Application of Proven Rover/NERVA Nuclear Thermal Rocket Technology for Near-Future Manned Planetary Missions

Stanley Gunn,
svgunn@aol.com

Ernest Robinson
ernev@speakeasy.net

Two years after the end of World War II, scientists at North American Aviation's Aerophysics Laboratory released a document describing a potential rocket propulsion system which would employ a graphite fuel element reactor to heat hydrogen gas, to a very high temperature, before the gas would be expanded out of an appropriate rocket nozzle. The fuel elements' incredibly high energy density enables such a propulsion system to achieve two major propulsion advances: a specific impulse several times greater than rocket engines employing solid fuels or liquid propellants, and a very high thrust (total impulse) needed for solar system exploration. There was, however, concern that the hydrogen gas would interact with the exposed heat transfer surfaces of the graphite fuel elements unless some suitable coating could be applied to the heat transfer surfaces.

As a result of developing interest in the possible high performance nuclear energy-generated advanced space propulsion systems, independent studies have been conducted which project: (l) substantial cost and safety benefits for the propulsion requirements of possible manned space missions, and (2) reduced flight times and crew exposure conditions to solar radiation. It has thus been apparent that if nuclear thermal propulsion development were completed, the undertaking of manned planetary exploratory missions would become safer and much less costly than conventional chemical propulsion.

In 1953, a joint space nuclear propulsion office (SNPO) was set up, combining resources of the Atomic Energy Commission (AEC) and NASA, to develop a practical, flight-worthy nuclear rocket to power planetary exploration. The Los Alamos Scientific Laboratory (LASL) and the Lawrence Radiation Laboratory (LRL) undertook focused studies followed up by a broad experimental test program. LASL first decided to use helium as the heat exchange gas and then use NH3 as the propellant gas. In 1956, North American Aviation's Rocketdyne Division, following design studies of possible nuclear thermal rocket engines, identified hydrogen as the most likely propellant, and proposed to the U.S. Air Force's Flight Dynamics Laboratory, at Wright Patterson AFB, the development of a multistage, axial-flow, liquid hydrogen pump (designated MK 9), designed to ingest 70 lbs/sec of LH2 with a discharge pressure of 1600 psia. This pump, years later, evolved to the LH2 pumps of the J2, J2X and other present–day LOX/H upper stage rockets. The Air Force backed development of this pump, and after its design had been finalized, Rocketdyne briefed cognizant N Division LASL staff, who then addressed the issue of what gas should be used as a reactor coolant, and elected to change to hydrogen as the single coolant and propellant fluid.

Testing the first (Kiwi A1) of a series of eight Kiwi reactor tests was initiated in July of 1959 at NRDS, the Nuclear Rocket Development Station, built within the grounds of the Nevada Test Site. The first Kiwi reactor core comprised, (1) A D2O CENTER ISLAND, (2) an annular stack of flat-plate, graphite fuel elements loaded with highly-enriched UO2 particles, (3) a top layer of unloaded fuel plates, and (4) and a peripheral radial reflector consisting of several continuous graphite cylinders.

On the first high power test, because of the ejection of graphite closure plates, the core exit fuel element temperature reached an unexpected level of 5200 R (ca 3000 K). Subsequent Kiwi A2 and A3 reactors featured robust graphite modules containing long, slender prismatic fuel elements. These reactors were each tested for several minutes in a power range of 80 to 100 MW (thermal), and produced gas exit temperatures ranging from 3200 R to 4000 R (2220 K). All of these tests employed converging, throat-exit nozzles, designed and developed by Rocketdyne, utilizing water as coolant.

Next, the 1000 MW 35-inch diameter core Kiwi B1A, Kiwi B1B and Kiwi B4A reactors were tested, and problems encountered corrected. Six prismatic fuel elements units, of the type used in the Kiwi B4D reactor, were formed into modules by stacking around cooled tie-rod subassemblies, forming hexagonal cross section repeating modules 52 inch long, with associated module structural support, which were successfully used in all of the subsequent Kiwi, Phoebus and NERVA reactors tests. These designations distinguished the LASL developmental cores under ROVER, the producible designs by Aerojet, and the Westinghouse NERVA flight prototype design under Nuclear Engine for Rocket Vehicle Application.

The fuel elements were formed by extrusion of the required graphite and carbides to form shapes with hexagonal cross sections (3/4 inch across the flats), and containing nineteen coolant passages. For the Kiwi B reactors coolant passages were 0.241 cm in diameter, and for the Phoebus reactors they were 0.245 cm in diameter.

By completion of testing of the seventh Kiwi (B4D) reactor (in NRDS Test Cell C), and the use of composite fuel elements (extrusion of uranium carbide, zirconium carbide in a graphite matrix), an average of 990 MW fuel power and an exit temperature of 2540 K, was achieved. The follow-on Kiwi B4E reactor was successfully tested at full power for 480 sec. Then Westinghouse designed and constructed NERVA NRX (Nuclear Rocket Experiment) A2, A3 & A5 reactors (also 35 inch cores), also fitted with composite fuel elements, which were successfully tested at powers of 1093 MW to 1120 MW with exit temperatures from 2230 K to more than 2400 K. Thrusting times for these NRX tests were 40 sec., 990 sec. & 580 sec.

The conduct of the first five high power Kiwi B reactor tests in Test Cell A and then the three NERVA (A2-A5) reactors, utilized a Rocketdyne MK 9 pump. Rocketdyne supplied the reactor exit-flow bell nozzles (RN-2) employed in the KIWI B test series, and the similar nozzles employed in the NERVA A2, A3 & A5 were supplied by Aerojet. The Rocketdyne nozzles were designed with their converging-diverging walls formed by a nest of coolant tubes, braised together, to provide both: (1) the hydrogen flow delivery to the reactor assembly, and (2) the regenerative transfer of initial heat to the hydrogen being delivered to the reactor core inlet. The shapes of Rocketdyne's nozzle divergent section were 80 percent bell. while Aerojet's nozzle divergent section was a cone. Later, for the planned conduct of the Phoebus 1B reactor tests, which was to be operated at 1500 MW and a discharge pressure of 750 psia, Rocketdyne designed a new nozzle (RN-6) for which the converging nozzle-walled tubular structure in the wall portion featured "two into one" tube splices, creating enhanced cooling capabilities.

Both of the Rocketdyne nozzles (RN-2 & RN-6) were realistically tested at their ground test facility in the Santa Susanna pass location, at the northwest corner of the San Fernando Valley, California. The testing system utilized an O2/H2 combustion chamber, operating at a mixture ratio ranging from 6 to 1 to 8 to 1, and approximately 900 psia, delivering sufficient high temperature combustion products to emulate the thermal load on the nozzle's wall tubing as projected in the full power nuclear tests at NRDS. To provide the required H2 flow and delivery pressure, a Mark 9 LH2 turbopump and a companion L0X turbopump, both driven by an O2/H2 gas generator, were employed in the test system. This test system operated at a 200,000 lbf thrust level, and became the actual prototype of the J-2 engine later employed in NASA's Apollo 11 program.

Recognizing the coming reactor test needs for more-powerful (higher flow rates, higher discharge pressures) liquid hydrogen turbo pumps, Rocketdyne designed, fabricated and tested a new (MK 25) turbo-pump assembly, capable of 40 percent increased flow and 25 percent increased discharge pressure, for use in planned higher-power reactor tests. This assembly (as a single unit) was installed in Test Cell C at NRDS for the conduct of both Phoebus 1A and Phoebus 1B reactors tests, NERVA A6 reactor test, and then, in dual mode, the Phoebus 2A reactor test. The Phoebus 1 reactors tests reached power levels of 1090 MW and 1450 MW, thrusting times of 630 sec. and 1800 sec., and exit gas temperatures about 2450 K. The NERVA A6 reactor test reached a power level of 1200 MW, duration of 3623 sec., and a gas exit temperature of 2560 K. The Phoebus 2A reactor test (55 inch diameter core) reached a power level of 4100 MW, a run time of 744 sec., and a gas exit temperature of 2256 K, producing a thrust over 200,000 lbs.

Another Phoebus 1B reactor core design change (and later in the Phoebus 2A reactor core), of significance for future propulsion system operating capabilities, was the incorporation of six-element support tie-tube clusters within the core assembly. By providing high-pressure hydrogen tie-tube coolant flow, first down and then back up to the core inlet region, a substantial source of heated hydrogen was available to: (1) power the turbo-pump without reducing the fuel element gas exit temperature (a saving of approximately 100 K), and, (2) to provide the energy source for optional bimodal electrical power. This subsequent NTR engine design could feature full flow (topping) capability for turbine-drive capability, rather than having hot gas bleed from the reactor's main coolant flow passages.

Pursuant to the ultimate goals of the NERVA Program, both Aerojet and Westinghouse were focused on the conduct of two, sequential, nuclear rocket engine systems test series: first the creation and testing of a breadboard engine system (NRX-EST), and then a "near flight-prototype" nuclear rocket engine (XE-PRIME). The NRX-EST breadboard engine system, were mounted on a rail car with its reactor nozzle assembly mounted above the engine's shielded turbopump, controls and insulated ducting. One exception is the propellant line inlet valve, unshielded from the reactor's radiation. The turbine drive gases were supplied from a hot gas bleed port, located in the converging section of the nozzle and cooled by dilution with cold H2.

The primary objectives of the NRX-EST test series were, (1) to demonstrate the feasibility of the hot gas bleed-turbine drive cycle, (2) to demonstrate the capability of "bootstrap" startups, and (3) to map the engine operating envelope by controlling the hydrogen flow rate and reactor core gas exit pressure over a wide range of values up to design flow and chamber pressure. These test objectives were pursued in a series of three low-power start up tests, and then three high power runs in which 1100 MW of operation, for a total of 24 minutes, and were thus realized.

Due in part to NASA’s broadened mission interests, Los Alamos' N Division undertook the design and construction of a 500 MW reactor, termed Pewee. The core had

402 fuel elements within the smaller (21" diameter) reactor core assembly, with 3 elements surrounding each tie tube, and contained both (1) composite and (2) carbide (uranium carbide, zirconium carbide) fuel elements with 27 different combinations of graphite matrix, coating processes, hot-end tips, etc. And, as in the case of Phoebus 1B, somewhat similar element support tie-tube clusters were incorporated which again could be used to both power the turbo-pump and generate bimodal electrical power.

To provide an appropriate liquid hydrogen pump for the conduct of the smaller scale 500 MW Pewee test program, Rocketdyne modified the MK 9 pump by reducing rotor and stator blade heights by 50%. The resultant reactor tests delivered 503 MW, a total duration (3 tests) of 2400 sec., and an average gas exit temperature of 2340 K.

The NERVA XE Prime engine system tests, in the ETF-1 test facility at NRDS, were the final successful tests of the NERVA program. The design of the test facility (see Figure 3), targeted an operating power of 1100 MW, and full power duration of 5 minutes. Its capabilities included accepting the engine's propellant effluent, directed downward into an exhaust-gas horizontal tunnel system, which had been reduced to an initial pressure of 1.6 psia, simulating high altitude conditions. The engine system featured two integrated clusters of engine components; the lower cluster contained the reactor and nozzle assemblies, and the reactor radiation shield; the upper cluster contained the turbo-pump assembly, feed lines, valves and external instrumentation. This engine's test series, conducted in June 1969, operated the engine with 28 startups, over a range of operating conditions, and an accumulated total thrust time of 3 hours and forty-eight minutes.

After completion of the NERVA XE Prime tests, an advanced water-moderated test reactor, termed Nuclear Furnace (NF-1) was assembled, pointed vertically downward in Test Cell C in order to demonstrate complete containment and scrubbing of the rocket effluent through a tunnel, removing essentially all hazardous radioactive materials released in generating the basic heat energy transferred to the propellant. This was a time of agitated public reactions over the perceived radiation hazards to civilians living near the Nevada Test Site. The test system provided a "scrubber" downstream of the nozzle to remove radioactive materials (and later dispose of them) from the flowing heated propellant.

The design of the Nuclear Furnace reactor assembly was scaled back in power to 44 MW, and was physically arranged to handle a combined mix of forty-nine (interacting) composite and all-carbide fuel elements. The targeted hydrogen flow rate was 3.7 lbs/sec at mixed-mean gas-exit temperature of 2300 K. The results obtained in four maximum power tests validated the possibility of an optimized nuclear rocket reactor core design with composite fuel elements upstream first heating the gas up to their normal maximum temperature, followed by a downstream hot section of all-carbide elements that superheat the gas to over 3000 K temperature, thereby achieving specific impulses exceeding 1000 sec, a value more than twice the best performing state-of-the-art chemical LOX/H rockets.

Based on the detailed technical data obtained from the all-composite fuel element reactor tests, LASL's N division set forth new values of achievable core-exit gas temperature of 2550 K and 1.3 MW/element. Finally, the Space Nuclear Propulsion Office in Washington D.C. issued a conclusion that an NTR operational space nuclear rocket could be operated at its requisite mission thrust and exit gas temperature, for a total of 10 hours, with a capability for sixty restarts.

After completion of the NERVA engine system tests and the Pewee reactor test, Rocketdyne undertook two series of MK 25 turbo-pump tests at Test Cell C, to demonstrate further possible advancements in pump tolerance of mixed flow operation within an intense radiation field. The first tests were conducted on modified pump bearing assemblies in which (1) the Teflon-coated Armalon cages of the duplex ball bearing assemblies were removed, replaced by a radiation-tolerant metal cage, and (2) the pump's discharge pressure connected to the clearance volume surrounding the ball bearing's outer races. This modification resulted in a hybrid bearing operation in which the angular-contact ball bearings only operated up to about 100 psi pump discharge pressure. Operation at pump higher speeds resulted in elimination of ball inner race-to-outer race rotation, creating a hybrid bearing system, which would be insensitive to high radiation exposure. The second set of tests were performed on a pump with modified inducer flow channels to produce shock compression of any mixed gas/liquid phase hydrogen, to maintain full pump discharge pressure. Thus the pumping system would still operate satisfactorily, although the engine's environment might be equivalent to being totally unshielded.

During the conduct of all the Rover reactor tests, and all of the NERVA reactor and engine system tests, the official government limits of radiation for scientists and engineers participating in test operations, was 3 rem/quarter and 5 rem/year. There were no incidents of any notable radiation injury to NRDS staff during the decade of ROVER-NERVA. However, because the public perception of radiation hazard has been a major PR issue for nuclear technology application, we digress at this point to quote Herman Cember , certainly among the best (if not the absolute best) known and esteemed personages in radiation effects and health physics, author of several books and standard tests on radiation and health physics who is famously quoted, "... it can be said that radiation ranks among the most thoroughly investigated causes of disease..." Table 1 below presents the order of expert views of various risks to the public, taken from a Rutgers University Study:

Motor Vehicles	1
Smoking	2
Alcoholic Beverages	3
Handguns	4
Surgery	5
Motorcycles	6
Pesticides	8
Private Aviation	12
Large Construction	13
Police Work	17
Fire Fighting	18
Nuclear Power	20

A ranking of this list by the public placed nuclear power as the number 1 hazard. This has established public education as the foremost challenge to gain acceptability of nuclear power and technology application, a need to overcome the overblown fear of all things nuclear. The fact is that radiation from nuclear technology is not the public hazard it is so often put up to be. Securing public support for the nuclear rocket is a prime challenge.

But for some of the nuclear rocket tests conducted, there were occurrences in which participants were exposed to radiation environments in excess of the limits. In particular, after the first high power test of the Kiwi B1A reactor, Rocketdyne's NTR LH2 Turbopump & Nozzle Section Chief was given permission to inspect the condition of the nozzle's coolant walls (once the nozzle had been removed from the reactor assembly), provided he only inspected the inside of the nozzle assembly for thirty seconds. This action was conducted, but the exposure saturated his radiation measurement badge so that it was unable to record the incident radiation intensity. Then, after the Kiwi TNT safety reactor test was conducted (to learn how destructive the reactor assembly would be if its control rods went wildly out of control) and the reactor assembly was self-destructed, the Los Alamos NRDS Assistant Director, two of his associates, and again Rocketdyne's NTR Section Chief were exposed to the after-test radiation surrounding the destroyed reactor assembly. The measured environment radiation was approximately 10 rem. Fifty years have passed, and the health of the above-defined test programs participants (as determined by the NTS Medical Surveillance Project Office's evaluation) remain unaffected by radiation.

The highly successful Rover & NERVA programs were terminated in 1973 because the Mars and Lunar missions, for which their proven technology was so beneficial, had been deferred indefinitely. But early 1989, the U.S. government (and also certain European countries) elected to again investigate nuclear thermal rocket technology programs. The possible interests in manned-Mars missions resulted in the return of interests in: (1) 75,000 lbf-100,000 lbf engines capable of over 900 seconds of Isp, and (2) 15,000 -25,000-lbf engines also capable of over 900 seconds of Isp. A cluster of three smaller thrust engines would provide an engine-out capability. An important capability for concurrent auxiliary electric power is available for these engines, using the tie tube assemblies developed in the Phoebus 2A and Pewee reactors, noted above, without any negative impact on the over-all propulsion performance.

With regard to candidate fuel element technology, considerable attention was (and still is) given to the further advancement and production of various all-carbide elements; but no activities have been initiated for the recovery of the production capabilities of fully proven composite fuel elements. Given the assessment, several years ago, by a former senior LANL scientist (and the fact that composite fuel element production equipment then-several years ago- still existed) that the availability of about three million dollars/year (ear-marked funds), over a 3-year period, could result in the retrieval of composite fuel element production capability. However, the impact of time has left available only a relatively small number of experienced scientists/engineers. Thus, if the retrieval and return to production capability of composite fuel elements is to be realized at a very minimum cost, it should be started soon.

Candidate 75,000 to 100,000 lbf NTR engine designs, were set forth in a 1990 AIAA Joint Propulsion Conference paper. The basis of the design incorporates the proven advances of possible NTR engine capabilities to be featured in future such engine designs. The core would contain 1870 loaded fuel elements operating at an average power level of 1.0 megawatts/fuel element. In particular, at a core exit temperature of 4860 R and a nozzle expansion ratio in excess of 300:1 the design engine system should deliver an Isp in excess of 900 sec; and if proper attention is given to the selection of the design of the propulsion system's non-nuclear components, operating in an intense nuclear radiation field, it should be possible to eliminate the propulsion system's radiation shield and increase the overall engine's specific thrust-to-weight ratio to approximately 7:1. In addition, the inducer design of the multi-stage axial flow pump (so well proven in the Rover Program) should result in performance to support full engine thrust requirements, even if the propellant tank pressure should lose supply of the engine systems tank pressurization system and decay to saturated conditions (assuming the elimination of any tank radiation shield).

Because of higher gas-exit temperature, the use of all-carbide fuel elements has been of interest for over forty years. However, given the specific weight of the all-carbide fuel elements being approximately two and a half times higher than the composite fuel elements, the total weight impact of this difference upon engine thrust-to-weight ratio, would reduce the vehicle size benefit resulting from an engine somewhat higher Isp of 1000 sec versus Isp of 900 sec. One approach to improving the benefits of all-carbide fuel elements is to combine the heating of the propellant, first with composite-graphite fuel elements (constituting 80% of the core length) up to approximately 4500 degrees R, and then all-carbide fuel elements (constituting the last 20% of the core length) up to 5580 degrees R. Thus the resulting increase in engine weight would only be approximately 1,100 lbs. and the size of the engine would remain essentially the same. Further benefits of such an approach would be the likely simplification of vehicle-replacement of the earlier, all-composite fuel element-reactor engine system with the above-suggested composite-carbide fuel element-reactor engine system.

In parallel with the developing 1970 interests in 75,000 lbf NTR propulsion systems, the success of the Pewee reactor tests resulted in LANL undertaking the conceptual design of a small 16,000 lbf NTR engine, patterned somewhat by the NERVA flight engine design. Then later, NASA Glen Research Center became interested in possible bimodal, so-called LANTR (LOX augmented) engine systems in which either thrust levels up to 25,000 lbf could be provided or electric power of 25 kWe could be generated. Relevant engine balance analyses indicate attractive possible missions for such a bimodal 25K NTR engine system. On the other hand, a separate nuclear electrical power generation system(s) is optional.

The issue of public concern with the renewal of NTR propulsion developments is the creation and ejection of radioactive pollutants in the exhaust gases. In the case of the Nuclear Furnace (NF-1) tests, the 49 fuel-elements-core, and low power, were sufficiently small that the resultant radioactive gases could all be readily scrubbed by mixing with water, passing through a cleanup tunnel system to remove fission products, and then released to the atmosphere. But for propulsion systems ejecting radioactive nozzle exhaust gases in flows ranging from 29 lbs/sec up to 109 lbs/sec more elaborate scrubbing systems are needed. Rocketdyne had developed methods for exhaust scrubbing and containment of pollutants, and conducted studies of candidate nuclear rocket exhaust scrubbing and containment, as well as possible closed cycle propellant reuse. Such a reuse system enables removal and disposal of radioactive contaminants, while cooling down, re-liquefying and returning propellant to the hydrogen run tank. With such a closed system operation, the candidate locations for the Nuclear Rocket Development Facility (NRDF) with engine test stands and reactor processing stations might be expanded from the Nevada Test Site, to the Idaho National Laboratory and NASA's White Sands Test Facility in southeast New Mexico. With regard to candidate locations for design, subsystem fabrication, subsystem assembly and testing, the non-nuclear subassemblies can be undertaken at both Glen Research and Marshall Space Flight Centers. The reactors could be designed, assembled, and shipped from either the Los Alamos National Laboratory, the Oak Ridge National Laboratory, or the Idaho Center for Space Nuclear Research. Still another possibility is the Lawrence Livermore National Laboratory. The complete system assembly, test and partial disassembly would be accomplished at the above selected NRDF test stand location, as well as the partial, post-test disassembly. The radioactive reactor core would be shipped by rail, in an appropriate shipping container, to the appropriate NRDF processing facility for disassembly and radioactive component disposal.

The time required for NTP engine development is dependent upon (1) the retrieval of procedures and equipment employed in the Rover and NERVA programs to produce the composite fuel elements, and (2) the government's decision of where the ground testing of the engine's subsystems, and the complete engine testing is to be done. If these retrieval and testing location decisions can be accomplished sufficiently early, it should be possible to conduct a "fast track", seven-year engine development program to support the initiation of an appropriate flight-readiness program. This “fast track” program could be substantially benefited by cooperative international programs, with allocation of well sited launch sites and coordinated manned Mars vehicle mission capabilities demonstrated in preliminary flight-readiness program. This will give stimulus to other follow on planetary missions, the next manned missions. Thus in order to plan realistically for the technical approach of such international space missions, there is incentive to restore collaborative technical interactions between Russia, France, China, Japan, United States and possibly other nations in the program, so that applicable technology and cost-sharing benefits are realized from these nations; in addition the collaboration of these nations should serve to increase the likelihood of future international good will.

The feasibility of rebuilding and testing a nuclear thermal rocket (NTR) for the Mars mission has been investigated. Calculations indicate that an NTR would substantially reduce the earth-orbit assembled mass. Compared to L02/LH2 systems the mass savings is 65% for the case of total propulsive braking. If multiple missions are planned or if propulsive braking is desired at Mars and/or at Earth, then the savings of several billion are a compelling rationale for NTR usage.

Radiation Hazard of Manned Missions

The intense neutron and gamma ray radiation fields produced by the operating reactor are a design issue in using NTR for manned missions. The ejected propellant poses a relatively minor radiation hazard since the LH2 does not become radioactive and the fuel element particulates, which are released into the LH2 from the core will rapidly disperse in the interplanetary environment.

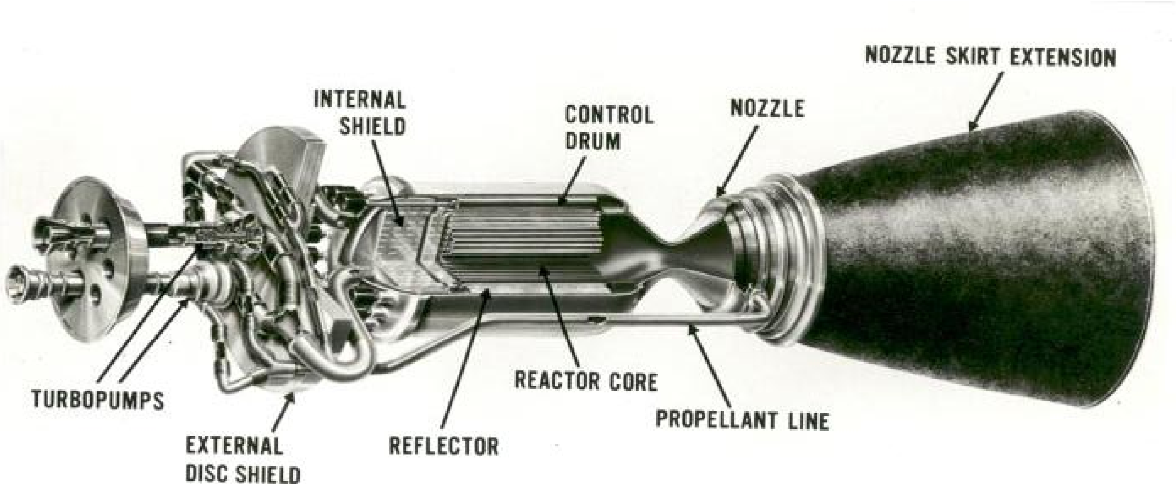
A combined tungsten and LiH shield will protect the crew from reactor radiation during the short propulsive phase and follow-on cool down. Further reduction of the neutron dose to the crew is accomplished by incorporating the LH2 tank between the crew and engine. This tank, for example, might contain the 15% contingency LH2, the last propellant to be used.

After the engine shutdown from full power operation, only gamma rays radiate from the reactor, and within a few days the intensity will drop by over three orders of magnitude.

In the event that this nation would decide to build a nuclear engine for a Mars mission, much of the costs of the NERVA program would not need to be duplicated by the new effort. The KIWI, much of the Technology, and some of the NERVA categories would be removed. The magnitude of effort to build the engine will depend if only a redesign of the NRX or Phoebus engines is taken from existing databases or if a redevelopment and improvement is undertaken. Reestablishing the capabilities existent at the termination of the NERVA program can probably be accomplished for a moderate cost. But he high Isp of nuclear propulsion could reduce the earth departure mass by a factor of 25, with a huge cost savings.

Dr. Stanley Gunn received his BS degree in Mechanical Engineering from Michigan State University and both a Masters and PhD in gas turbine, rocket and jet propulsion from Purdue in 1953. Soon after, he joined North American Aviation Propulsion Technology and combustion instability issues of high-thrust, hydrocarbon/LOX thrust chambers. When Rocketdyne was established Dr. Gunn formed a new division of concerned with advanced propulsion and high-performance chemical, nuclear, electric and photon propulsion, and managed the prototype LH2/LOX engine, its thrust chamber and its liquid hydrogen turbopump, which later led to the design of the Apollo J-2 engine. From 1960-1970, the decade of nuclear rocket development, Dr. Gunn was Section Chief of the Nuclear Propulsion Section where the analytical and hardware design for the Kiwi, Phoebus and Pewee reactors were conducted. Later he was assigned as Program Manager for Nuclear Propulsion in charge of revisiting the Rover/NERVA, at the time, seen as critical to a near-term, manned mission to Mars. Dr. Gunn retired from Rocketdyne/Rockwell International in 1993, but continues to actively participate in many of the technical fields he has managed. He is also an active member of the AIAA and the Nuclear and Future Flight Propulsion Technical Committee. In 2003, AIAA bestowed him with the prestigious Wyld Propulsion Award and the Pioneer Award for his significant career accomplishments.

Ernest Y Robinson received an MSME in Nuclear Engineering from Oregon State Univ. and began his professional career on the Nuclear Ramjet Program at the Lawrence Radiation Laboratory in Livermore CA., working with W. Weibull on refractory ceramic fuel elements. His career included support to NASA programs in the Prometheus Program for nuclear space power and propulsion, in the short-lived JIMO program and the Space Exploration Initiative that, briefly, took a look at nuclear rockets. He retired in 2002, from the Aerospace Corporation, as Distinguished Engineer.



The Prototype Flight Nuclear Rocket Engine

Flight Prototype Nuclear Rocket XE-prime on its way to Test Stand.