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and
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at the 31st annual meeting of the
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# MISSIONS FOR NUCLEAR ROCKETS

In the few short years since the start of this space age, we have made dramatic strides toward learning about that part of the solar system near the earth and about the means of using our space technology and equipment for the benefit of mankind. We have put men into space; we have launched and learned from the Explorer space probes; we have had the successful Mariner experiment; we have had Tiros, Echo, and Telstar. All of this work is but the early beginning that lays the foundation for the extensive explorations still to be conducted and the benefits to be derived in this generation, in the next, and infinitely on in time. It is inevitable that the strong start we are making in space will continue as a never-ending exploration of space. It is, therefore, extremely important that we establish our space program in such a way that it will contribute directly to the logical conduct of a long-term, dynamic, and challenging effort.

We have, I believe, a commitment to lay the foundations for the future. As part of this commitment, I believe we must provide our on-going space program for the next decade and the indefinite future with nuclear propulsion systems which

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will overcome the restrictions imposed by the chemical combustion rocket systems on our ability to travel far and fast with high payloads. Long-term preeminence in space requires this substantial effort on nuclear propulsion technology and systems so that missions beyond the first manned lunar landing mission may be performed. The two major nuclear systems being investigated are the nuclear rocket and the nuclear electric propulsion systems. Although their performance potential may overlap for some missions, I believe they become complementary as we look ahead toward a long-term space program and consider the development times involved. I will, however, during this discussion present only the mission potential of the nuclear rocket and leave the discussion of electric propulsion for another meeting; otherwise, I am afraid I would do an injustice to both of these important nuclear systems.

Although there is, as you know, no firm, approved, scheduled space mission for the nuclear rocket at this time, there are so many advanced missions for which nuclear rockets are desired or required that an urgent and aggressive program on nuclear rockets must be conducted to develop these systems. It is necessary that the kind of experience and "know how" that was available for chemical systems when the decision was made to aim for the moon, be developed for nuclear rocket systems in time to permit decisions and commitments to be made logically and confidently regarding the missions beyond the moon and the vehicles that should be developed beyond the Saturn V vehicle. Such decisions will, I believe, be forthcoming as we approach the accomplishment of the lunar mission. Our program is being conducted to provide the kind of information and experience that I have been discussing and to provide systems that will permit us to proceed aggressively to accomplish the advanced mission objectives when they are firmly established.

Although the subject I am to discuss today is the mission for the nuclear rocket, I am sure that those of you who are associated with the nuclear rocket program and familiar with the program, as well as those of you who are new to this important development area, will want to know something about

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the status of the program today. We have learned a great deal, but we still have much to learn and do.

The program started in 1955 at the Los Alamos Scientific Laboratory of the Atomic Energy Commission and it has continued to receive its major effort and emphasis at that Laboratory. After several years of comprehensive analysis and laboratory tests on materials, physics, heat transfer, dynamics and other disciplines, the Los Alamos Scientific Laboratory initiated the testing of complete research reactors, the KIWI-A reactor series, in 1959. Those tests were designed primarily to determine the ability of uranium-loaded graphite fuel elements to heat hydrogen to a temperature of interest for nuclear rocket propulsion. The three KIWI-A reactors which were tested in 1959 and 1960 provided enough confidence in the design techniques and the materials to permit us to go ahead with the KIWI-B reactor series. The KIWI-B reactor series is aimed at providing a basic reactor design which can lead directly, with continued engineering development effort, to a flight reactor system. The engineering development is to be done by the NERVA contractors who were brought into the program in July of 1961. The NERVA developers are Aerojet-General as the prime contractor, with the Westinghouse Astronuclear Laboratory as the principal subcontractor responsible for engineering the reactor portion of the NERVA engine.

In the KIWI-B series of reactors, the Los Alamos Scientific Laboratory established several designs which represented different approaches to the solution of problems associated with the use of a brittle material in the environment of a nuclear rocket. The first of these, the KIWI-B1A reactor, was tested with gas coolant flow in December of 1961. A similar reactor (KIWI-B1B) was then tested with liquid hydrogen inlet flow, as is required in a flight rocket engine, in September of 1962. A photograph of that reactor at the test cell is shown on the first slide (figure 1). This is the general configuration of the test setup of all reactors run to date. They have been fired with the exhaust jet pointing upward to simplify the facility installation. The nozzle in this test was regeneratively cooled with liquid hydrogen. The results of this test indicated that the reactor could be started stably with liquid hydrogen. However, in this KIWI-B1B design,

damage occurred in the reactor core similar to damage that had occurred in certain of the KIWI-A tests. The fact that this damage has not been explained through extensive laboratory tests and analysis has made us discard the KIWI-B1 design, for the present, as a candidate for the NERVA engine. It is important to point out that prior to this test, the decision had been made to proceed with the KIWI-B4 type reactor design as a basis for the first NERVA reactor design. This decision was made on the basis of the best available analytical and laboratory experimental data and the fact that the KIWI-B1 type of design had failed in the KIWI-A tests and the failure was not explained. It was also based on the belief that the KIWI-B4 provided greater margin of performance for operation of the reactor.

The first of the KIWI-B4 reactors, the KIWI-B4A, was tested by Los Alamos in November of 1962. A photograph of that reactor is shown on the next slide (figure 2). It is externally very similar to the KIWI-B1 reactor; however, the core design is substantially different. Almost as soon as the test of the KIWI-B4A reactor was started, flashes of light were noted in the exhaust jet. These flashes of light were an indication that material from the core was being carried away in the jet. However, the test was continued until the frequency of these flashes became so rapid that it was apparent that more could be learned by shutting down and examining the reactor than by trying to barge ahead to design power conditions. Upon examination, it was found first, that a thermal insulation component around the reactor had broken and parts of those thermal insulation components had been ejected from the reactor. Upon continued disassembly, it was found that fuel elements had been cracked and, now that the disassembly is complete, it is apparent that there was extensive damage in the reactor. The data indicate that vibrations probably took place in the reactor and that the vibrations were probably generated within the reactor. Work is now actively underway by Los Alamos and Westinghouse to modify the mechanical design so as to reduce to a minimum the possibility of such mechanical vibrations. Although there is very strong feeling among all participants of the program that this vibration is the explanation for the damage, we have determined that before further full-scale, hot tests are run,

component, subassembly, and full-scale mechanical testing and cold-flow testing will be conducted to evaluate the failure mode hypothesis that has been made of the KIWI-B4A reactor damage. Such testing will also be conducted to check the suitability of redesigns of that reactor to overcome the mechanical difficulties experienced.

The current status of the reactor program is, therefore, that major accomplishments have been made by the Los Alamos Scientific Laboratory in the development of the materials technology required for nuclear rocket reactors including the development of techniques for fabricating fuel elements and protecting them in a hydrogen environment. In addition, Los Alamos has made major progress in evaluating and accomplishing the start-up of a nuclear reactor rapidly with liquid hydrogen. As part of this phase of the program, they have gone a long way toward establishing the control parameters and control methods for nuclear rocket reactors. The nuclear physics aspects of these reactors are well understood and designs can proceed with a fairly high level of confidence in this area. The greatest area of concern at the present time is in the area of mechanical engineering design of the reactor within known limitations of the materials, physics, and heat transfer processes. Through a thorough design and test effort, I am convinced our program will lead to a successful nuclear rocket reactor of the general type that we have been discussing for use in our NERVA engine and RIFT flight test programs.

Those of you who are familiar with the program will recall that I have said that we will not initiate the heavy procurement or development of major non-nuclear components and systems until we have a demonstration of successful reactor operation with liquid hydrogen under conditions that approach those that are required in the NERVA engine. The program has been conducted on that basis and will continue to be so conducted. Our major emphasis will continue to be on the reactor. We are, however, proceeding with non-nuclear component work in both the engine and the flight test stage programs aimed at evaluating the critical design and operating problems. While we will be pursuing work in these critical non-nuclear areas, the procurement of large numbers of flight components aimed at developing those components to high reliability will not be conducted

until successful reactor operation is achieved. The President has already indicated that when successful reactor operation is achieved, additional funds may be forthcoming for the heavy hardware effort.

For the sake of completeness on the status of our program, I believe that I should, for those of you who are not familiar with the effort, indicate the features of the NERVA engine and the plans for flight testing the RIFT stage. As I mentioned earlier, the NERVA engine will be developed by Aerojet-General and Westinghouse; and, in addition to these contractors, Bendix and American Machine and Foundry are subcontractors to Aerojet.

A full-scale mock-up of the NERVA engine is shown on the next slide (figure 3). The engine stands 22 feet high. Shown in the slide are the reactor, the regeneratively-cooled nozzle, the control drum actuators, and the thrust structure at the top of the engine. The turbopump, shut-off valve, and gimbal bearing about which the entire engine may be swiveled to direct the thrust vector are mounted within the upper thrust structure section. The large spheres at the top of the engine are pressurizing gas bottles used as a drive source for the pneumatic actuators in the system. These bottles are refilled during operating cycles of the engine.

The reactor used in the NERVA engine will be a direct outgrowth of the KIWI reactor work. These reactors are already very similar in design and are becoming more similar as Westinghouse and Los Alamos cooperate and collaborate in the design modifications to be made as a result of the KIWI-B4A experiment. We are, therefore, conducting a single reactor development program in which all tests will be directed toward the goal of achieving a reliable NERVA engine.

The objective of the RIFT program is to flight test this NERVA engine. In addition, the objective of the RIFT program is to try to flight test the stage which should, with continued development, lead to an operational stage on a Saturn V vehicle. The RIFT stage is being developed by the Lockheed Missiles and Space Company. A drawing of the RIFT stage is shown in the next slide (figure 4). The stage will be 33 feet in diameter, the same diameter as the Saturn V vehicle, and it will stand approximately 80 feet high from the base of the engine to the

top of the stage itself. With a nose cone added, the total stage will be about 137 feet tall. The trajectories for the RIFT flight have not yet been established, but the plan is to boost the RIFT stage by the first stage of the Saturn V using a dummy second stage and fly the RIFT stage over a limited range trajectory impacting in deep Atlantic Ocean water. Careful consideration is, of course, being given to the safety of the operation and I am convinced that the flight test can be conducted in a completely safe manner for operating personnel at the Cape as well as for general population.

Now that I have presented to you a summary of the status of the program, I would like to go on to the important area of the missions for which nuclear rockets will be used.

I believe it is entirely safe to say that if they were available today, nuclear rocket stages would be included in almost all of our rocket vehicles. This indicates that nuclear rockets are in no way restricted to the accomplishment of any particular single mission. They could be used to do almost anything we may want to do in space. Unfortunately, however, they are not available today and the "bird in the hand" approach makes it necessary for us to identify the kinds of missions that they can perform substantially better than chemical rocket systems.

The type of mission for which the nuclear rocket is obviously required is illustrated on the next slide (figure 5). This is the Mars manned landing mission that I have described frequently as a mission that cannot be done by conventional chemical combustion rocket systems and that requires the use of nuclear energy if it is to be performed. In this case, a nuclear-propelled spacecraft is established or assembled in an earth orbit. The spacecraft is then propelled to an orbit about Mars, jettisoning hydrogen propellant tanks as these tanks are emptied. A Mars exploration vehicle lands on Mars and then returns the exploration party to the orbiting spacecraft. The spacecraft is then propelled back to earth by a nuclear rocket system.

The weight that must be established in the earth orbit to accomplish such a mission depends on many factors. Among

these factors are the time to be allotted for the full round trip, the allowable radiation doses to which the crew is to be subjected, the radiation levels existing in the space environment, the year in which the mission is to be performed since it determines the energy required as a result of the eccentricity of the Mars orbit, the performance that may be expected from the nuclear rocket in terms of specific impulse and thrust-to-weight ratio, and the size of the capsule required to perform the mission. Analyses and detailed studies are underway or being initiated to evaluate all of these factors. These analyses are being conducted by the Marshall Space Flight Center, Lewis Research Center, Manned Spacecraft Center, and various industrial groups. The importance of some of these factors is indicated by the fact that the radiation assumptions could result in gross spacecraft weights in earth orbit that vary by factors of 2 and possibly more. The year in which the mission is performed could have a major effect on the size of vehicle required because of variations in energy required. The effect of flying to Mars in a year in which Mars and the Earth are in the most favorable relative spatial position energywise as compared with flying in a "poor" year when the eccentricity of the Mars orbit demands high energy could give factors of 4 - 7 difference in gross weight depending on the specific impulse that can be expected. The higher the specific impulse, the smaller the effect of the year of flight.

It is, therefore, at the present time, extremely difficult to specify a particular total weight of the vehicle for such a mission. Although uncertainties exist in the absolute values of spacecraft weight, I believe that comparisons of nuclear and chemical weights are valid. The important point I want to emphasize is that chemical systems for such missions will have to be so heavy that they cannot be considered feasible. The ratio of chemical weight to nuclear weight established in the earth orbit varies from 5 to over 10 for the various analyses that have thus far been performed. In the "bad" years, the advantage of nuclear systems over the chemical systems could become almost infinitely large. The ratios of chemical-to-nuclear spacecraft weights established in an earth orbit have generally been computed for a trip time of 400 days. If shorter trips are required, the differences between nuclear and chemical rockets would be increased. It is these very large factors of

performance advantage for the nuclear rocket and the extremely large gross weights that would have to be established in an earth orbit for the chemical rockets that have led us to the conclusion that the chemical rocket could not perform such a mission. It is also this large difference in total weight established in the earth orbit (even if the ratio of chemical-to-nuclear spacecraft weight turned out to be only 5 to 1) that has led to the conclusion that the nuclear rocket development and hardware costs would be fully compensated for, or paid for, in the very first Mars landing mission.

The system that would have to be developed for the performance of these Mars manned landing missions would also be needed for the missions to be performed as preliminaries to this difficult mission. As a prelude to such a mission, I would expect that we would want to perform the kind of mission shown in the next slide (figure 6), in which the nuclear propelled spacecraft would travel to Mars, be established in a Mars orbit for a limited period to permit manned observation of the planet without any landing and then the spacecraft would return to earth. Such a mission might be performed leaving an option to land if all goes well. With proper program design and timing, engines and stages developed for the Mars landing could be used in a flyby mission in which a nuclear-propelled vehicle simply passed by Mars and returned to earth. This is the Martian analog of the circumlunar mission.

We could, therefore, conduct a logical step-by-step effort aimed at landing men on Mars through the use of nuclear rocket propulsion, by first sending a manned flyby expedition around Mars, then sending a manned expedition into orbit around Mars for observation of Mars, and finally, landing men on Mars. Such an effort would obviously be a very major undertaking, possibly more difficult than the manned lunar landing mission now under way. It will require extremely careful planning because of the many variables that could affect mission requirements. The development of the nuclear rocket, the space sciences program, the communications program, the space power work, the mission and vehicle studies, and our spacecraft technology effort will all provide information that would ultimately be required in the performance of such a mission.

Such a Mars landing program is not part of the approved or scheduled mission efforts now being conducted. The steps that I have indicated have not been approved in any way; however, I believe they would form the basis of a logical effort aimed at qualifying men and equipment for such a difficult planetary landing mission. Much work is required to prepare for the planetary missions and to fully investigate the kind of a program that should be conducted. Just as the lunar landing mission is the major mission objective of this decade, planetary exploration should become the objective for the next decade.

If it is determined, after careful study, that the eccentricity of the Mars orbit and the radiation doses during the latter half of the 1970's requires an excessively large energy increment and excessive space radiation shielding, then Venus may be an early and desirable target. The results being obtained and to be obtained from the Mariner spacecraft will certainly provide information on the feasibility of performing such missions. If Venus turns out to be a desirable objective, then an operational version of the RIFT vehicle could be used for the Venus flyby mission shown on the next slide (figure 7). Such a mission is not dependent in any noticeable way on the year in which the mission is performed so it could essentially be performed as soon as we can get ready. The 100,000 pound spacecraft should be sufficient to provide room for the necessary power supplies, data acquisition and transmission equipment, the scientific instruments, and the life support equipment that are required as essentials for such a flight, and the chemical and course correction system. This payload is indicated for a 370 day Venus mission. The nuclear stage would fire for only a short time from earth orbit to accelerate the spacecraft to the energy necessary to coast to Venus. No restarts would be required.

I expect that nuclear rockets will also be used as soon as they can be made available for missions nearer the earth and for unmanned planetary missions as a result of the development to operational status of the NERVA and RIFT systems. As I pointed out earlier, the RIFT stage will be so designed that it may be propelled by the NERVA engine as a third stage on the Saturn V vehicle. The lunar orbit payload of such a vehicle

is shown on the next slide (figure 8) as a function of the thrust of the nuclear third stage. These payload values, varying from approximately 100,000 to 130,000, are approximately double the value of the all chemical Saturn V vehicle. The RIFT stage could also be developed to serve as a lunar orbit reusable ferry. In such an application, the operational version of the RIFT stage would be established in an earth orbit and loaded with whatever propellant loading might be required. The nuclear stage would then propel its cargo to an orbit around the moon from which point that cargo would be landed on the surface of the moon. The orbiting nuclear stage would then be loaded with cargo to be returned to the earth orbit. Once returned to the earth orbit, the nuclear stage would be refueled so that it could perform its mission once again. Although we cannot now assure that the required number of restarts and long total operating time of nuclear reactor systems for rockets are indeed achievable, I am confident that they are developable to the required performance conditions.

Although my emphasis so far has been on manned applications, the next slide (figure 9) indicates some of the unmanned capabilities of the operational version of the RIFT stage. A Mars orbiting spacecraft possibly including the landing of instruments and a Jupiter flyby mission are shown. These payloads of 25,000 and 15,000 pounds respectively, are, of course, substantial values.

I have tried during this time to give you a brief summary of the status of our program aimed at developing the nuclear rocket. I have also tried to indicate the wide variety of missions that could be performed by nuclear rockets and I have tried to show those missions for which the nuclear rocket will be essential. An aggressive program must be conducted to develop these nuclear systems that will be needed for the advanced missions that, I am convinced, will inevitably follow the first manned lunar landing. Preeminence in space will depend on our freedom to travel in space at will. The high energy capability of nuclear rockets will constitute an essential requirement for such free travel.



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