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Space Nuclear Propulsion Office
U.S. Atomic Energy Commission
Washington 25, D. C.

Your Ref. Your Letter of: Our Ref.: Sz/Ln 15 January 1964

Dear Dr. Finger:

May I thank you again for sending us your paper on space nuclear systems. We have had your manuscript translated and realized that you discuss certain technical details which are too far advanced for our readers. I would therefore like to ask you to please accept a few cuts.

I am sending you enclosed the translated manuscript in which I have already made the cuts. I hope that you will essentially agree to this. May I ask you to mark any corrections you may wish to make.

I also have an additional request:

Our readers will wonder how a nuclear reactor works as a space vehicle engine. It would be best to add a schematic drawing of the KIWI and to explain the operation in the caption. Would you kindly send us such a drawing.

Furthermore, I read recently in the newspapers that project ROVER is encountering difficulties. Since you have not mentioned this in your manuscript, I would like to know whether this is an entirely different project, or why you do not describe project ROVER in your paper.

Hoping to hear from you soon, I am

Sincerely yours,

(Signed)
H. Schultze

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NUCLEAR POWER FOR SPACE TRAVEL

Dr. Harold B. Finger, Space Nuclear Propulsion Office, Washington

No other source of energy can compete with nuclear energy for carrying great loads through space. An intensive exploration of space will therefore only be possible with the help of nuclear energy. The advantage of nuclear energy over chemical propulsion does not lie - as one might think at a first glance - in the fact that a few kilograms of uranium furnish the energy necessary to carry out extensive excursions into space during the next ten or twenty years. The liberated nuclear energy is not used directly for propulsion, but is transmitted to a fuel (for instance hydrogen) which furnishes the required thrust for the space vehicle. When the fuel is used up no further propulsion is possible, even if there were still enough fissionable uranium on board. The advantage of nuclear propulsion lies, however, in the fact that it makes possible the development of an extremely high specific impulse, i.e., a high thrust per kilogram of fuel, passing per second through the system. The hydrogen flows through the nozzle with a velocity three times higher than in a chemical propulsion system. This means that a smaller amount of fuel needs to be carried in the space vehicle than would be required for a chemical propulsion system. Therefore the payload can be higher or the vehicle can go farther into space.

The early and practical utilization of nuclear energy in space is a major goal of NASA's advanced propulsion and power generation program. To this end a program has been adopted to utilize only the technical possibilities available in the near future. Our program is composed of two major parts: nuclear rocket systems and nuclear electric power and propulsion systems. A large portion of these programs is a combined effort by the Atomic Energy Commission (AEC) and the National Aeronautics and Space Administration (NASA). /2

Nuclear Rockets

The nuclear rockets program is composed of several stages (Figure 1):

1. Development of the nuclear reactor (KIWI)
2. Development of the reactor propulsion system (NERVA)
3. Flight test of the reactor propulsion system in a rocket (RIFT).

The reactor technology obtained during the KIWI project will serve for the development of a flight propulsion system in the NERVA project. The NERVA propulsion system will be flight tested in the RIFT stage. The RIFT stage will be designed to fit the Saturn V rocket.

KIWI Project

The pace of the projects for the reactor propulsion (NERVA) and the RIFT flight vehicle is set by the progress made in the nuclear reactors. In 1959 and 1960 three KIWI-A research reactor tests were run. In 1963 activities have concentrated on components tests and "cold" reactor tests, i.e., without uranium. Figure 2 shows a KIWI reactor at the test cell. This type of test set-up has been used for all reactor tests run to date. The exhaust jet pointing upward simplified the facility installation. The nozzle in this test was cooled with liquid hydrogen. It was seen that the reactor could be started stably with liquid hydrogen. However, in the last KIWI version (B1) damage occurred in the reactor core, which has led to the discard of this design as a candidate for the NERVA engine.

The most recent reactor test, KIWI B4A was conducted in November /3
1962. This reactor was externally very similar to the KIWI B1, but the core design was substantially different. Almost immediately after the test was started, flashes of light occurred in the exhaust jet of the KIWI B4A. After disassembly of the reactor, it was found that there was again extensive damage, probably caused by vibrations that originated in the reactor. Work is now under way to modify the mechanical design so as to reduce to a minimum the possibility of a recurrence of such vibrations.

In the near future, major emphasis will continue to be placed on the reactor. However, work on nonnuclear components will also proceed.

NERVA Project (Nuclear Energy Reactor Vehicle Assembly)

The next element of our program is the development of a reactor
propulsion system. Figure 3 shows a full scale mock-up of such a NERVA /4
engine. The engine stands over 7 meters high. The large spheres at the top of the engine are pressurized gas bottles used for the drive of the pneumatically powered control organs of the system.

RIFT Project (Reactor in Flight Test)

The primary purpose of the RIFT project is, as mentioned previously, the flight test of the NERVA propulsion system. Its design will, however, consider its eventual development to operational status as a third stage on the Saturn V vehicle. Figure 4 shows a drawing of a proposed version of the RIFT stage. It will be 11 meters in diameter, the same diameter as the Saturn V. From the exit of the NERVA jet nozzle to the top of the stage, it will stand approximately 28 meters high. With the required nose cone added the total height of the stage will exceed 43 meters.

Several special problems have come up during the development of this RIFT stage. The liquid hydrogen tank will be the largest of its kind ever constructed. The low temperature of the liquid hydrogen on one hand, and the nuclear radiation of the NERVA reactor on the other, affect structure, insulation, propellants, etc., in such a way as to present research with problems of a completely new kind. The nuclear flight safety requirements will require the development of new techniques for check-out, launch operations, and destruct systems in addition to those that are already provided for range and flight safety in nonnuclear applications. The combination of the comparatively heavy gimballed nuclear engine and the large, but relatively lightweight, liquid oxygen tank present unique aerodynamic and structural loadings.

Four flight tests are planned utilizing the Saturn V launch complex /5
at the Atlantic Missile Range. These flights will be conducted with the RIFT stage mounted on the Saturn V first stage. Water ballast will be used to obtain the proper acceleration conditions.

Nuclear Rocket Development Station

The nuclear rocket development station (NRDS = Nuclear Rocket Development Station) comprises an area of approximately 140 kilometers northwest of Las Vegas, Nevada, at which facilities are being provided for all full load testing of reactors, engines and stages. The test facilities are divided into reactor facilities, NERVA engine facilities, and RIFT stage facilities. Some of the reactor facilities such as Test Cell "A" have been in operation for several years and have provided for assembling, disassembling and testing the KIWI reactors. In addition, some of the NERVA facilities are under construction and others are under design. Construction of the first engine test stand is well along and the second engine test stand is being designed. The building for assembly, maintenance and disassembly of NERVA engines is under construction. In addition, support facilities will be designed and built during this year and next year.

It is important to emphasize that the NRDS facilities being built in Nevada represent a national development capacity for nuclear rockets that will not be duplicated anywhere else. This site can therefore really be considered as The National Nuclear Rocket Development Station.

Nuclear Electric Energy Generation

In addition to nuclear energy for nuclear rocket propulsion, nuclear energy will also be required to generate electric power and electric propulsion. In the range of hundreds of kilowatts to many megawatts, the only practical source of electrical power is nuclear energy: for orbiting manned space platforms, manned interplanetary spacecraft, communications satellites and unmanned planetary probes. These applications can generally be divided into /6

1. the need for on-board power for communication, life support, data acquisition, etc., and
2. the power required for electric propulsion.

The estimated electrical power required for operations on board is in the order of 30 to 60 kilowatts. This is still within the capability of the SNAP-8 Electrical Generating System now under development by NASA and the AEC. These estimates are based on a manned orbiting laboratory which might weigh 100 tons, so that the SNAP-8 system would use about 2 percent of that weight.

Another propulsion application, in the more distant future, is the manned interplanetary spacecraft. Such a vehicle would weigh 500 tons or more, might require assembly in orbit and would require 20,000 to 30,000 kilowatts for its large electric rocket propulsion system. The usefulness of an electrically propelled spacecraft depends very substantially upon the weight of the nuclear electric power generation system which produces the energy for the electric rocket engines. A power generation system weight of 5 kilograms per kilowatt or less, including shielding, would make such a spacecraft competitive with a nuclear rocket for a manned Mars mission.

Electric Power Generation: SNAP-8 Development Project

SNAP-8 is a 35 kilowatt, reactor-powered, electric power generation system suitable for space-flight applications. As shown in Figure 5, it is composed of two major components, the nuclear system and the power conversion system. The working fluid, a mixture of sodium and potassium, is heated in the reactor and pumped into the boiler where its heat energy is transferred to the mercury in the boiler. It is then pumped back to /7
the reactor and is reheated.

The heat energy transferred to the boiler causes the liquid mercury in the second loop to boil. The resulting mercury vapor passes through a turbine which extracts enough energy to drive the generator. The mercury vapor is then cooled in the condenser and the resulting liquid pumped back to the boiler for reheating.

Thus, the heat produced in the reactor is transferred to the turbine section. There, approximately 10 percent of the energy is extracted in the form of electricity. The unused heat energy is then rejected to space by the radiator.

Cycle temperatures range from 700°C in the reactor to 80°C in the generator. These temperatures in combination with the 10,000 hour maintenance free operation requirement are presenting difficult problems in materials selection and bearing and seal design.

The objective of further projects is the development of future systems such as shown in Figure 6. A 1150°C turbo-electric system (on the left in Figure 6) would probably utilize lithium and potassium as working fluids. The thermionic system for the direct conversion of heat into power (on the right in Figure 6) is a simpler system, having fewer moving parts. It requires, however a maximum temperature of approximately 1660°C. Both systems have estimated design weights on the order of 5 to 10 kg/kW. Technologically, both are far beyond current ground-based power generating devices. The uncertainty in space environment due to micrometeorites and the lack of basic and engineering knowledge concerning materials, heat transfer, flow processes, etc. create serious obstacles to be overcome before hardware development of such advanced systems can be undertaken. /8 It is of decisive importance to determine the effects of relatively extended weightlessness on liquid metal boiling and condensing heat transfer. In order to obtain the eight or ten minutes of weightlessness needed to establish equilibrium conditions, freely falling vehicles will be dropped at high altitudes. Experiments weighing up to 500 kilograms will be launched by small (13 Mp thrust) solid material rockets. The first experiments are in direct support of SNAP-8 and will work with mercury fluid and SNAP-8 boiler and condenser components and configurations.

Electric Propulsion

Figure 7 illustrates the three main types of electric rocket engine: the arc jet, the ion engine and the plasma jet. The arc jet develops thrust by heating a working fluid such as hydrogen or ammonia and expanding it through a nozzle. The ion engine depends upon electrostatic forces and reactions to accelerate a working fluid such as cesium or mercury, thereby developing thrust. The plasma engine utilizes electromagnetic forces to accelerate plasmas. As can be seen in the left-hand column of the Figure, the specific impulse[1] range of the arc jet is 700 to 1500 sec. The specific impulses of the ion engine are in the 3500-10,000 sec range. The plasma jet offers the potential of covering the whole range of the other two. The engines are ranked in order of

[1]Footnote indicated in the German but none given. Also compare to the corresponding passage on page 13 of the original English manuscript.

developmental status. The arc engine is closest to being ready for application. The right hand column of the Figure lists the major problem areas for each engine type.

The major problems to be solved in the arc jet engine pertain to dissociation losses which directly affect engine efficiency and electrode erosion which has a direct effect on engine life. Typical efficiencies obtained to date range from 40 to 50 percent, while endurances of several /9 hundreds of hours have been demonstrated in ground operations.

The technology of ion engines is not yet as advanced as for arc jets; it is sufficiently advanced however, to permit the planning of flight tests, to evaluate existing solutions for such problems as beam neutralization, and to determine the consequences of extended exposure to space environment.

Figure 8 shows a 3 kW basic ion engine module now under development. The dimensions are approximately 7.5 x 15 cm. This unit will be used for basic research and development and is of a size suitable for solar-powered operation. A 30 kW engine would be composed of nine basic modules. With dimensions of approximately 0.9 x 1.2 meters, it could operate with the SNAP-8 Electrical Generating System described previously. The ultimate goal may be a megawatt cluster of 30 kW modules. This engine system would measure 6 x 8 m and could be used to propel a large interplanetary vehicle.

The plasma jet technology program is really just beginning. As indicated earlier, plasma propulsion systems offer the potential of good performance over a broad range of specific impulse. However, before efforts can be concentrated on one or two main solutions, we should have a better understanding of the many engine concepts.

Translated for the National Aeronautics and Space Administration
by John F. Holman and Co. Inc.