Chapter V
Momentum from the Lunar Race

Memorable Achievements in Tumultuous Years

Sharp contrasts in events marked the last half of the decade of the 1960s. Fantastic space achievements—the astronauts of Apollo 8 orbited the Moon and sent back spectacular pictures,[1] lunar landings tested many assumptions, the near-disaster of Apollo 13 demonstrated the effectiveness of fall-back support systems—shared the spotlight with recurring national tragedies and growing civil unrest.

The RTG program, although it gathered momentum from its association with space triumphs, could not remain completely unaffected by the civil strife and the growing dissension over the nation's entanglements in the war in Vietnam. The war began to dominate not only coverage in the print media and television, but also the allocation of federal funding. The space program suffered as a result.

In 1966 *Aviation Week*, commenting on yet another lull in the fighting in Vietnam, saw it as a pause "that hopefully might lead to meaningful negotiations but more likely [it] is simply a prelude to greater escalation of that conflict."[2] This proved to be the case, and the government's apportionment of funds reflected a shift in priorities. NASA budgets began a steady decline even as technical developments, although slowed by the Apollo fire at Cape Kennedy in January 1967, progressed towards a manned lunar landing.

AEC budgets for space nuclear applications came under ever closer scrutiny as well. Eventually, it was the more highly touted nuclear propulsion effort, followed by the space power reactor program, that felt the budget crunch most strongly. The RTG program, modestly funded at the start, received a boost from NASA contracts at the beginning of this period, and held its ground through the decade primarily by remaining anchored in defined missions while constantly seeking new roles for its devices.

Building for Momentum

The true space spectaculars projected in the early years of the decade required years of developmental steps After the third Transit carrying a SNAP 9A was aborted in April 1964, it was five years before another RTG flew on a successful space mission As preparations proceeded for using isotopic power on NASA missions, experience dictated that safety continue to receive major attention Indeed, major changes in safety were an important part of the story of the RTGs in the last half of the decade One reason for the changes in safety concepts and procedures was the great increase in the amount of radioactive fuel being flown The SNAP-3 units used on the Transit launches at the start of the decade bore just 1800 curies of Pu 238 on unmanned missions while the SNAP -27s that accompanied Apollo 12 on its manned lunar landing mission in 1969 bore 45,000 curies of Pu-238[3]

During the latter part of the 1960's, the organizational changes implemented at the mid point of the decade had two significant impacts commitment to higher powered NASA missions, which progressively increased the magnitude of the RTG effort and the amount of radioactive fuel in the devices, and mobilization and decentralization of technical and administrative support so as to bring into play more of the far flung laboratories and other facilities of both the AEC and NASA

In describing the new organizational arrangements for the nuclear space program of AEC and NASA, Finger noted that the changes brought together all of the AEC work on space nuclear systems into the agency's new Space Nuclear Systems Division It also brought together all of the AEC and NASA work on space nuclear systems so that the program could be conducted in a collaborative way The new arrangements allowed program review and discus sion to occur among all the responsible AEC and NASA people, including the personnel at the laboratories of these agencies, and those at headquarters [4] Under the new arrangement, when a specific nuclear power system was to be used on a particular mission, AEC personnel were assigned to the responsible Mission Center Finger explained the rationale for this policy

> The subsystems that must go into a spacecraft to make its operation fully successful must be so closely interrelated, their operating charac teristics so closely integrated, that changes to any one of them may

> have a significant effect on any other subsystem in the spacecraft. Further, the mission launch date depends on every component of the spacecraft; schedule charts and management controls must be established on a uniform basis for all subsystems. Only by close and intimate working relations can such coordination be assured...."[5]

Finger saw the AEC laboratories as "large technical organizations that have deep competence in most of the disciplines involved in this work and also have test equipment that can be applied...in the isotope development program as a means of strengthening our management in this rapidly expanding area." In keeping with NASA and AEC policies of promoting the development of broad industrial competence, however, industry would be called upon and relied on "to develop and provide the isotope power systems that will be needed for mission application and...for development of advanced capabilities in this area."[6]

A major feature of the decentralization of responsibilities was the delegation of technical direction of AEC's isotope power supply development program to Sandia Corporation of Albuquerque, New Mexico—an AEC-affiliated laboratory that already had responsibility for testing in the SNAP safety work. Although it had limited experience with isotope heat sources, Sandia was considered to have extensive system analysis experience and the most comprehensive capability for and understanding of space system development in the AEC. Also considered in the selection of Sandia was the importance of tying the aerospace safety work closely to the power system design and development work. Finger held that Sandia's safety work "defines design conditions and should be incorporated as a direct part of the system design and development activity."[7]

Finger recalled that he especially saw the importance of making it clear that the technology was no longer the province of one organization. Moreover, the new and complex systems that came on line and used RTGs after 1965 required very strong technical expertise— the kind that could be best supplied by laboratory technical competence and no longer could be delivered by the central general manager of a program. He stressed his conviction that overall responsibility must devolve on the *mission* agency—the organization responsible for integrating all the components and subsystems, including the RTGs, into a final mission system. "If I had one problem from the beginning," he said in considering the expansion of joint AEC/NASA efforts, "it was my feeling that much more testing was needed. The RTG people at the AEC had been operating on a shoestring, and they really didn't comprehend the extent of testing that was needed." In contrast, NASA, which was to develop the much larger systems that would use the RTGs, was accustomed to much testing.[8]

Bernard Rock* recalled how the NASA missions influenced his own orientation. "My background was technical, but I soon saw how important management was in the NASA scheme of things; and I sensed that this concern with management was correct. I went out and enrolled in some courses in engineering administration." Recalling the major NASA missions that then came along for the RTG program, he said: "The Nimbus program really helped me a lot. I saw how much more detailed we had to be. Then Apollo was many orders of magnitude greater in size and complexity than Nimbus."[9]

The magnitude of the Apollo effort can be seen in the fact that the AEC's proposed fiscal 1965 budget of $6.3 million was doubled to $12.5 million[10] for fiscal 1966. This figure did not include money being spent by other agencies, such as NASA and DOD, for work on isotope propulsion space power. For RTGs alone, the AEC, which had spent about $3 million in fiscal 1964 and 1965, expected to spend more than $8 million in fiscal 1966 for development of isotope-fueled auxiliary power systems for space applications.[11]

As the RTG program looked ahead in early 1966 to expansion for new mission applications, close attention was given to the problem of maintaining momentum in the total space nuclear program. Preparing in March for a briefing of Vice President Hubert Humphrey on the space nuclear systems effort, Finger emphasized that it would be difficult to get Congressional support unless the space program were defined in a way that indicated the need to advance propulsion and power capability beyond the Apollo Mission for specifically-defined missions that would use the new systems.[12]

Program momentum concerned the top administrators at NASA, as they sought to define post-Apollo research and development. In the words of Deputy Administrator Robert Seamans,† "The capability now coming on

*Presently Director of the RTG program and at the time of the organizational change of the mid-1960s, a project engineer.

†Robert Seamans, Jr., who had been Associate Administrator of NASA since 1961, became Deputy Administrator in January 1966 following the death of Deputy Administrator Hugh Dryden in December 1965.

stream cannot be mothballed."[13] Nevertheless, as NASA in its fiscal 1967 budget request attempted to break out of the $5.2 billion budget plateau it had been restricted to for three fiscal years, and to obtain funding for an extended Apollo Extension Systems program, prospects were that a cut rather than an increase was in the offing. Writing about NASA's budget problems and its requests for additional funds, a space journal commentator wrote in February 1966:

> ...the harsh requirements of the war in Viet Nam punctured this happy prospect, and NASA found it could not even hold the old line on its budget. Though the final figure had not been disclosed at this writing, it appeared likely that it would come close to $5 billion, the first major rollback in the brief history of the space agency.[14]

Social and political influences had ever increasing impact on the nation's space program and its RTG components. Nonetheless, the major items in the RTG program inventory carried the program through the decade—to the realization of important technical developments and a place of honor in the culmination of the race to the Moon. Two SNAP devices had major roles in the NASA missions which required the close AEC-NASA coordination that marked the last half of the decade. SNAP-19 became an auxiliary power source for NASA's Nimbus weather satellite. SNAP-27 provided the power supply for the Apollo Lunar Surface Experiments Package that was left on the Moon by all Apollo missions but the first one. These two milestone RTGs and their Nimbus and Apollo missions warrant special treatment in this history of the RTG program.

The Test on Nimbus

A request from NASA to the AEC to determine the feasibility of using a 50-watt RTG for the Nimbus weather satellite was transmitted in July 1963. The request led to isotopic system design and integration studies by the AEC in cooperation with NASA and to NASA's establishment of a requirement for SNAP-19. The use of SNAP-19 on the NASA weather satellite Nimbus was a crossroads for the RTG program. It led to a major reconceptualization of safety procedures and was a prelude to NASA's uses of RTGs on Apollo and other space missions. Milt Klein*

*Deputy Manager under Harold Finger of the joint AEC-NASA Space Nuclear Propulsion Office After Finger's acceptance in March 1967 of a new role at NASA, Klein replaced Finger as manager of the joint office and Director of the AEC's Division of Space Nuclear Systems.

recalled that the RTG program people persistently requested NASA to define missions using RTGs, but until Apollo, all they got were test flights.[15]

With the Nimbus mission, however, the program received a test opportunity that was the gateway to space spectaculars. Early Nimbus spacecraft were powered exclusively by solar cells; as an experiment in the use of RTGs, the Nimbus-B satellites carried two of the isotopic units as auxiliary power supplies to the solar cells. Rock said: "Nimbus was an experiment to demonstrate to the civilian space community, as Transit had to the military community, that RTGs would work. We needed this experiment. After Nimbus, NASA made a commitment to RTGs, and Apollo brought us out of a low-level operation to a major effort."[16]

The SNAP-19 design resulted in a 30-watt generator. Two of these devices were to be used on the Nimbus-B spacecraft which, at the time the formal agreement between AEC and NASA was signed in September 1965, was scheduled for launch sometime in 1967.[17]

The AEC-NASA agreement on SNAP-19 was a prototype for all agreements between the two agencies on RTGs for NASA space vehicles. It acknowledged that both agencies recognized the potential performance advantages of RTGs over other space-power concepts "when applied to certain long duration space missions" and that cooperative efforts between the AEC and NASA would be required "to ensure effective system development and space vehicle integration. . . ." The agreement covered the SNAP-19 power supply for Nimbus-B spacecraft and also other power units that might be mutually agreed to in writing.[18]

The safety issue became a major concern in the SNAP-19 Nimbus experience. "Before Nimbus," said Dix, "our safety concept was 'burnup on reentry.' But now we were going to 34,000 curies of radioactive material, which would be an appreciable fraction of the total in the atmosphere. We had some terrible sessions with the Space Council. That first INSRP (Interagency Nuclear Safety Review Panel) on Nimbus was a bloody one."[19] The INSRP deliberations led to design changes in the SNAP device and to revised safety concepts.

As a result of experiences on SNAP-9A and the increase in curies for SNAP-19, the fuel form for SNAP-19 had been changed from plutonium metal to plutonium oxide in the form of small microspheres carried in capsules. On SNAP-3 and 9A, the safety concept called for the plutonium metal to burn up on re-entry and become molecular particles which would be distributed harmlessly and in very small quantities in the biosphere. The first safety concept on Nimbus was that the microspheres would be dispersed on re-entry as the capsule burned up and would fall to earth as BB-like particles 50 to 150 microns in diameter—too large to be inhaled by living organisms. Tests at Ames, however, showed that the microspheres broke into sizes that could be inhaled. The second change on Nimbus was the adoption of the "intact re-entry/break open on impact" concept, in which a graphite block that contained the capsule which held the plutonium survived re-entry, with the capsule and plutonium becoming a frozen pudding during re-entry; upon impact with average soils of the Earth, the graphite block would break open, permitting the pudding inside to disperse in a small crater formed by the impact.[20] The third change was the adoption of an "intact re-entry/intact on impact" concept, in which the capsule was made of refractory materials which did not melt during re-entry; the intact capsule, containing the plutonium, was retrieved as a whole unit after impact on Earth.

Paul Dick at Martin-Nuclear (now Teledyne) remembered the "crash" effort required by this change in safety concept. "One morning we were called to Germantown by Bob Carpenter and told our safety concept on Nimbus wasn't working. We had six months to develop an intact re-entry source." Guy Linkous of Martin-Nuclear recalled that this project absorbed most of their people for a while. Dick noted with pride: "We did that job successfully, although I think no one believed we could do it. ...I doubt if we could accomplish that kind of turnaround in six months today. There are more requirements imposed by more organizations today."[21]

Development activities for the intact re-entry heat source were initiated in March 1967.[22] Late in the year, INSRP recommended approval of the launch, after having evaluated various types of risks associated with different phases of the total mission. This did not eliminate dissent, particularly from Harold Price, AEC's Director of Regulation, who went on record with the following position:

> ...the risk of exposure of people from failure of the SNAP-19/NIMBUS-B mission appears to be greater than that associated with the design basis accidents for nuclear reactors. For this reason, we are unable to concur in the recommended launch of the mission. On the

> other hand, we are not in a position to assess the importance of the mission or the potential benefit to be derived therefrom, and therefore, we do not recommend against it.[23]

The launch was approved by the AEC in December 1967 and, with the recommendation of the Space Council, by the president in January 1968.[24] A few days before the launch, Seaborg sent letters to both Webb at NASA and Foster at the Defense Department suggesting "that a joint DoD/NASA/AEC program be initiated to enhance the probabilities of locating and recovering nuclear sources lost in space operations. . . ."[25]

Linkous described his perspective on the happenings at Vandenberg on 18 May, 1968 when the Nimbus-B launch was aborted some two minutes after liftoff: "We were all at NASA Goddard for the launch and all of a sudden these NASA guys all sat back and took their headsets off."[26] Harry Press, then Nimbus Project Director at Goddard, termed it "a frightening experience for all of us. We rewrote the press release right away. We really weren't prepared [with information] for an early abort like that one. The things we really worried about most in those days were blowups on the pad."[27] It was discovered later that a human error in setting a guidance gyro had caused Nimbus-B-1 to veer off course shortly after launch. The Range Safety Officer sent a destruct signal at about 120 seconds into the flight, at an altitude of approximately 100,000 feet; thus, the RTG had not left the Earth's atmosphere nor gone through re-entry. The upper portion of the Agena stage (the spacecraft and RTG) was estimated to have fallen "about two to four miles north of San Miguel Island," in the Santa Barbara Channel. The water depth in this area was said to vary from about 300 to 600 feet.[28]

It was October 1968 before the RTG was recovered from the Santa Barbara Channel. A Navy search had failed to locate the spacecraft. Dix credited Sam McAlees of the Sandia Corporation for an analysis that accurately directed searchers where to look. He also praised the work of George Ogburn, responsible for emergency operations on his own staff, for long hours spent on a choppy channel troubleshooting the retrieval. Dix recalled: "Sandia had a submersible doing something in that area and we asked them: 'Can you go by that point on your way out?' There are terrible currents in that area. But they found the RTG on September 27 and it was recovered two weeks later."[29] The media soon ran pictures showing the Nimbus-B spacecraft resting on the channel floor under 300 feet of water and cited the recovery of the SNAP-19 nuclear generators near the spacecraft wreckage.[30] The capsule was sent back to Mound Laboratory and the fuel re-used.

The RTG safety program, although not truly tested in its new concept of intact re-entry through the atmosphere, had come through without a blemished record. Before the summer was over NASA announced publicly its plans for a launch in spring 1969 of a replacement Nimbus-B weather satellite with SNAP-19 power supplies.[31] Procedures for approval of this Nimbus-B-2 went forward smoothly. Even though the fuel inventory increased slightly in order to utilize a slightly less efficient, but more stable thermoelectric conversion material,[32] approval came quickly after requested because interdepartmental review of the nuclear safety aspects of the mission had already taken place in preparation for the unsuccessful flight of 18 May 1968.[33] The second Nimbus to fly with SNAP-19s was successfully launched on 14 April 1969.

Speaking from his perspective as the Nimbus project director who directed that NASA weather satellite project throughout the prior decade, Harry Press said: "It turned out that RTGs were really not well suited for near-Earth missions like Nimbus. But we had been having problems with solar cells, and the RTG people pressed those devices on me." Press had reservations because "the safety problems were so great, and even though all this was paid for by the AEC, it led to expenses for us. We hired some specialists to look over their shoulders. ...on the rest of the Nimbus missions, we decided RTGs weren't worth the trouble, the hassle, the approvals, the safety testing. Solar cells were much more suitable."[34]

Whatever the disappointments, negative reactions were not strong enough to retard the RTG program's forward motion with NASA. At least at top decision-making levels, the devices had proven themselves for space missions—and for the great technological feat that had been building for nearly a decade.

Riding the Thrust of Apollo

Webb saw the thrust to get man out to the Moon and return him safely to Earth as a demonstration that America had developed capabilities for doing almost anything with its technology. New technological advances of the Apollo program included the SNAP-27 RTG, and the program requirement for 5,800,000 pounds of propellant fuel,[35] in contrast to the 100,000 pounds used to launch earlier spacecraft carrying RTG's.

On another technological front, scientists were interested in learning as much as possible from the manned lunar landing program and envisioned scientific stations emplaced by man on the Moon, transmitting data on such things as seismic lunar surface vibrations, global responses of the Moon to fluctuations in solar and terrestrial magnetic fields, and changes in the low concentrations of gas in the lunar atmosphere.[36] These ideas crystallized in an ALSEP contract with Bendix Aerospace Systems Division of the Bendix Corporation. Beginning with the second lunar landing mission, Apollo 12, an ALSEP was emplaced at each landing site.

In a move to broaden the industrial base of firms competent in RTG science and technology, in mid-decade the AEC encouraged corporations other than the Martin Company to respond to a request for proposals for development of a new Pu-238 fueled, 75-watt isotopic power unit for space uses.[37] In June of 1965 a contract was awarded to General Electric for $4.6 million, for performance for the SNAP-27 program which at that time was to be applied to NASA's Surveyor Lunar Roving Vehicle. Within the year, however, NASA requested the AEC to develop a generator for the ALSEP on its Apollo missions; at this point the SNAP-27 program was redirected to the requirements of the ALSEP. By spring 1966, as a second modification to GE's contract was approved, SNAP-27 program costs were estimated to exceed $10 million. The RTG device under development was now defined as "a 50-watt (e) radioisotope power system for the Apollo Lunar Surface Experiment Package (ALSEP)."[38] The SNAP-27 would be the sole power supply for the ALSEPs left behind on the Moon.

According to Augustine Pitrolo, who became the SNAP-27 program manager at General Electric, Bill Millard at General Electric came up with the idea of plugging in the power supply on the Moon. A later study at NASA undertaken to determine the power supply needed for the lunar surface experiments and to examine the feasibility of using SNAP-19, led the space agency to request the AEC to develop the SNAP-27. Pitrolo explained that the SNAP-27 could not work on an unmanned spacecraft as it was dependent on having an astronaut plug the fuel supply into the generator on the Moon.[39]

The SNAP-27 program was a part of the nation's most prestigious and challenging space program: the Apollo lunar landings. Pitrolo described the landing process: "We had to solve every problem you could imagine. You have to understand the pressure the Apollo program was under to get moving. With the original Apollo launch schedule, we only had a two-year lead time; and we would never have been ready with RTGs of the best quality." The Cape Kennedy fire in early 1967 delayed the total Apollo program approximately one year, which enabled the SNAP-27 program to catch up and supply high quality hardware to power an ALSEP.

One of the first and biggest difficulties was getting predictability from the materials being used. The SNAP-27 team was committed to using the 3M Company's lead telluride thermocouples, and they had to learn about lead telluride processes themselves. Other tasks included learning how to join and coat the beryllium that was used as case material. There were numerous safety problems also. One of the biggest challenges was putting the RTG on the Lunar Module Craft, which carried two astronauts from the command module to the lunar surface. Weight was a primary concern. Moreover, the Lunar Module was not a re-entry vehicle; it would remain on the lunar surface. Yet it was the vehicle on which, according to mission planners, the RTG had to be transported. This meant that a re-entry container had to be constructed just to carry the RTG capsule. The RTG people were restricted to 7 to 12 pounds of weight for this cask.[40]

"Harry Finger saved our program," said Pitrolo. "When we first presented our ideas to him under the $4.6 million contract, he said: 'You're success oriented, but you don't have the technology base you need.'" Finger then defended the program with Congress to obtain more money. His success there enabled the General Electric people to expand their capabilities so that they could do the necessary tests themselves, learn about the materials, and become involved in safety. Pitrolo reported, "Later Finger told us: 'Now I feel confident if you run into trouble you'll be able to fix things.'"[41]

The SNAP-27 program exemplified the type of broadened base of technical support Finger said was necessary as the RTG program became involved in more complex space-mission systems. According to Pitrolo, there were several budgets on the SNAP-27, including the fueling funds (Mound Laboratory), funds for the Sandia technical support (along with separate safety funds allocated to other laboratories), and the General Electric budget which included some funds for safety analyses. The General Electric personnel not only developed their own capabilities with materials and other key aspects of the generator, but performed many safety tests, sometimes going to Albuquerque to use Sandia test facilities. "We ran a lot of impact tests with sleds at Sandia," said Pitrolo, "and we did a lot of work with hot capsules. Remember, the re-entry velocities and the heating rates for a lunar return are much higher than for an earth-orbital mission." Sandia frequently ran independent tests to verify data that had been produced by General Electric.[42]

By the time of the first lunar landing mission, there had been personnel changes in the program. Prior to the fire at Cape Kennedy, Webb had called upon Finger to head a task force studying NASA organization. In March 1967, after the fire, Webb appointed Finger to serve as Associate Administrator for Organization and Management at NASA. Finger never returned to the space-nuclear work. He was replaced on the project by Milton Klein.

Webb retired from NASA shortly before the elections in 1968, although he remained on call to President Johnson for further duty at NASA, should he be needed.[43] Webb said he made this move to clear the way for the incoming Nixon administration and the final stages of the race to the Moon. He also said, "I would have been a little slower in taking those last steps [on Apollo 8, 9, 10]. After the fire in 1967, we couldn't stand any more mishaps. But Paine [his successor at NASA] moved right along step by step with no delays in the revised schedule." Webb was delighted with the outcome and the successful culmination of the efforts he had set in motion and done so much to nurture.[44]

At the AEC, Seaborg received unofficial word as early as 10 October 1968 that the SNAP-27s would not be used on the first manned lunar landing.[45] When the decision had been firmed, he received an explanation from George E. Mueller, NASA Associate Administrator for Manned Space Flight:

> ...we have sharpened the focus on some of the problems involved. The first landing mission represents a large step from orbital operations...The 1/6 g lunar surface environment will be a new experience. We cannot simulate it completely on Earth. We find...that we simply do not have as much metabolic data as we would like in order to predict with high confidence, rates in a 1/6 g environment. Only educated guesses are possible on the difficulties the astronaut will

> have in maneuvering on the surface or the time it will take him to accomplish assigned tasks.[46]

Mueller went on to reassure the AEC Chairman:

> The decision not to carry ALSEP on the first mission is due to the time necessary for deployment and not to any concern of operating with the RTG. You have the strongest advance assurance I can give that ALSEP will be carried on the second mission. I also foresee significant RTG use in the future as lunar exploration progresses.[47]

The RTG people and the General Electric SNAP-27 people watched the mid-summer Apollo 11 historical events and Neil Armstrong's "giant leap for mankind," like most Americans, as fascinated TV viewers. By November 1969 some of these people were far more than ordinary spectators as the Apollo 12 mission unfolded. Pitrolo was at Cape Kennedy on November 14 for the launch. It was a rainy day with extremely low clouds that caused the launch vehicle to disappear from view soon after liftoff. Then a half minute into launch a power failure was reported as a lightning bolt struck the spacecraft and opened the main circuit breakers. Pitrolo thought: "My God, we're going to have an abort." But the craft soared into the sunlight as Pete Conrad reported: "We had everything in the world drop out." To which Mission Control replied: "We've had a couple of cardiac arrests down here too."[48]

When the mission reached the lunar surface, Pitrolo was at Mission Control in Houston as astronaut Alan Bean deployed the ALSEP and prepared to activate the RTG. By then America's second pair of Moon walkers had developed a TV audience fascinated by their light-hearted demeanor and "bunny hopping" across the lunar surface. But as the moment of truth of the RTGs approached, the TV transmission went out. Transcripts of the lunar surface dialogue recorded the problem encountered by Bean as he tried to remove the plutonium-238 fuel capsule from its graphite cask in the Lunar Module so that the SNAP-27 could be activated:

> *Conrad:* "It really gets you mad, Houston, ...Al put the tool on, screwed it all the way down and the fuel element would not come out of the kit. He's taking the tool off and working it again."
>
> *Bean:* "I tell you what worries me, Pete. If I pull on it too hard, it's a

> very delicate lock mechanism...Just get the feeling that it's hot and swelled in there or something. It doesn't want to come out....Come out of there, rascal."[49]

Pitrolo felt the real trouble was that after the removal of the cover, the unit had not cooled down as quickly as had been anticipated and was not at the temperature it had been during training for removal.[50] Finally, with a few taps from a hammer on the tool to give it a better grip, the fuel capsule came out and the RTG activated. SNAP-27 began to produce the power for the ALSEP as planned and predicted.

The quiet technology was not highly noticed by the general public in its lunar surface supportive role, but nevertheless it had shared in a truly spectacular space triumph. This was clear in the reaction of scientists to the ALSEP:

> Significance of the successful deployment and operation of ALSEP, in relation to the smaller experiment package left on the moon during the pioneer Apollo 11 landing mission, was expressed by one scientist this way:
>
> "It's really an enormous jump, probably the biggest jump we will ever take in understanding the moon. Not that we won't do more and better things, but this is the first enormous step."[51]

Reports on the ALSEP and the RTGs continued to appear in the news as the days went by.

Pitrolo was present at Cape Kennedy for the launch of Apollo 13 in April 1970—"A beautiful day; a beautiful, perfect launch." Back home in bed some nights later, this mood changed abruptly when he received a phone call at 3:00 in the morning from Carpenter. "I answered immediately," he said, "because I was lying there awake. So Carpenter says: 'Oh, you've heard.' I said 'Heard what?' Then he explained about the explosion on Apollo 13 and said 'They might be coming back at higher velocity than normal.'" As all America was learning, the astronauts were riding home using the Lunar Module and its life support systems and engine as a lifeboat. Plans were being made for them to re-enter the command module and to separate the Lunar Module from it before atmospheric re-entry. Pitrolo got his people together preparatory to calculating problems of a higher-than-normal-velocity re-entry. However, normal re-entry trajectory and velocity were achieved, as had been calculated in the pre-launch safety review accounting for this type of abort. The detached Lunar Module broke up on re-entry, as anticipated, while the graphite-encased plutonium-238 fuel cask survived the breakup and went down intact in the 20,000 foot deep Tonga Trench, as had been projected for an aborted mission in a 'lifeboat mode' situation.[52]

There was no noticeable public concern about a radiation hazard when the nuclear power devices returned to Earth. Carpenter went on national TV with CBS in Houston to reassure the public that there was no danger and that the heat source would not burn up on re-entry and would fall harmlessly into the deep Pacific. Interest in the problem proved limited to "reporters thinking up news" and asking "What about this nuclear thing?" Dix recalled only two inquiries from the public, one was from a dentist in California and the other came from a law school in Australia. Pitrolo doubted "that the rank-and-file public was very aware of the nuclear thing on those Apollo missions—and on that one that was aborted. Of course, *we* were very alert and very much aware."[53]

The AEC continued to pay attention to the Apollo 13 abort. A press release by the AEC on 28 April 1970 in response to press inquiries on SNAP-27 re-entry reassured:

> Air sampling over the predicted impact area of the SNAP-27 fuel cask freed from the Apollo 13 lunar module showed no traces of radiation above that already present in the atmosphere. The absence of additional radiation indicates that the cask containing the plutonium fuel survived as designed the heat of re-entry, impacted in the South Pacific intact and sank to the ocean bottom.[54]

The nation was showing signs of flagging interest in the race that had now been won. Even before the Apollo 13 launch an assessment in the trade press held that the:

> World tour by the Apollo 12 crew is being looked upon as a public relations flop by some National Aeronautics and Space Administration officials, who are arguing against a similar trip by the astronauts of the forthcoming Apollo 13 mission. Crowds at parades and receptions for the three Apollo 12 crew members have been noticeably smaller and less enthusiastic than those during the tour of the Apollo 11 crew....

> Requests for press credentials for Apollo 13 also are sharply lower than on previous flights [55]

The RTG program followed through on its commitments to complete the Apollo mission series But the momentum and national spirit of the halcyon days of the race for a manned lunar landing were never recaptured The NASA plans for post-Apollo spectaculars—particularly *manned* missions, to other planets or for further lunar explorations—foundered in the budget crunch of the 1970s Still, the RTG program found ways to maintain modest momentum of its own even as other aspects of the space nuclear effort at the AEC faltered If there were no more Apollo supermissions to be served with power in space, there were other spacecraft, with highly interesting space missions, that could and would utilize the unique capabilities of isotopic power

Chapter VI
A Maturing Program

Competing Issues

The first Apollo missions were the climax of a race to restore American prestige regarded as lost as a result of the initial Soviet space successes. The remaining Apollo missions, all carrying ALSEPs powered on the Moon by SNAP-27s, represented a winding down of the nation's space program. Spectacular pictures from the last Apollo missions provided final glimpses of America's end game in the manned race to the Moon. Even before this, however, the country was moving into a period when the focus that had been placed on the space program was shifting to other issues.

In a ticker tape parade in New York City honoring the Apollo 14 astronauts there was evidence of conflicting public priorities. A sign held up along the parade route read, "White astronauts fly to the moon while black children die in welfare hotels." Demonstrators near the steps of the city hall competed with the mayor's remarks by chanting, "Crumbs for the children, millions for the moon."[1] One industry spokesman saw mounting criticism of the defense establishment affecting technology in general. Writing in a space journal, he said:

> All these [dissenting] groups focus their criticism on the defense establishment and the "military-industrial complex." They have increasingly included basic science and fundamental technological pursuits in their criticism.[2]

The NASA budget which stood at $5.2 billion in Fiscal Year 1965, had been pared to below $3.3 billion in Fiscal Year 1971, while social programs got $77.2 billion that year, and defense $73.5 billion.[3]

In the first five years of the decade of the 1970s, the RTG program participated in seven successful space missions, equalling the number of successful missions the program had known in the previous ten years, which began when the first SNAP-3A flew on a Navy Transit satellite. Two other missions during that decade, Nimbus-B-1 and Apollo 13, were aborted. Through this string of successes the program benefited from its own technical momentum and illustrated a growing maturity even while the total space program was slowing down. The measure of its growing maturity was its ability to find missions in a shrinking space effort and solve technical problems even as nuclear technology lost public favor, and in the face of on-going organizational and personnel changes in the key federal agencies.

Sustaining Program Momentum

By the beginning of 1971, the RTG program had firm commitments for supporting a number of space missions, most of them for NASA but also one Transit navigational satellite for the Navy. Missions that would fly with RTG power systems during the succeeding four years were:

	Launch Date
Apollo 14 (SNAP-27)	31 January 1971
Apollo 15 (SNAP-27)	26 July 1971
Pioneer 10 (SNAP-19)	2 March 1972
Apollo 16 (SNAP-27)	16 April 1972
Triad-01-1X (Transit-RTG)	2 September 1972
Apollo 17 (SNAP-27)	7 December 1972
Pioneer 11 (SNAP-19)	5 April 1973

NASA had commitments to supply SNAP-19s for the Viking missions to Mars. The AEC contracted with General Electric to conduct a "technology readiness" effort for a Multi-Hundred Watt (MHW) RTG in anticipation that NASA would place specific requirements for a Grand Tour of planets later in the decade. At this time DOD also came to the AEC with a request for development of the Multi-Hundred Watt RTG for its Lincoln Laboratory communications satellites.

In considering this request, the Director of Space Nuclear Systems, Milton Klein, expressed some of the major budgetary problems then current in the RTG program. Klein focused on the distinction between "technical readiness" and "development." The former was defined "as the conduct of work up to a point sufficient to demonstrate that all significant technical problems have been identified and the solutions sufficiently demonstrated so that a potential user will have *confidence* that the technology will work if developed on a realistic schedule for mission use." "Development" was defined "as that work conducted beyond the technology readiness phase to provide a flight-worthy and qualified system and 'tailor' the system to a specific mission..." The current program situation was clarified:

> Over the last few years, firm mission requirements have been funded by reducing SNAP technology [readiness] programs. These reductions have reached the point where very little technology work is left in the program. Thus, that source of funding for firm user requirements is essentially no longer available. More importantly, there exists a dangerous lack of technology activity which if allowed to continue will severely impair the future use of nuclear power systems in space and affect the space program itself. (The SNAP program has virtually evolved into a 'job shop' to meet user agencies near term flight scheduled projects with only a very small effort being put into the technology which will be needed in the future.)[4]

In spite of these concerns it was basically as a "job shop"—but an aggressive one, constantly seeking missions for its devices—that the RTG program sustained momentum through difficult years. Klein said: "The bloom went off the rose after the success of the Apollo man on the Moon program. But nuclear power was needed on more distant unmanned space missions, and we were lining up on those missions."[5]

Testifying before the JCAE on the Fiscal 1972 budget requests, Klein cited a history of recent successes. He told the committee:

> Nuclear power is already playing an important role in space activities. For 22 months, SNAP-19 radioisotopic thermoelectric generators... have been supplying supplemental power to the Nimbus III weather satellite....On the moon, two SNAP-27 RTG's are working perfectly to supply power through the long lunar nights and days to the lunar surface experiments...left there by the Apollo 12 and Apollo 14 astronauts...[6]

Looking to the future, he told the committee that efforts on five flight missions would be supported, although activities to advance the technology beyond the flight-related projects would be limited. The Pioneer probes to

Jupiter, the Viking Mars Lander, and the Navy's Transit satellite were all to use RTGs. Deliveries for the Transit satellite were scheduled to occur later that year. Flights of the Pioneer spacecraft to Jupiter were scheduled for 1972 and 1973.

Retrenchment from the decentralization that had been fostered by Finger began to take effect. Sandia started to phase out its major technical role and AEC planned to continue only a "quality assurance" role for the corporation through 1971.[7] There were concerns in the program when Seaborg left the AEC in mid-1971, because he had been very much involved technically in the RTG program and had given it stature.[8] The program, however, continued to follow through on its mission commitments while it sought other commitments.

Klein was replaced as director of the Space Nuclear Systems Division by his former deputy director, David Gabriel late in 1971. Gabriel's efforts to maintain the stature of the RTG program were actually aided in early 1973 by the decision to make major cutbacks in space nuclear propulsion and space reactor power. The radioisotope effort survived, while other more highly funded efforts to develop nuclear propulsion and reactor power for space uses did not. In surviving, the RTG program had the field of nuclear applications in space to itself. An AEC announcement in January 1973 made clear that the focus on the near-term was a major factor in the economy moves:

> Following a determination by the National Aeronautics and Space Administration that its research and technology programs should focus on near-term developments, the AEC has taken parallel action in related programs.
>
> Programs to be terminated include nuclear rocket propulsion work at Los Alamos Scientific Laboratory and at the Nuclear Rocket Development Station in Nevada....
>
> The cutbacks will also affect the space reactor thermoelectric programs of Atomics International...and the space reactor thermionic programs of General Atomic...[9]

As a counterpart of this reduction in the overall space nuclear effort, the joint AEC-NASA Space Nuclear Systems Office was dissolved.

The AEC announcement went on to publicize the extensive programs in RTGs which would continue at the agency. Cited specifically was the work on RTGs "...for NASA's Viking Mars Landing Program, NASA's Mariner Jupiter-

Saturn mission, and for the military Lincoln Space Satellite."[10] APL monitored RTG developments constantly because of its contracts on the Navy's Transit navigational satellite program, which had been using RTG equipment for 10 years. APL's Dassoulas said that there had been problems with the SNAP-9As and that APL went back and forth between solar and nuclear, keeping an eye on developments in both technologies. During the decade, APL continued its concerns about the vulnerability of its systems and this rekindled its interest in the RTGs.[11] The AEC had new thermoelectrics by then, so Triad could be outfitted with a 30-watt, 24,000 curie Pu-238 RTG as its sole source of power.[12] The launch on 2 September 1972 was successful, and ten years after being placed in orbit, the Triad was still functioning. Dassoulas explained that the Navy did not continue then with RTGs because of an anticipated lag between launches and AEC cutbacks that would curtail production lines. Moreover, improvements in solar power made this source less vulnerable. Reflecting a mounting concern of those years, Dassoulas added that APL did not want to be caught with only nuclear systems if nuclear power in space was finally forbidden.[13]

The Apollo missions that completed the manned lunar landing program—Apollos 14, 15, 16 and 17—all carried SNAP-27s to power an ALSEP to be left on the Moon. The last of those launchings was on 7 December 1972. The Apollo RTGs worked so well they eventually had to be shut down.[14] After the last launch, an AEC program status report showed that even Apollo 12, the first to carry a SNAP-27, which by then had been operating for over three years, was still producing 69 watts of power, compared with its initial output of 74 watts. All the other Apollo SNAPs were producing at least 70 watts at the time of the report.[15] Five years after its deployment on the Moon, the SNAP from Apollo 12 was producing 83.5 percent of its initial power. All five RTG-powered ALSEPs continued to operate until they were shut down on 30 September 1977.[16]

At the start of the decade, a year after the first lunar SNAP flew on Apollo 12, as an honor to the RTG program, a SNAP-27 was presented to the Smithsonian Institution.[17] Public interest in the lunar missions diminished, however, and cuts in funding forced curtailment of the Apollo program. Apollo 17 was the last to fly, as Apollos 18, 19, and 20 were cancelled. With the liftoff of Apollo 17 in December 1972, it seemed to many that it was unlikely man would return to the Moon again in the twentieth century.[18]

General Electric's SNAP-27s were designed uniquely for manned space missions, but the momentum of the Apollo experience carried them to the Multi-Hundred Watt contract and future deep-space applications. Before the Apollo program ended, an unmanned planetary mission found uses for RTGs.

The Challenge of PIONEER

Charles Hall, Pioneer Project Manager at NASA-Ames in Sunnyvale, California, managed the program from the time it was moved to Ames and defined as an interplanetary probe to Jupiter. He refers to the Pioneer program as a "rowboat" compared to the Apollo "battleship." This meant that people did not scrutinize his program as much and because of its comparatively small budget, it could be pulled along in the wash of Apollo. Hall was one of the program directors sold on RTGs by the marketing of the RTG people.[19] His experiences further proved the technical capabilities, under pressure, of the RTG program and its contractors.

Hall had reservations about using the RTG on a three-year space mission because the first Nimbus carrying an RTG failed on launch and, also, the power degraded too fast on the RTG that accompanied the successful Nimbus launch in 1969. On the other hand, he was unsure whether a mission to Jupiter could use solar cells. The scheduled launch date for the first planetary Pioneer, Pioneer 10, was early 1972, and these questions about power source were undecided three years before the launch date. To expedite system development, Hall convinced NASA headquarters that a sole source contract should be negotiated with TRW. This was done, and TRW proposed the use of solar cells. "The design was pretty limited," Hall commented, "but it still looked better to me than going through all the hassles with the AEC of using RTGs."[20]

NASA headquarters favored the use of the RTGs, as did AEC's Space Nuclear Systems Division. At about the time of the completion of the solar-power study for Pioneer, Carpenter from the AEC came to Ames to talk with Hall about the SNAP-19, developed by Teledyne and last flown on the Nimbus weather satellite. Hall was finally convinced that much had been done to improve the SNAP-19 since Nimbus. It was made more attractive, in Hall's view, by the AEC's agreement to fund all development costs and to build all the prototypes free. Hall, still worried about reliability, because the RTGs would be the sole power source, decided to put four RTGs on the spacecraft when the Jupiter mission needed the power of only three.[21]

A letter of agreement signed with the AEC, although difficult to put together, later avoided problems and contributed to good working relationships. TRW continued as the spacecraft contractor. In December 1970 prototype generators were delivered. It soon became apparent that good working relationships were vital. One of the generators, in testing, began to degrade rapidly in power and Hall insisted on a comprehensive assessment of what he feared was an inherent problem. He described the work that followed as a "tremendous engineering job" involving Teledyne personnel, and Bernard Rock and Harold Jaffe of the RTG program. This team identified the problem within a month."[22]

The defective device was examined at Teledyne facilities near Baltimore. A sample of the gas inside, supposed to be a mixture of argon and helium, revealed traces of hydrogen and water vapor. Moreover, the metal of the RTG had been weakened by water which had saturated the device. Hall attributed the flaws to a failure to maintain a low humidity atmosphere in loading; Teledyne attributed the basic problem to outgassing from the heat source.[23]

Several actions were taken to correct the problem. The ratio of gas fill in the generator was altered. A redesign eliminated the many seals in the Nimbus SNAP-19 to the point that the device carried on Pioneer had only one seal. The assembly procedure changed to a glove box process whereby all the assembly steps, including welding, were carried out in a sealed box into which the worker inserts his hands by means of gloves mounted on the side of the chamber. The assembly was conducted in a submarine-like, controlled atmosphere chamber. A new and more efficient thermoelectric material called "TAGS"* was introduced. These actions persuaded NASA and Hall to proceed with RTGs.[25]

The launches of Pioneer 10 on 2 March1972, and of Pioneer 11 on 5 April 1973, received less publicity than the manned missions to the Moon. The purpose of the two spacecraft was to "extend the studies of interplanetary phenomena beyond the asteroid belt, fly-by Jupiter...and transmit data several years after [a] Jupiter encounter before...departure from the solar system."

*The term TAGS is derived from the names of the major constituents: tellurium, antimony, germanium and silver. TAGS is a solid solution of silver antimony teluride in germanium telluride.[24]

Some of the thirteen experiments to be performed involved celestial mechanics, meteoroid astronomy, asteroid detection and Jovian radiation belt examination The four SNAP-19 generators had to provide at least 120 watts of continuous electrical power throughout the mission, which would vary between 645 and 795 days depending upon the specific day and hour of launch [26]

The launch of Pioneer 10 went relatively unnoticed by the public, but interest heightened considerably as the Jupiter fly by occurred twenty-two months after the mission began Hall recalled vividly the ten days at Ames in December 1973 when Pioneer 10 encountered the planet Jupiter The press was there every day, along with a gathering of very interested space scientists One of the great unknowns was the strength of the radiation field that would be encountered "I thought the radiation problem had been oversold," said Hall, "but those readings really got high The press knew we were getting very concerned We prepared a release every day "

Dix also was present at Ames to watch the data coming in In his view, "Pioneer was the most successful spacecraft ever flown " Pioneer survived the radiation around Jupiter and continued to perform its experiments perfectly A concern early in the mission had been that asteroids would penetrate the sealed capsules as the vehicle passed through the Asteroid Belt, but that problem never materialized

Headlines in the San Francisco Bay area papers proclaimed "Pioneer Makes It " The public, perhaps not as excited as space specialists about radiation hazards, saw pictures of that distant planet taken by special photo equipment [27] Space journals, too, gave extensive coverage to the triumph of Pioneer 10 and the survival of its payload, the RTGs, in the severe radiation environment near Jupiter They noted, also, that Pioneer 10 was the first man-made object to leave the solar system [28]

After the success of Pioneer 10, Pioneer 11 (enroute) was retargeted onto a path that would take it by Saturn as well as Jupiter Arrival at Jupiter was scheduled for 2 or 3 December 1974, and arrival at Saturn about 5 September 1979 [29] On the arrival at Jupiter, space reporters mentioned that Pioneer came through the zone of peak radiation danger in better shape than the earlier Pioneer The spacecraft had survived "worst case conditions" and there was a note of great expectancy in the reports that the functioning vehicle and its scientific equipment were continuing on a course to the first space encounter with Saturn.[30]

Not only had radioisotopic power survived extreme radiation, but according to Hall, "in the escape trajectories of those Pioneers from the solar system, the RTGs really paid off. They're still operating, although they are degrading. After 13 years, the power on Pioneer 10 is down to about 120 watts. I think it will run out of power in 1994." According to Hall, later Pioneers—to Venus—did not use RTGs because they went close to the sun. He explained: "If you're going to stay near the Earth or even go around the sun, solar is cheaper, and less trouble."[31]

Nuclear Fears and Energy Dilemmas

At the close of 1974, the nation faced new unknowns both in space and in the future of nuclear power. An era ended as the AEC completed its final days. A history of the Atomic Energy Commission summarized the changed situation:

> *In* the preceding decade the Atomic Energy Commission had lost much of its privileged status with Congress and the American public. The exclusive monopoly and the mantle of secrecy had been largely removed, and no longer did atomic energy seemingly provide the perfect formula for both military defense and civilian energy needs.[32]

The space program also faced many uncertainties. Plans for manned planetary exploration had been shelved. An unmanned space program was still alive, but there were revisions and delays in more ambitious plans for Grand Tours of the solar system. Viking '75 to Mars was firm and on schedule; NASA administrators speculated about a Viking '79 mission and the possibility of a Pioneer Jupiter orbiter mission in 1980. Such a program would require RTG power—and perhaps reactor power for the deep space needs of the 1990s and after.[33]

A basic concern was the extent to which future missions would have to rely on the use of the space shuttle which NASA had been pushing since the beginning of the decade as a major cost-effective element in its post-Apollo programming. Use of a manned shuttle as a launch platform would bring new problems to designing for safety in the use of RTGs. Dick of Teledyne pointed out, "Early on, when nuclear was much in vogue, publicity was good. But when the anti-nuclear thing got started, we assumed a low profile on uses of nuclear power."[34]

Exchanges between NASA and the AEC in 1974 reflected concerns about future space nuclear needs and capabilities for meeting them. In June, the NASA Administrator, James Fletcher, wrote to AEC Commissioner William Anders of his concern about AEC plans to discontinue the SNAP-19 after Viking '75 and replace it with a new selenide technology RTG.[35] In his reply that summer, Anders expressed the problems posed by an $800,000 reduction in the AEC Fiscal 1975 appropriations request for the Space Nuclear Systems Division:

> ...while we agree on the importance of such activities as maintaining the SNAP-19 and the Multi-Hundred Watt RTG capabilities; advancing toward the higher performance, low cost selenide RTG's; and continuing work on very high performance, lower cost dynamic systems as well as higher power reactor systems, the funding requirements of this program would exceed that expected to be available. This funding situation is one in which we will need your support of both near term and future budget cycles with all elements of Government if we are to enhance the program as we mutually desire.

Anders proposed the creation of a joint AEC/NASA coordinating board to assure compatibility of programs, to exchange information, and to report status and needs as appropriate.[36]

Six months later the AEC ceased to exist and was replaced by the Energy Research and Development Administration (ERDA). Robert Seamans was the proposed new director. At his confirmation hearings in December 1974, he said:

> Our purpose in ERDA is to provide more options than we have today, to increase our sources and to improve the efficiency in the consumption of energy.
>
> I believe the President and the Congress have wisely recognized the importance for a strong R.&D. agency capable of developing and sustaining a balanced and practical program for energy generation and conservation that will anticipate the needs of our Nation. We must make the best use of all viable sources of energy, and we must at all times minimize the possible environmental risks that these sources

may pose. The creation of ERDA can meet these goals."[37]

New actors entered the scene, new structures came into being, and a new orientation to nuclear power and to energy problems was implemented. At the space-nuclear program level, there were many uncertainties.