The Pied Piper—A Historical Overview of the U.S. Space Power Reactor Program

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Senator Anderson: Is SNAP by any chance kin to the Pied Piper?
Colonel Armstrong: It is Pied Piper renamed, sir.
From the Joint Committee on Atomic Energy Outer Space Propulsion Hearings, 1958.

Introduction

This paper covers the highlights of the early space reactor program. In 1954 the Rand Corporation initiated Project Feedback to study the merits of military reconnaissance satellites (Augenstein 1982). This activity evolved into Weapons System 117L (Kearton 1964), an Air Force Program. In the fall of 1955, the Atomic Energy Commission (AEC) asked industry to bid on the development of a space reactor system for the Air Force; and a reactor concept by Atomics International (AI) was chosen in the spring of 1956 (JCAE 1962 and Jarrett 1973). The combined reactor and isotopic power program was designated SNAP (Systems for Nuclear Auxiliary Power). Even numbered SNAPS were reactors and the odd numbered SNAPS developed by Martin Nuclear were radioisotope power sources. SNAPS 1 and 2 used common mercury Rankine converter technology. A SNAP 3 prototype was put on the President's desk on January 16, 1959; and another was put in orbit on June 29, 1961. Both were radioisotope thermoelectric devices.

The zirconium hydride uranium (UZrH) reactor family included SNAPS 2, 4, 6, 8 and 10; a total of six reactors were developed and tested by AI. NASA became involved in SNAP 8 in 1959. SNAP 50 was begun at Pratt and Whitney in 1958 as an outgrowth of the Aircraft Nuclear Propulsion Program; it was terminated in 1968. The Medium Power Reactor Experiment (MPRE) began at Oak Ridge National Laboratory (ORNL) in 1959 and ran until 1966. The 710 Gas Cooled Reactor began in 1961, was reoriented in 1965, and passed away in 1968.

The thermionic reactor was started in 1959 at Los Alamos National Laboratory as the "plasma thermocouple". This followed the earlier Los Alamos studies on space reactors (Bussard and Kiehn 1956). Work on an in-core thermionic reactor was done later at General Atomics (GA) and General Electric (GE). GA was chosen as the main contractor on July 1, 1970. Although the program was "terminated" in January, 1973, the in-core thermionic reactors showed significant promise and power growth potential prior to that time.

The entire space reactor program was "terminated" in 1973. It gradually and painfully rose from the ashes and became the SP-100 Program that we have today.

On June 15, 1983, Mr. Herman Roser put the matter in cold perspective in his address to the National Research Council (Roser 1983):

> While the nuclear navy is an outstanding example of the use of nuclear reactors to achieve defense energy security, we have not fared as well in our reactor programs for space power, aerospace propulsion, and space propulsion after spending almost 3 billion dollars on SNAP reactors, aircraft nuclear propulsion (ANP), nuclear ramjets (TORY/SLAM), and the nuclear rocket program (KIWI, ROVER, NERVA, and ORION).
>
> On space reactors we lag the Soviets by 10 years even though the U.S. launched the first space reactor in 1965, a small 500 watt power source. Two Soviet nuclear-powered satellites were over the Falklands according to *Defense Daily*. My people were involved in two Soviet space emergencies: The Cosmos 954 reactor emergency in Canada in 1978, and the recent Cosmos 1402 reactor reentry this January. It requires only a little imagination to be concerned as to what the Soviets are doing in space today and what they will be capable of doing in the future with their advantage in space nuclear power, given their

possession of hardened multi-hundred kilowatt or megawatt nuclear reactors in orbit.

Program Resource History

Figure 1 reflects the funding history of the program. A low level of total funding existed until 1960 when SNAP 10A was being developed for SNAPSHOT on April 3, 1965. Significant Air Force funding involvement started in 1955, and NASA funding started in FY 1960. A funding level of $60–100 million existed from 1962–1966 on space nuclear power reactors. In 1967, the funding level started to decrease rapidly until 1973 when the termination of the nuclear propulsion and

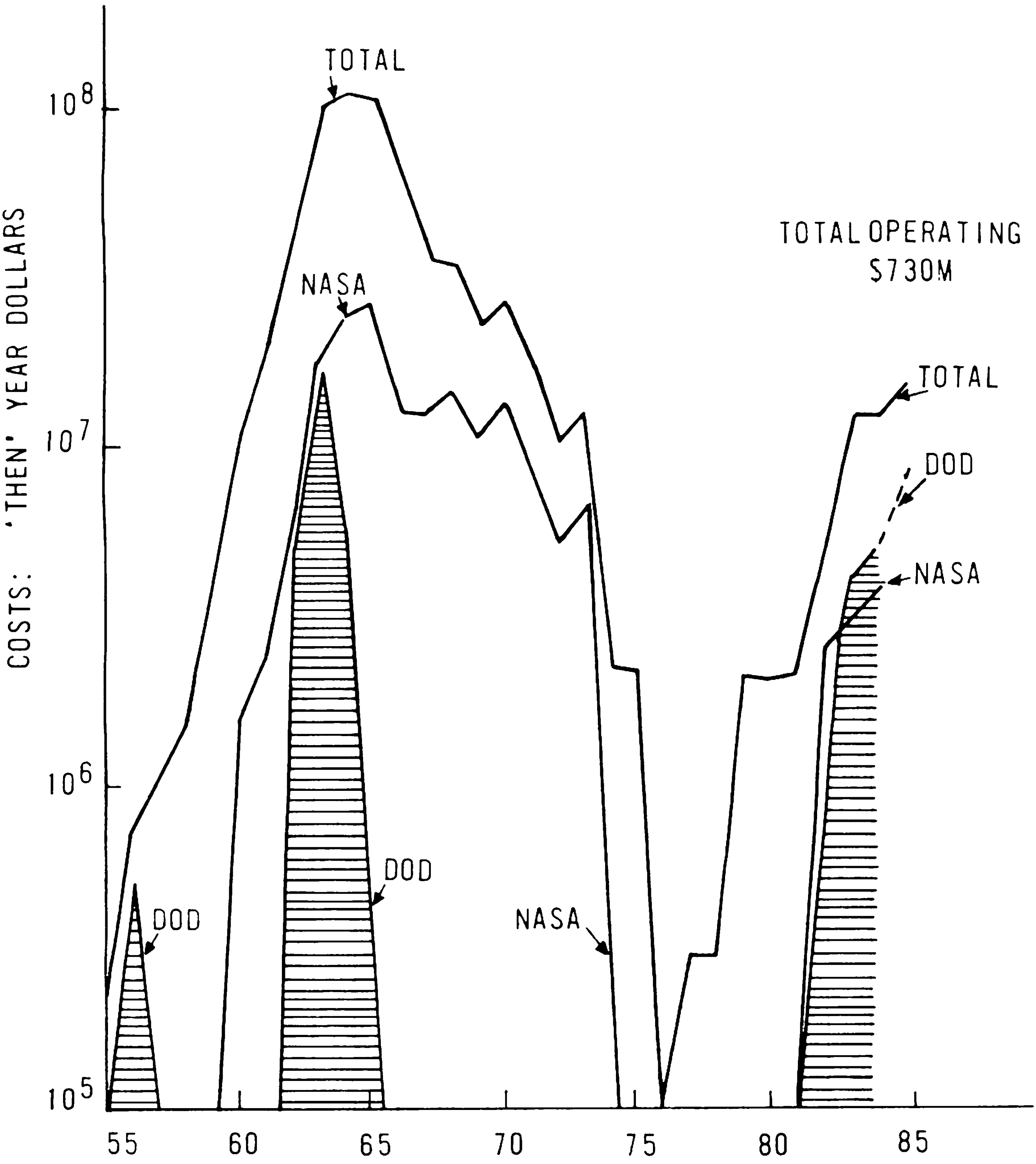

Figure 1 Historical Costs for Past Space Reactor Program.

power program was announced. The space power reactor program was officially "terminated" again in 1976. The program then literally went to the ground. A final terrestrial application for hydride reactors was terminated in 1979; but a fossil application for thermionic converters is still alive. In 1979 SPAR (Space Power Advanced Reactor) was initiated; and the SP-100 program was initiated in 1982.

It is estimated that about $840 million has been spent on space nuclear power reactor systems by the Department of Energy (DOE) and its predecessors, NASA, and the Department of Defense (DOD) since the inception of the reactor program in 1955. When converted from "then year" dollars to current dollars to correct for inflation, this is equivalent to several billion dollars in today's dollars.

Operating costs of record are about $730 million through FY 1984. Unrecorded costs (estimated to be about $35 million) include

- Certain DOD costs associated with SNAPSHOT, mission and advanced system studies, and in-house manpower;
- Costs of NASA in-house manpower, contracted related materials research, and mission studies; and
- Expenditures of industrial in-house funds.

In addition, facility and equipment costs are estimated to toal $75 million for building ($35 million) and equipping ($40 million) 14 DOE and NASA test facilities.

The interagency funding distribution is estimated as: DOE and its predecessors, 70 percent; NASA, 24 percent; and DOD, 6 percent. These estimates are based in part on firm historical data compiled by Carwile (Carwile 1973) on budget histories of record, and on subjective estimates of unrecorded expenditures.

With respect to historical total funding, the UZrH reactor was first; the liquid metal cooled fast reactor was second; and the thermionic reactor was third. The gas cooled (710) and boiling metal (MPRE) reactors were tied for fourth.

SNAP 2, 10A, and SNAPSHOT

The SNAP 2 was the first design in the space reactor program initiated by AI in 1955 under contract to the AEC. It was designed to produce 3 to 5 kWe using a TRW mercury-Rankine power conversion system. Two reactors were tested under the SNAP 2 program—the SNAP 2 Experimental Reactor (SER) and the SNAP 2 Developmental Reactor (S2DR). The SER achieved criticality in September 1959, and was shut down in December 1961. A total of 5300 hours of testing was completed at temperatures greater than 482°C. The S2DR was the first reactor to be tested with a flight control assembly, and testing began in April 1961, with final shutdown in December 1962. Congressional action on the DOD fiscal year 1964 budget necessitated the elimination of the proposed flight program. The reactor program was terminated in FY 1964 but development of the mercury-Rankine converter effort continued until fiscal year 1967.

The SNAP 10A program began in 1958 upon a specific Air Force mission request. The initial conceptual design was a conduction-cooled 300 We reactor system. It was to use thermoelectric elements and have an overall unshielded weight of 330 lbs. In 1960 the SNAP 10A program was redirected towards a 500 We convection-cooled reactor using a modified SNAP 2 core.

SNAPSHOT, the first launch of a reactor power system into space, occurred on April 3, 1965. A SNAP 10A thermoelectric reactor (FS-4) was launched on a modified Agena vehicle from Vandenberg Air Force Base on a polar trajectory. Prior to the launch, a "twin" reactor (FS-3) was put on parallel ground test on January 22, 1965 and accumulated 10,000 hours at power until it was shut down in March 1966.

SNAPSHOT achieved a nominal orbit (705/695 nautical miles) with a lifetime of over 3500 years. It reached a power of 580 + watts on April 4 and during the next six days the power varied from 560–660 watts, leveling at about 590 watts on April 9 as the power was trimmed. On May 15 after 36 days of stable operation, the power had decreased from 590 to 530 watts. Forty-two days into the flight, it had successfully operated for 1014 hours, and its output was 527 watts. On May 16 (Orbit 555) acquisition of the spacecraft was lost for 40 hours; it was finally reacquired on May 18 (Orbit 574). At that time the reactor reflectors were disassembled and hanging by the cable harnesses, and the reactor had shut down.

After 43 days of successful performance, a spacecraft malfunction had apparently caused a sudden and unexpected reactor shutdown. The SNAPSHOT failure analysis concluded that the most plausible cause was a spurious spacecraft command signal resulting from high voltage failure of the spacecraft's decoder (Pohlman et al. 1965).

The SNAPSHOT Debate

In 1959 it was recognized that a small reactor was desirable for space missions. Subsequently systems' criteria were transmitted to the AEC; and early in 1960, a development test plan for four flights was prepared by Lockheed under Air Force direction. In June 1961, Lockheed received the go-ahead for a program to qualify SNAP 10A and 2 by using an Atlas/Agena combination (Kearton 1964). In 1963, however, changes in Air Force programs cancelled SNAP requirements; and in February 1964, the Air Force withdrew its support of SNAPSHOT. Budget cuts forced reshuffling priorities; consequently the SNAPSHOT program was eliminated "because it was not supported by a formal military requirement; it was supported as advanced technology" (JCAE 1964).

SNAPSHOT was a difficult enterprise from the very beginning. The Administration, except for the AEC, did not want to launch the SNAP 10A; however the Joint Committee on Atomic Energy (JCAE) did. The extensive Congressional Hearings on it involved many key Administration officials. The issue was one that has plagued this program from the start, that is, the chicken-and-the-egg dilemma. Why should it be flight-tested without a firm operational mission requirement? How can you get an operational mission for it, if it hasn't been demonstrated in flight? Can't we do a technology flight test that contributes to future multiple missions?

On February 5, 1964, there was an extensive philosophical discussion between the Administration and Congress concerning whether or not the flight test should proceed without a firm mission requirement. The JCAE Vice Chairman stated (Kearton 1964):

> I think we are making a very grave error, in failing to learn from past history, if we expect a requirement to be set for a specific device before it is technically demonstrated. If we had to depend on a military requirement for a nuclear submarine (or a hydrogen bomb), we undoubtedly would be without one today.

On March 3, 1964, the JCAE Chairman chided the President's Science Advisor for not wanting to flight test SNAP 10A without having a specific mission requirement for it (Kearton 1964). On March 3, 1964, the Director of the Bureau of the Budget presenting the President's position to the JCAE point out that (Kearton 1964):

- DOD and NASA could get 500 watts from other power systems;
- The test would not contribute to the development of more complex future reactor systems such as SNAP 8;
- The data can just as easily be derived from ground testing;
- The SNAP 10A funds are not wasted since they contributed to SNAP 8 technology; and
- International publicity has already been gained from the first isotopic power system flight in June 1961.

As the flight date approached, the JCAE Chairman remarked to the AEC's Chairman (JCAE 1965): "You realize that the prestige of the Committee is riding on that project." SNAPSHOT was indeed the JCAE's project. A JCAE member in 1966 summed up the premature orbital shutdown as: "Just bad luck." On March 3, 1967, the JCAE and Administration collectively considered SNAPSHOT a success since the United States demonstrated that it could safely launch and operate the world's first reactor power system in space.

SNAP 8

The SNAP 8 program was initiated in fiscal 1960 to develop a 30–60 kWe system for space power and propulsion. (SNAP 4 and SNAP 6 were terrestrial reactor concepts.) The AEC sponsored reactor development and NASA was responsible for the power conversion system.

The SNAP 8 used a modified SNAP 2 core with 211 fuel-moderator elements. A total of six beryllium drums were used to control the power level. It was initially set to use a mercury-Rankine power conversion system with NaK as its working fluid. In the late 1960s, the power conversion system was no longer considered unique, but rather several alternative power conversion subsystems could be used with the SNAP 8 reactor.

Two reactor systems were ground-tested, the SNAP 8 Experimental Reactor (S8ER) and the SNAP 8 Development Reactor (S8DR). S8ER used as a proof-of-concept test reactor was tested from May 1963 to April 1965; it had an outlet temperature of over 704°C. A post-test examination determined that 80 percent of the fuel elements had cracked cladding. S8DR was a prototype flight system tested to provide long-term operating experience. The testing which began in January 1969 ended prematurely in December 1969. After approximately 7000 hours of operation it was found that many fuel elements experienced cracked fuel cladding which caused an increase in the coolant activity and a decrease in reactivity.

The advances made during the SNAP 8 program were used in conceptual design studies through 1973 when the entire space reactor program was terminated.

Liquid Metal Cooled Reactor (SNAP 50/SPUR)

During 1958, Pratt and Whitney began developing the technology for the SNAP 50/SPUR (Space Power Unit Reactor) Program. This work was done under the Aircraft Nuclear Propulsion (ANP) Program in an attempt to meet the design requirements for supersonic flight. After the termination of the ANP Program in 1961, the project was redirected to the Air Force's SPUR Program. The design was for a 1093°C (2000°F) fast, lithium cooled, refractory alloy reactor coupled to a potassium Rankine power conversion system. In the program coordinated by a joint AEC, Air Force, and NASA committee, the SNAP 50 was expected to meet power needs from 300 to 1000 kWe for electric propulsion or power.

Work on the SNAP 50/SPUR included a reactor and system conceptual design, critical mockups, small scale testing, and fuel materials testing. Upon completion of the development phase, Pratt and Whitney submitted a proposal for continued work which would have enabled them to ground test a prototype system. Their request was denied because of the uncertainties in defining a specific mission requirement. The program funding was reduced by 75 percent in 1965; and the objectives were changed to a long-term basic technology program. The major program was terminated, and the technology program transferred to Lewis Research Laboratory

(LRL). In 1967, the funding was reduced to such a low level that the program could no longer be considered viable; and in 1968 the program was shut down.

Medium Power Reactor Experiment (MPRE)

The MPRE Program was begun in 1959 at ORNL. A small but intensive design and development program was carried out until 1966 when the program was terminated. The MPRE was designed to meet power needs up to 150 kWe. Both the reactor and test facility were designed and a series of component and system test rigs were designed, built and operated to check and validate the design work. MPRE was to fill the power level gap between UZrH and SNAP 50 reactors.

The MPRE design was a direct-cycle component in which potassium was boiled in the reactor core and then was passed directly to a Rankine cycle turbine. The system's growth depended on whether or not refractory metals were to be employed. However the program was ended in order to allocate the funding to other advanced reactor systems.

710—Gas Cooled Reactor

The 710 Program was initially begun in 1961 under the ANP project when General Electric submitted a proposal to the AEC for use as a back-up design for the Rover Rocket Program. In 1965 the program was reoriented toward developing a nuclear power source for space. As an alternative to liquid metal systems, the nuclear power source was to produce 200 kWe for up to 10,000 hours of operation.

The 710 was designed as a fast reactor, which used refractory metal-fuel cermets. It was to have been cooled by an inert gas which could have been used in a direct-cycle, Brayton power conversion system. In 1967, however, the program was reduced to a fuel element development program; and in 1968, the program was terminated to allow continuous funding in the thermionic and liquid metal cooled reactor programs.

Thermionic Reactor

The thermionic reactor program known as the plasma thermocouple was started in Los Alamos in 1959. In 1964 both NASA and industry (General Electric and General Atomic) entered the program. In 1970 General Atomic was selected to develop a thermionic fuel element and a thermionic reactor test. In 1971, the NASA and AEC thermionic efforts were combined and in January 1973 all space reactor thermionic efforts were terminated. Budgets for the thermionic program were $4\frac{1}{2}$ to $9 million between 1964 to 1972 and the total program costs exceeded $70 million (Price 1968 and Carwile 1973).

The thermionic reactor historically has been just as advanced as the bridge reactor which could span power levels ranging from several kilowatts to several megawatts. The reactor's problems have been primarily associated with diode lifetime at high temperature and have involved areas such as emitter cracking and shorting, fission gas release, fuel/clad interactions, and fuel swelling. Areas of improvement have been in high temperature metallurgy, emitter and collector surfaces, and their spacing (JCAE 1969). The thermionic reactor potentially offers minimal moving parts, high redundancy, high efficiency and small radiator area, low specific mass, and a broad power range capability (DOD/AEC 1974). In-pile results based on thousands of hours of testing toward the end of the program were quite promising (Beard 1984).

The Soviets tested TOPAZ, the first thermionic reactor, in 1971 and have tested several more since that time (JCAE 1969), including Romaska which is the 5 to 20 kilowatt size and perhaps higher.

Safety

Historically, the safety program on space nuclear reactors and isotopic power has been in two parts—project safety and independent safety. The former is the project's line safety program associated with the design and development of the reactor by the contractor including ground testing and aerospace nuclear safety. This has amounted to roughly 10 percent of the total project cost for a flight hardware system such as SNAP 10 and a much smaller proportion for reactor systems in the software stage.

An independent Aerospace Safety Program was also established to investigate safety problems raised by reviewers concerning reactor safety neutronics at launch and reentry disassembly, burnup, and/or impact behavior of the reactor. This program, principally for SNAPSHOT, expended roughly $35 million.

Three safety neutronic tests were conducted—SNAPTRAN 1, 2, and 3. The first was a series of small transients and the latter were destructive excursion tests of full scale reactors to simulate water flooding and impact. It is doubtful that such tests could be done today. The other tests were reentry flight demonstrations to determine the reentry disassembly of the system and the burnup of fuel elements. About one half the effort was on safety neutronic analyses and tests; the other half was on trajectory, stability, breakup, aerodynamic heating, thermochemical, thermo-mechanical, ablation and terminal velocity tests, analyses, and evaluations.

Participants in the Aerospace Safety Program included, among many others: Atomics International, the Air Force Weapons Laboratory, Phillips Petroleum, Sandia National Laboratories, NASA laboratories, and Weiner Associates.

The End and the Beginning

After the space reactor power and propulsion programs were officially "terminated" early in 1973, there was a rather stubborn rear-guard action to keep the space power reactor program viable. In fact, the program probably never came to a full stop; there was always a spark burning somewhere.

The underlying motivations of the proponents for keeping the spark lit seemed to relate to the following considerations:

- the enormous potential afforded by the ultimate energy source for the exploration of outer space;
- the belief that space reactors are synonymous with survivable large space power; and
- the visibility, progress, and reality of the Soviet space reactor program along with the threat and outright competition that it posed to the United States both technologically and militarily.

On February 17, 1972, the proposed FY 1973 space electric power budget was 46 percent greater than FY 1972's budget. Two thirds of the increase was due to isotopic flight systems requirements. The joint AEC/NASA program was aimed at testing a 5 kWe UZrH thermoelectric system by 1977 and an in-pile thermionic program aimed at reactor system tests by 1979 (Gabriel 1972). On March 28, 1973, the Director of the joint AEC/NASA Space Nuclear Systems Division told Congress (Gabriel 1973):

> The scope of the program has been reduced (to isotopic power) by the recently announced terminations of the nuclear propulsion and power reactor elements . . . their termination now is related to the emphasis on near-term objectives and the fact that NASA mission activity is such that they will not be used in the foreseeable future.

The atmosphere was distressingly heavy in 1974 with the loss of the Division director, the departure of the old timers and their institutional memory, as well as the exodus of an experienced cadre of reactor and converter people, presumably to solve the Nation's energy problems. To make matters worse, the AEC passed gently away with the birth of ERDA. However, the few survivors started rear-guard actions.

Under the direction of a tenacious Air Force Colonel assigned to the AEC, an Ad Hoc Study Group composed of members from AEC, NASA and DOD was appointed (DOD/DDRE 1973) "to evaluate the future DOD needs in space power and to indicate the possibility of meeting those needs with space power systems." From April to July 1973, the group produced four germane memoranda of record, including an unsigned interagency memorandum-of-understanding (Crane et al. 1974). The group issued its final report on March 29, 1974 and recommended preserving the UZrH reactor program and using the Space Test Program to "stimulate a focused space power program for earlier payoffs on DOD missions." (This author recalls quietly initiating the transfer of UZrH reactor components from Santa Susanna to Los Alamos for storage in case they might be needed later; the components were finally sent for reprocessing last year.)

A DOD/ERDA Space Nuclear Applications Steering Group was established in May 1975, (Dix et al. 1976), "to encourage a proper development program for space nuclear energy systems." The author was its executive officer and one of its members. On December 4, 1975, the Air Force initiated a space-based radar study with a nuclear reactor power option offering hope for the program. On February 26, 1976, an Advanced Space Power Working Group was established with the author and Colonel R. W. Johnson as its co-managers. On August 11, 1976, the DOD Steering Group Chairman sent a letter to ERDA's Assistant Administrator for Nuclear Energy stating (Vossberg 1976):

> In our continuing efforts to ensure that future space power requirements of the DOD can be met on a timely basis, I wish to call your attention to the growing likelihood of need for space nuclear reactor systems in the 10 to 100 kilowatt electric range in the late 1980s and beyond.

On April 29, 1976, an NASA/ERDA Space Nuclear Applications Steering Group was established (Bauer 1976) for space nuclear power to build upon work by the DOD/ERDA Steering Group. Unfortunately, much of this effort was directed toward isotopic power since NASA space base activities possibly requiring reactors were not scheduled until 1984–1985.

On Janaury 11, 1977, at the same time as the demise of the Joint Committee on Atomic Energy, the DOD/ERDA Space Power Steering Group issued the following statement which led to the Space Power Advanced Reactor (SPAR) activity at Los Alamos.

> The Steering Group has identified approximately ten conceptual DOD space system capabilities where on-orbit power levels of 25 electrical kilowatts or above may be required. These capabilities include communication, surveillance, and other future defense systems. Of these missions, only one—Space-Based Radar—is undergoing serious DOD planning.
>
> The Steering Group commissioned an evaluation of the Space-Based Radar application, in which three independent studies were performed. The studies compared solar-photovoltaic/battery power supplies with nuclear reactor power supplies. The results were: (1) for a system requiring 50 kWe or more, the reactor power supply was superior to the solar/battery power supply in weight, survivability, and power growth capability and (2) the solar/battery power supply was competitive up to the range of 25–50 kWe, but at higher power levels the viability of solar/battery systems becomes questionable.
>
> Although the Steering Group has been unable to identify any approved and budgeted DOD missions in the high power range (i.e., greater than 3 kWe), a reactor power supply is presently the only candidate

> spacecraft power system option for future high power applications. This fact, combined with data on space reactor power capabilities outside the U.S., the enhanced military capability provided by having sufficient power to operate on-orbit equipment such as radar, and future threats to our space defense posture afforded by similar high power capabilities in the hands of adversaries, has led the Steering Group to recommend that a reactor power development program be initiated by the U.S. following intensive precursory studies to define the reactor power system and its requirements.

At last, when the program was getting underway, the Cosmos 954 reentry occurred in January 24, 1978, and the subject of space reactors was discussed at the United Nations where a working group on the subject was active until February 1981. The matter of banning the use of the United States' space reactors was also debated within the Administration; consequently somewhat negative pressures were applied to the program in 1978 and 1979. This matter, however, was satisfactorily resolved.

In 1979 the DOE initiated a modest space nuclear reactor component technical program called Space Power Advanced Reactor (SPAR). In SPAR, Los Alamos National Laboratory evaluated several advance reactor concepts that emphasized the Heat Pipe Reactor (HPR). On February 14, 1980, a tri-agency meeting was held at NASA; and the DOD/NASA/DOE Steering Committee and Space Reactor Working Group was formed, which was active until June 1981 to discuss the unification of DOE's Space Reactor Development Program and NASA's space reactor program. In 1981, the Air Force initiated studies on a rotating bed reactor at Brookhaven National Laboratory.

During fiscal years 1979, 1980, and 1981, NASA funded work in the heat pipe area and power conversion at its own laboratories and at Los Alamos. In 1982, DOE and NASA combined their efforts to form a new program called SP-100 (Space Power 100 kWe) (Kerrebrock 1982). About this time the participants realized that DOD also had to be involved in this program if it were to succeed; subsequently, DOE and NASA joined forces with DARPA on February 11, 1983 and through a tri-agency agreement the new SP-100 Program was created (Cooper 1983). The Memorandum of Agreement states that (Kerrebrock 1982) "SP-100 will be run by a Program Director from DARPA reporting to me (head of DARPA) and receiving programmatic direction from a tri-agency Steering Committee chaired by the Department of Energy." The stated objective of the SP-100 Program (Wright and Trucello 1983) is to review the technology, define the system, perform mission analyses, establish mission requirements, and recommend a space reactor system for a ground engineering system by July 1985. The SP-100 technology program is now well underway.

Summary

Certain lessons can be learned by looking back at the history of the program; and in hindsight, we can offer some subjective observations.

Firm Requirements Versus Needed Technology

The Congress argued in 1964 that the Space Reactor Program should continue even though the original Air Force requirements for SNAP 2/10 had yielded to other space power technologies. The Congress observed correctly that the development of the hydrogen bomb and nuclear submarine did not result from prior firm user mission requirements and that technology which fulfills generic National needs should be allowed to proceed through hardware operational demonstration. If the past is a prologue for the future, it could be advanced that the space reactor development ground flight test program should proceed without having a single firm near-term mission requirement. The program could be justified by a number of potential missions requiring high power levels. A corollary to the above is that a generic advanced space power flight program is an exigency, if the United States is to be preeminent in space, which is an appropriate justification in itself.

Mitosis and Dilution

In times of National prosperity the space reactor program was carrying five reactor subsystems and six converter subsystems simultaneously, many of them in various stages of hardware. Excuses for what Congress called a "jigsaw puzzle" were: divergent mission requirements between DOD and NASA users, needs for back-up systems and advanced technology to satisfy long-range requirements, the variability and independence of technological thought of the various participants, and finally political pressures and realities. This accelerated the decline of the program and set the stage for the multiple choice technology situation existing at the onset of the SP-100 Program.

A strongly managed, well-focused program should be more productive with the selected system having the flexibility of power growth and product improvement. It is difficult enough to start the development of one flight system at a cost of two billion dollars much less sustain several programs on multiple reactors, converters, and power levels and their attendant supporting technology programs.

Program Architecture

The space reactor program started out in the 1950s as a proof-of-principle activity and was very much flight test-oriented at the beginning. Prior to the SNAPSHOT flight, the program architecture began to change toward a more leisurely ground testing technology research and development program with elaborate test facilities proposed to simulate space conditions. Unfortunately, the program never regained its thrust toward a flight goal, and it settled into a nearly fatal technology survival program.

In advocating the SNAPSHOT in 1964 against an almost adamant President, Congress cited its reasons for early flight testing. These included shortening schedules, reducing costs, salvaging resources, proving that reactors could be launched safely and could be operated in a real space environment, demonstrating that the hardware could be put in orbit with a payload to break the requirement's stranglehold, and finally that the *esprit de corps* of those associated with the program could be enhanced by setting a tangible goal.

There are several options for the overall architecture of the space power reactor program. One promising first-track option is to perform reactor system tests in orbit to minimize the necessity for ground test facilities and the interventions attendant with them, to reduce programs costs, and to shorten schedules to facilitate early operational readiness.

Concept Selection

The zeal for a flight-oriented program has its hazards also. The only reactor system flown by the United States was underpowered and was, in hindsight, incapable of large growth in terms of temperature, power level, and efficiency. The basic UZrH reactor fuel element was inherently flawed as subsequent SNAP 8 life tests on the ground ultimately demonstrated. Yet, the Government was so heavily committed that its only options were to try to recoup its investment by vainly trying to correct the flaw or by starting new exploratory programs on other reactors. The lesson here is to be sure to pick the right power and converter subsystems early on and assure that they are capable of growth and have an adequate margin before the program is accelerated into flight developmental hardware status.

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