congress on the creation of a civilian space agency, NASA, to run the nation's space activities. At the end of the year it was officially created and a number of military programs transferred to it. The Air Force responsibilities in the Rover program, as noted previously, were transferred to NASA. While some of these newly transferred military programs were given increased funding as NASA began to establish its programs and priorities, the Rover program was not given an increase; in fact, it was not even mentioned, or mentioned only 20 years in the future, in the planning documents that NASA was developing at this time. As the KIWI-A test, to demonstrate feasibility, had not occurred, there was little the Democrats in Congress could do to accelerate the program.

After the KIWI-A test in July 1959, the AEC formulated a budget for an aggressive program leading to a flight test in the mid-1960s timeframe. This was submitted to the Bureau of the Budget, the agency which formulated the Administration's budget for transmittal to Congress. The Bureau of the Budget disallowed the AEC's budget request and kept the program funded at a level of effort sufficient only to do further feasibility demonstration work.

When this budget became known in January 1960, when it was transmitted to the Congress for review and approval, it aroused many Democratic members, particularly Senator Anderson. He had expected the project to be accelerated following the KIWI-A test, and he moved to determined action. In February 1960, he notified NASA and the AEC that he had scheduled executive session hearings to cover the following points on the Rover program: to establish firm operational objectives, a flight test schedule, and a management structure suitable to accomplishing those objectives. Immediately upon receiving Anderson's letter, NASA sent a letter to the Bureau of the Budget supporting the AEC in the program. The following day, the Bureau notified NASA and the AEC that the original budget request was partially amended and that the AEC could reprogram from its other funds to make up the remainder, if it wanted. In the closed hearings that news was conveyed to Anderson; however, the hearing produced no new NASA position on flight dates, objectives, or organization structure.

Nonetheless, after receiving Senator Anderson's letter, both agencies began discussions to determine their reaction to the strong Democratic emphasis. But with a Republican Administration conservative toward space, both NASA and AEC leaders were limited in their freedom of action. Thus, they could not establish officially approved flight dates and firm objectives. In view of this situation, the questions discussed in the Rover program in the early half of 1960 were essentially organizational. Centralized management had been discussed in the AEC and NASA since the space agency was created, but as the nuclear rocket was viewed as a long-term development effort in NASA, the need to establish a joint office to manage and coordinate the program was not considered important. The Democratic emphasis changed this attitude though. In early April 1960, NASA and the AEC agreed on forming a Space Reactors Branch, headed by a NASA man, in the AEC's Division of Reactor Development. The proposed arrangement was shown to Senator Anderson, but he questioned the plan, favoring an office modeled after the one headed by Admiral Hyman G. Rickover who ran the U.S. nuclear submarine development program. Here one man with real authority ran the program. That type of office had considerably more power than the one proposed by the agencies. Shortly afterwards, a new plan was proposed, based on the Rickover model, and was accepted by Senator Anderson and the Joint Committee. As indicated, Harold Finger was named to head this office.

Throughout the summer of 1960, the staffs of the two agencies worked to implement the agreement; by late August 1960 a memorandum of understanding was signed between NASA and the AEC establishing a Nuclear Propulsion Office. However, this office did not have anything meaningful to do at this time because a full-scale, flight-test oriented nuclear rocket program had not been approved. That decision was being left to the next Administration.

Having a national decision on a program on the magnitude of the nuclear rocket program was necessary for policy and managerial reasons. On the national level, expending anywhere from one-half to one billion dollars envisioned in 1960 to develop an operational nuclear rocket meant a tacit commitment to use that vehicle in the space program. But constructing a nuclear rocket, capable of moving very large weights in space, implied a commitment to a very expanded space program aimed at unmanned or manned space--even planetary exploration. This fact was appreciated by many Democrats. And at the party's nominating convention of 1960, John F. Kennedy, who was least knowledgeable about space, was nominated for President; Lyndon B. Johnson, who was very well informed about space was selected to be Vice President. Senator Anderson was somewhat disappointed as he had backed Johnson for President. Nonetheless he supported both candidates strongly. Although Presidential nomination politics dominated the convention, key

Democrats inserted a plank in the Democratic platform, calling for the development of the nuclear rocket as part of an accelerated space program.

Kennedy won the election but upon assuming office in January 1961 was not predisposed to a large space program. International events placed the President on the defensive and forced him to change his position. The Soviet success in orbiting a man and recovering him safety on April 12, 1961, the flight of Yuri Gagarin in Vostok, was transformed quickly and effectively into a worldwide political, military, and ideological message. Hailed as a triumph of socialism over capitalism and as an illustration of Soviet military strength used for peaceful purposes, the political meaning of the Gagarin space feat was not lost on the developing nations: Socialism was propagated as the wave of the future. Discouraging as this Soviet feat was and embarrassing as the bungling of the Cuban Bay of Pigs was to the President, Kennedy decided that he had to initiate a positive policy in part to redeem his campaign promise of getting the country moving again. After some initial hesitation, the President decided that for political, military, and ideological reasons, the Soviets had to be challenged and surpassed in space, a substitute program like desalinization of water did not have enough international prestige or visibility. Kennedy then assigned to Vice President Johnson the responsibility for making recommendations concerning the scope and direction of the space program on April 19, 1961.

The following day, Johnson began arranging meetings and hearings in order to determine what the scope of an accelerated program should have and how much political support that program would have in the government and the nation. Since Sputnik, landing a man on the Moon had been considered by many Americans to be the proper goal for a space program. In the last days of April 1961, the manned lunar landing became the favorite objective of many government and industry figures in an accelerated space effort. In discussing an enlarged effort, though, Johnson spoke with many informed people who considered a number of other programs and projects which would enable the U.S. to continue space exploration and not reduce all activity after a lunar landing. Foremost among those projects was the nuclear rocket because it was justified as having planetary or lunar resupply capabilities. In this context, developing a nuclear rocket in the 1960s would extend American leadership in space well into the 1970s and 1980s.

For the next six weeks Johnson worked on developing a space policy for the nation and submitted it to the President in mid-May. Kennedy reviewed and approved without change the recommendations given him by Vice President Johnson. On May 25, 1961, President Kennedy addressed the Congress and asked the nation to commit itself to an all-encompassing space program, having as its central objective the landing of a man on the Moon and returning him safely to Earth before the decade was out, and to developing a nuclear rocket which when completed might take men to Mars, perhaps even to the end of the solar system itself.

The following day, NASA and the AEC translated the President's policy into specifics, that the President had decided favorably on the flight test as an objective for the nuclear rocket and that NASA now was authorized to develop a flight rated nuclear rocket engine and to integrate that engine into a rocket vehicle. The target date for a flight was set at 1966-67. Progress towards realizing the 1966-67 flight date now was only limited by technical factors--how fast and how successfully could Las Alamos test the KIWI-B series of reactors on liquid hydrogen. (At this time, NERVA became approved and would be the logical successor to the KIWI series of reactors. NERVA stood for Nuclear Engine for Rocket Vehicle Application).

Thus, the tests of the KIWI-B series of reactors were more than just technical matters viewed only by scientists and engineers. They became the symbol for a large and expansive space effort after the lunar landing. However, no such missions were approved in the President's speech; they were just alluded to. But the full implications of the President's leadership in space policy started becoming readily apparent in 1962 as the budgets of the AEC and NASA came under increased scrutiny. To flight-test a nuclear rocket by 1966-1967 meant that hundreds of millions of dollars had to be allotted in 1962. This to many critics was only the tip of a very large iceberg because if the nuclear rocket were flight-tested successfully there would be even more pressure to use it for far more exotic space missions, perhaps a manned flight to Mars. For this reason determined efforts were made to reduce Rover's size and scope.

The failure of the KIWI-B1B and B4A tests in September and November 1962 were used most effectively by the critics of an expanded space program. They wanted to delay the funding for the NERVA and for the flight test of a nuclear rocket on the grounds that the technology was not ready. To help offset this criticism, Senator Anderson arranged for President Kennedy to visit Los Alamos and the reactor test site in Nevada before making this decision on the budget. This visit occurred during the first week in December 1962, about a week after the KIWI-B4A test.

In the midst of a technical briefing on Rover, the President interrupted to state he wanted to discuss the serious budgetary problem his administration faced with the very large flight test program being proposed by NASA. Kennedy stated he wished to listen to the arguments for and against supporting the Rover program at the projected level. Harold Finger defended the flight test objectives, noting that while the Saturn-V, being developed for the lunar landing program, was being designed on the basis of chemical propulsion, nuclear rockets had influenced its design. Furthermore, it might prove very important in landing men on the Moon before 1970 should there be a failure in the Saturn-V system. Essentially, however, Finger noted that nuclear rockets combined with Saturn-V's figured prominently in NASA's planning for the missions of the 1970s. The President's Science Advisor, Jerome Wiesner, countered, stating that the failure of the KIWI-B1B and the B4A demonstrated that nuclear rocketry was technically premature, that additional basic reactor research was necessary before starting NERVA and the flight-test programs. Rather, NERVA should be oriented to a low-level technology demonstration effort since NERVA was an expensive and technically formidable effort compared with the KIWI program. The flight test should be canceled. Essentially, Wiesner continued, the nuclear rocket was premature and could not be considered useful even as a backup for the lunar landing mission. Mars and lunar base applications were well beyond the pace for any serious government planning--perhaps a generation away from Presidential approval.

The following morning, the President flew to the Nevada test site to visit the nuclear rocket test facilities. Sitting on his bed on *Air Force I*, the Presidential plane, Kennedy again discussed the nuclear rocket's funding and mission applications. The President's advisors again restated their views, that the nuclear rocket was premature, that unless the lunar base program was approved, where nuclear rockets would make one hundred trips a year to the Moon, or unless a manned Mars mission was authorized, the expense of developing nuclear rockets could not be justified. Just before landing in Nevada, the President decided to delay the flight-test program, pending the outcome of the KIWI-B4 tests.

This issue remained unresolved throughout the nine months of 1963. However, as the budgets of the AEC and NASA were being developed in the Fall of 1963, the objectives for the nuclear rocket and by implication for the post-lunar landing space missions for NASA were being debated. Kennedy was mindful that several of his other key programs were entering the expensive hardware development stage, the Minuteman and Polaris nuclear weapon systems and the lunar landing program. All would require significant increases in funding. Reflecting the buildup, the total budget loomed to just over $100 billion, but the funding level for Rover had not been determined when Kennedy was assassinated in November 1963.

On assuming the Presidency, Lyndon Johnson embarked on a course to renew confidence in the government and in part this desire was reflected in his decision to pare the budget below $100 billion. In this context, Johnson considered not only the Rover program, but also the entire space program. In mid-December, there was a meeting of President Johnson and the heads of NASA and the AEC. They discussed three funding levels for Rover: a $300 million per year level aimed at a fight-test objective; a $200 million per year level aimed at flight-rated engine, but no decision on a flight test; and a $150 million-per-year level aimed at research and technology, with no flight-rated engine development of flight test. Johnson ruled out the $300 million-per-year option. Thus, discussion centered on the $200 million-per-year versus the $150 million-per-year option. There were some Presidential advisors present at this meeting who advocated a $70 million-per-year effort. No decision was reached at this meeting, but it was apparent that the third option had emerged as the leading choice.

The next week was spent in weighing the political implications of the $150 million research and technology plan, essentially with key Democrats in Congress. There was a second meeting during Christmas week, but it was apparent that Johnson had reached his decision before the meeting began. The Rover program would be reoriented to a research and technology effort at a funding level of $150 million per year; NERVA would be redirected to a ground-testing reactor program and the flight test terminated.

The nuclear rocket program went on to be an outstanding technical success. Liquid hydrogen ceased to be a problem and the reactor fuel elements were developed and improved. Reactor control and operation techniques were enhanced by Los Alamos, which also proceeded to develop a 5000MW reactor suitable for planetary missions and by the private industrial firms working on NERVA that developed a series of continually improved designs for their experimental reactors (Figure 4). Repeated starts and stops were practiced as well as running for long periods of time at full power. In 1968, a NERVA reactor ran at full 1100MW in power for one hour without damage. Experiments to improve the fuel element lifetimes to five-ten hours also were started; an engine with that capability would be a very cost-effective vehicle for a lunar base. But such missions were never approved. In 1972, with Senator Anderson in ill health and in his final year in the Senate, the Rover program was terminated by a Republican Administration. There simply was no need for a nuclear rocket as there were no missions for it.

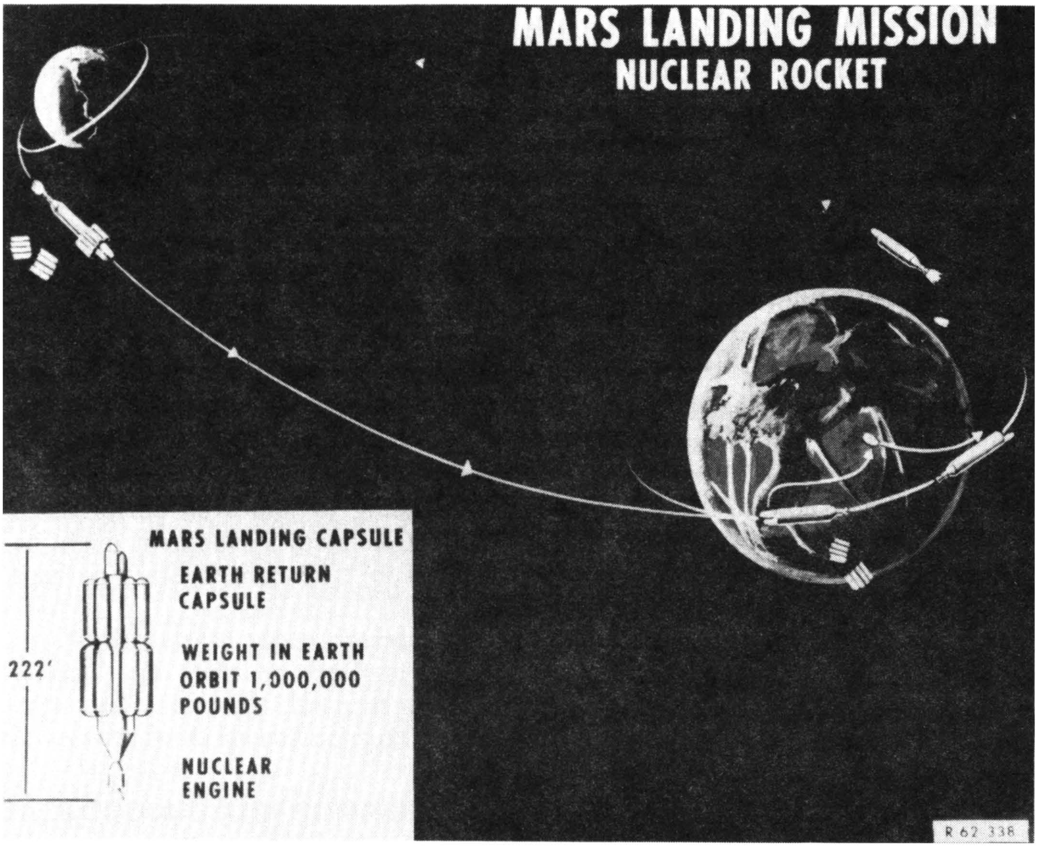

Figure 4 Typical 1962 planetary mission concept where reactor power of first stage leaving Earth orbit is about 10,000 Megawatts.

AN EVALUATION OF PROJECT ROVER

The Rover program was an unqualified technical and managerial success. Technically, very severe engineering problems with a graphite-liquid hydrogen heat-exchanger nuclear rocket were tackled and solved in a relatively short period of time--about 15 years. And in the final years of the program there was successful work on developing a nuclear rocket capable of multiple restarts. Had the program not been terminated in 1972, there is no doubt that there would have been further technical improvements. Perhaps there might be even better second-generation nuclear rockets. However, the task of developing a flight-rated system would have remained even if the Rover program were not terminated. This would have posed a number of challenging engineering problems, but not insurmountable ones.

From a managerial perspective, there were some early differences of views with respect to the AEC's and NASA's approaches to research and development. However, after the KIWI-B4A test, these problems settled down. During the last ten years of the program, the joint AEC/NASA office was firmly in charge and successfully managed the efforts of the AEC and NASA laboratories and the private industrial firms who were brought into the program. Everyone worked as a team to produce the technical successes which were obtained in the mid and late 1960s.

However, the Rover program faced insurmountable political problems. It was the favorite program of an influential but aging Democratic senator and when he left office, there was no one in the Congress who could effectively muster support for the program. Had there been a mission for the nuclear rocket though, that support might have been found in the Administration or the Congress. But it was most difficult to justify funding a program which was aimed at developing a rocket engine for advanced space missions--a lunar base or a manned Mars expedition--when NASA's space activities after the lunar landings were being severely curtailed.

If U.S. attitudes change, as they might, for there are indications of renewed public support for manned space exploration, the nuclear rocket program could be reestablished. If it is, there will be a solid body of technical successes and managerial know-how to build upon, perhaps leading to improved performance second-generation nuclear rockets. Then President Kennedy's statement might be fulfilled, that the U.S. would have a nuclear rocket to "take men to Mars, perhaps to the end of the solar system itself."