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When the Atomic Age Met the Space Age

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Introduction

Since before the beginning of the Space Age, aerospace engineers have sought to develop increasingly efficient propulsion systems. Chemical propulsion systems that burn a fuel and oxidizer to produce thrust were the first to be developed. With their high thrust-to-weight ratios (i.e. a small size engine can produce a large amount of thrust), liquid fueled chemical rockets were the first to allow us to overcome the bonds of gravity and pass the threshold into space.

The most efficient chemical propulsion systems today burn liquid hydrogen and oxygen and have an I_{sp} of about 450 seconds. Called "specific impulse", I_{sp} is a measure of the efficiency of a propulsion system. It can be thought of as the amount of thrust you get from a unit weight of propellant. With an I_{sp} of 450 seconds, for example, one pound (0.45 kilograms) of propellant yields a thrust of 450 pounds (2,000 Newtons) for one second. The I_{sp} also gives an engine's exhaust velocity when it is multiplied by the acceleration due to gravity. As every rocket scientist knows, the higher the exhaust velocity, the faster a rocket of a given weight will travel. Conversely, higher exhaust velocities can translate into a larger payload for a given rocket.

Higher exhaust velocities can be achieved by increasing an engine's operating temperature and pressure. But limitations in the strength of available materials used in an engine's combustion chamber restricts how high these can go. The best of today's chemical propulsion systems are already close to the theoretical maximum I_{sp}. Use of the most energetic chemical propellant combination, liquid hydrogen and fluorine, could provide a modest increase in engine I_{sp}. But the engineering difficulties of using dangerously reactive liquid fluorine offsets any performance advantages. Today rocket engine developers are more concerned with maximizing the engine's thrust-to-weight ratio and minimizing manufacturing costs. Significant new developments in engine efficiency lie elsewhere.

Another family of propulsion systems that offer significantly higher I_{sp} are based on ion or plasma technology. Here electromagnetic fields are used to accelerate an ionized working fluid to very high speeds. Although such systems can have an I_{sp} in excess of thousands of seconds, they have minuscule thrust-to-weight ratios. With the addition of the weight of the power generation system required to run these engines, these systems are only capable of tiny rates of acceleration. While these propulsion systems do have their applications, those seeking high acceleration rates combined with high I_{sp} have to look elsewhere.

One of the most promising possibilities within the reach of our technology is nuclear propulsion. Unlike a chemical rocket that uses combustion to heat the propellants that are expelled to generate thrust, a nuclear rocket uses an atomic reactor to superheat a lightweight propellant - ideally hydrogen. Although chemical and nuclear engines share similar engineering limitations, the much lower molecular weight of hydrogen compared with the combustion products of a hydrogen-oxygen engine (i.e. water vapor) results in much higher exhaust velocities for a given engine temperature and pressure. This yields an I_{sp} that is three times higher - on the order of 1,000 seconds. But can such an engine be built?

The Birth of Nuclear Rocketry

Not long after the first successful atomic bomb tests, scientists and engineers began to ponder the potential peaceful uses of this potent source of power. As early as 1944, Stanislaus Ulam and Frederick de Hoffman at the Los Alamos Scientific Laboratory (LASL) considered how nuclear detonations might be used for space travel. While such a scheme was later studied in detail as part of ARPA's (Advanced Research Project Agency) Project Orion and the British Interplanetary Society's Project Daedalus, it was felt that a slower, controlled release of atomic energy would be more suitable.

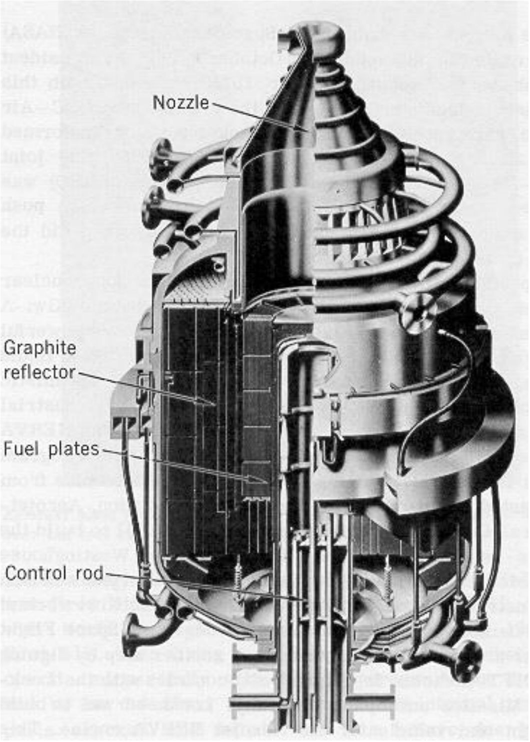
In July of 1946, North American Aviation and the Douglas Aircraft Company's Project RAND each delivered secret reports on their internal nuclear propulsion studies to the USAF. These landmark reports identified the "heat transfer" nuclear rocket (where a reactor heats a working fluid) as the most promising form of nuclear propulsion. Such a propulsion system could in principle be incorporated into an ICBM to lob nuclear warheads across the globe. But despite the glowing report and the promise of the technology, it was recognized that there were still many technical issues that needed to be resolved.

Not aware of the earlier secret studies, a group of engineers from the Applied Physics Laboratory at Johns Hopkins University openly published the results of their own independent studies in January 1947. In 1948 and 1949, two British space enthusiasts, A.V. Cleaver and L.R. Shepherd, also published a series of ground breaking papers in the *Journal of the British Interplanetary Society* on the same topic. But even before this series of papers was published, an American educated, Chinese scientist named H.S. Tsien (who later went on to head the Chinese atomic bomb program) gave a talk at the Massachusetts Institute of Technology about nuclear powered "thermal jets". In all these studies, it was concluded that nuclear propulsion seemed to be viable. And given the number of people who independently arrived at the same conclusions, it was clear that the USAF would not have a monopoly in nuclear propulsion studies.

But all this early enthusiasm for nuclear rockets was dampened by a subsequent technical report done by North American Aviation. This report concluded that nuclear powered ICBMs were not practical. North American scientist felt that the reactor of a nuclear rocket would have to operate at the fantastically high temperature of 3,400 K (5,700 F) - many times that of existing reactors. No known material could withstand such temperatures and maintain the strength required in a rocket engine. With this and other problems identified, interest in nuclear rockets faded noticeably as the 1950s began.

An Idea Resurrected

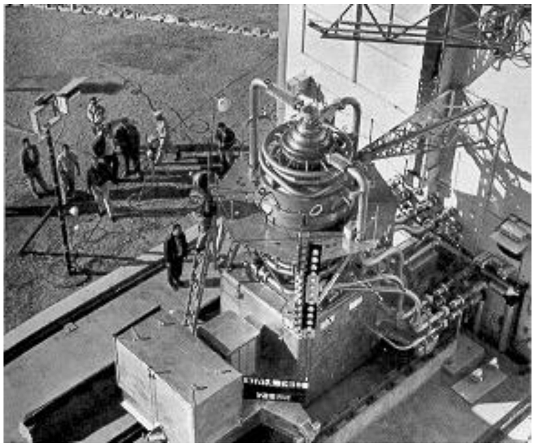
But not everyone agreed with the apparently bleak prospects for nuclear rockets. While development of nuclear rocket engines was largely abandoned after the North American report, work on nuclear-powered jet aircraft engines continued. In the early 1950s Robert W. Bussard who had been working on these nuclear aircraft propulsion systems at AEC's (US Atomic Energy Commission) Oak Ridge National Laboratory in Tennessee reexamined nuclear rockets. Based on his work he concluded that the earlier reports were far too pessimistic and that nuclear rockets were probably practical after all. Bussard felt that they could effectively compete with chemical rockets especially on long flights with heavy payloads. Based on Bussard's calculations and salesmanship, the USAF decided to reopen studies on the concept for possible use in ICBMs in 1955.



Cutaway drawing showing the main components of a Kiwi-A test reactor. (Los Alamos Scientific Laboratory)

As part of the new AEC-USAF program, the Nuclear Propulsion Division headed by Raemer E. Schreiber was formed at LASL. A similar group was also formed at AEC's Lawrence Radiation Laboratory operated by the University of California. But budget cutbacks in the June of 1956 resulted in an elimination of duplicate efforts and a consolidation of the various nuclear propulsion groups. The result was Livermore taking on the task of developing a nuclear ramjet under the code name "Project Pluto". The nuclear rocket program went to Los Alamos under the code name "Project Rover".

A series of different paper studies with such fanciful names like "Dumbo" (an engine reactor design) and "Condor" (a proposed nuclear rocket) were studied. Eventually a reactor design named "Kiwi" was selected as a first step. Like its flightless namesake from New Zealand, the Kiwi test reactors would not fly but were nonetheless essential to the development of a practical nuclear rocket engine. Kiwi-A was a series of "battleship" test reactors that would use compressed hydrogen gas to perform ground-based studies of potential nuclear rocket engine components. The uranium carbide fuel would be mounted inside of a graphite core that could operate at temperatures as high as 3,000 K (4,900 F). Not only could the graphite withstand temperatures up to 3,300 K (5,500 F) before beginning to weaken, it was also an excellent moderator that could slow fission-produce neutrons so they can maintain a nuclear chain reaction inside the core.



A Kiwi-A reactor being prepared for test. (LASL)

But even before the first Kiwi-A was built, there were already changes in the wind. Towards the end of 1957 it had become apparent to USAF planners that the Atlas missile would provide the US with an ICBM capability without the need to resort to exotic technologies like nuclear rockets. The infant nuclear rocket program would have died for a second time were it not for the launch of Sputnik on October 3, 1957 (see **Sputnik: The First Man Made Satellite** in the October 1997 issue of *SpaceViews*). The competitive pressures produced by the new Space Race meant that advanced technologies like nuclear rockets would be aggressively developed to give the country an edge in space exploration.

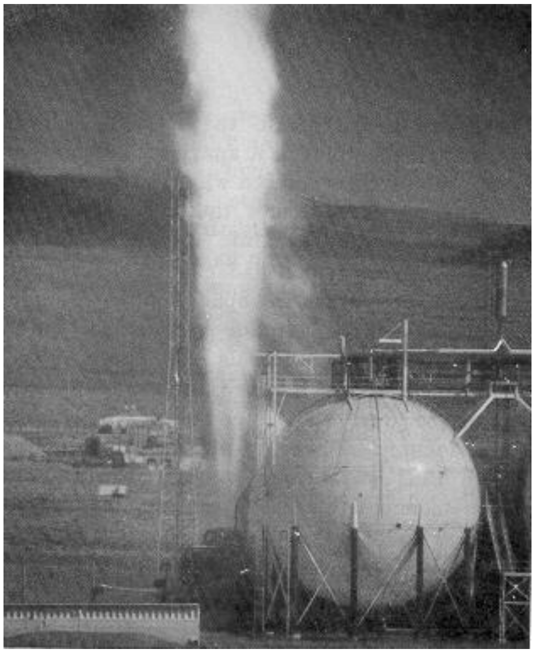
With the formation of NASA on October 1, 1958, the joint AEC-USAF nuclear rocket program was transformed into a joint AEC-NASA activity. While no longer needed for defense, nuclear rockets were ideal for space applications. In August of 1960 the joint AEC-NASA Space Nuclear Propulsion Office (SNPO) was formed with Harold B. Finger (who seven years later would become the Associate Administrator of NASA) as its manager. The goal of SNPO was to develop nuclear rockets that would aid the country's effort to beat the Soviet Union to the Moon and planets.

While all these administrative changes were taking place, engineers were busy preparing for the first actual hardware tests. The first Kiwi-A reactor firing took place in July 1959 (40 years ago this month) at the Nuclear Rocket Development Station in Jackass Flats, Nevada (145 kilometers or 90 miles outside of Las Vegas). It successfully fired for five minutes producing 70 megawatts of power while reaching temperatures as hot as 1,777 K (2,739 F). During the balance of 1959 and into 1960, two more Kiwi-A reactors were successfully tested. With such a promising start, work proceeded on the next step: Kiwi-B.

Producing Flight Hardware

From its inception, optimistic engineers at SNPO set out on an aggressive plan to build nuclear rockets. In the fall of 1960 they proposed to build the first nuclear rocket engine called NERVA (Nuclear Engine for Rocket Vehicle Application). NERVA would generate about 245 kilonewtons (55,000 pounds) of thrust with a still incredible I_{sp} that approached 1,000 seconds. In July 1961 Aerojet-General Corporation was chosen as the contractor for the engine while Westinghouse Electric Corporation's Astronuclear Laboratory was to build NERVA's reactor. Now a vehicle that would harness NERVA's power had to be designed. In May of 1962 NASA Marshall Space Flight Center let a contract to Lockheed Missile and Space Company to build RIFT (Reactor In-Flight Test). But with no operational missions for such a powerful rocket stage identified, such advanced planning was probably unjustified.

As planning proceeded, the Kiwi-B test program commenced. The Kiwi-B series would test actual reactor designs meant for flight. It was designed to run at about 2,300 K (3,700 F) and produce 1.1 gigawatts of power. Unlike the Kiwi-A series which used compressed hydrogen gas, the goal with Kiwi-B was to operate using super cold liquid hydrogen. In December of 1961 Kiwi-B1A was successfully tested using compressed hydrogen gas. The first test with liquid hydrogen took place in September 1962 using Kiwi-B1B. Part way through the test, however, the graphite core cracked and failed with the burning debris being ejected through the nozzle.



The exhaust plume from a successful reactor test. (LASL)

Hoping that this failure was just due to a faulty component, the test program continued with Kiwi-B4A. Kiwi-B4A was to test the full-sized reactor design favored for use in NERVA. But as the first test on November 20, 1962 proceeded, debris was soon seen being ejected through the engine's inverted nozzle. There was obviously a major design flaw in the Kiwi-B reactor that caused the graphite core to fail when using liquid hydrogen.

Over the next year and a half, SNPO engineers and scientists struggled to understand the problem and hopefully correct it. While work slowly proceeded to build a modified Kiwi-B, RIFT continued to languish because of lack of missions. The problem was similar to those experience early on with Marshall's other major program, the Saturn-C: Too much performance too early (see **Saturn's Growing Pains** in the May 1, 1999 issue of *SpaceViews*). By the early 1960s, it seemed that nuclear rocketry's time had not yet come.

Bibliography

William R. Corliss, Propulsion Systems for Space Flight, McGraw-Hill Book Co., 1960

William R. Corliss, Nuclear Propulsion for Space, AEC, 1967

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