Chapter VII
Persistence Amid Change

Years of Uncertainty

On January 19 1975, the Atomic Energy Commission was abolished and most of its functions transferred to the new Energy Research and Development Administration (ERDA), except for regulatory functions which were transferred to the Nuclear Regulatory Commission (NRC). Nuclear power, under increasing attacks from public interest groups, and losing favor on economic grounds among private developers, suffered further slippage through this loss of the AEC, chartered by Congress to promote its advancement. At ERDA, nuclear energy was reduced in status to an option in direct competition with such alternatives as fossil fuels, solar energy, energy conservation and a nascent synthetic fuels program. More than any of its competitors, nuclear energy became wrapped in controversy. The controversy led to uncertainty in the nuclear power space and RTG programs.

After Seaborg left the AEC, the RTG program lost its most visible advocate and the agency's public announcements on the RTG role in space missions became muted. Mission launches and anniversaries of successful RTG missions were no longer used as occasions to issue statements projecting future applications of nuclear energy. No voice from ERDA, nor later from the Department of Energy, would direct messages to the public about the accomplishments and promise of the quiet technology.

Critics of the AEC's dual mandate—to develop and promote nuclear power while protecting the public safety through regulation—argued that the AEC neglected nuclear safety research while encouraging commercial licensing. Seaborg's replacement, James R. Schlesinger, tried to change the agency's public image from that of an agent of the nuclear industry to that of a "referee serving the public interest."[1] His successor, Dixy Lee Ray, created a Division of Reactor Safety Research, and continued to expand the safety research program.[2] Throughout the RTG program, research and development in safety had always been combined with research and development in spacecraft and missions because of an awareness that one disaster would spell the certain end of the program.[3]

Although energy policy had not been a major issue in the 1976 presidential campaign, soon after his election President Carter described the energy crisis, and its testing of the nation, as "the moral equivalent of war."* He requested the creation of an energy department to wage this battle. The Department of Energy (DOE) came into being on 1 October 1977, with James R. Schlesinger as its first secretary.[4] The competition nuclear energy had encountered at ERDA increased at DOE. In addition to focusing on the full range of energy options, the new department melded some 5,000 staff from the Department of Interior, almost 4,000 from the Federal Energy Administration, some 1,500 from the Federal Power Commission, and nearly 9,000 from the now disbanded ERDA.[5]

Several actions and events during Carter's first days at the White House suggest a retreat from a Federal policy of embracing nuclear technology. Even before the establishment of DOE, the president announced that the United States would defer indefinitely the reprocessing of spent fuel from civilian reactors and delay construction of the Clinch River Fast Breeder Reactor.[6] A short while later, when a Soviet spy satellite containing a nuclear reactor fell in northwest Canada in January 1978, President Carter initially assured the public that the United States would not fly such devices in space. He was later to soften this position to make it less unequivocal.[7] Fourteen months later, in March 1979, a loss-of-coolant accident occurred at the General Public Utilities' commercial reactor Three Mile Island Unit 2.[8] Sensational press coverage resulted in intensified public concern over the risk of lethal radiation from any form of nuclear energy. By this time, however, even the strongest supporters of nuclear energy in Congress could no longer speak through the Joint Committee on Atomic Energy, whose disbanding had been approved concurrently with the passage of the legislation creating DOE and its responsibilities divided among a half dozen House and Senate committees.

Some in the RTG program felt strongly about the changing environment. When the AEC building was transferred to ERDA, the broadened scope of energy programs placed those working on nuclear programs in the minority,

*A phrase borrowed from the philosopher William James.

and the emphasis, according to a recollection by Carpenter, shifted to the question of "how many barrels of oil did you save today." Carpenter resigned his post in the program after two years, to take a position in private industry.[9] Dix stepped away from his safety role in both the program and on the INSRPs to become DOE's Director of Safety and Environmental Operations.[10]

The joint AEC-NASA office had been disbanded several years earlier. Under ERDA, a new Division of Nuclear Research and Applications (NRA) was established to "carry out a program of advanced nuclear R&D in the areas of terrestrial and space applications...."[11] In June 1976, Rock became the Assistant Director for Space Applications.[12] With the loss of a strong advocacy voice at the top of the organization, key program administrators such as Rock became responsible for publicity of the program. At appropriations hearings, defenders of nuclear research and applications took the position that while development of the RTGs for the space program would continue to receive primary emphasis, emphasis on the terrestrial program would increase.[13]

Uncertainty pervaded the space front. One champion of the space program said of the years following the Apollo triumphs and the Watergate scandals, "For young Americans, in particular... the exploration of space came to be seen as just another gaudy sideshow in a carnival run by scoundrels."[14] Space advocates saw the shuttle program absorbing much of the NASA budget and hoped that this manned orbital transportation system would eventually lead to a new era in the nation's space program. In the meantime, momentum was lost in the space program. The major surviving manned space activity was the joint American-Soviet Apollo-Soyuz Test Project which used the Saturn launch vehicle and the Apollo spacecraft. The liftoff for the Apollo-Soyuz Test Project in July 1975 marked the break-up of the Saturn launch team at the Kennedy Space Center and the loss of a team that, according to NASA Administrator James Fletcher, had made a "fantastic contribution to our country."[15]

After assuming office, President Carter made it clear that no new major space efforts were planned and that exploiting the potentials of the shuttle would be the focus of America's space program. At a White House press conference in May 1977, the president spoke of expanded use of spacecraft in foreign policy and expressed interest in Landsat and communications spacecraft.[16] Early in 1978, the journal *Astronautics and Aeronautics* decried "NASA's Loss of Thrust," and sought Webb's comments. Webb, who had set NASA on its path to the Moon, saw the need for NASA to recapture its role as leader of a global enterprise; but he, too, felt this enterprise should stress international terrestrial applications "...in education, communication and transportation, looking toward more viable political, social and economic systems for nations willing to work with us in the years ahead."[17]

In the RTG program in the last years of the decade, attention centered on remaining commitments to support NASA's unmanned planetary missions and military orbital missions. New initiatives to establish relationships with DOD resulted in the creation of a Space Nuclear Systems Applications Steering Group. RTG program directors recognized that regardless of the nuclear-power and space-program climate, the RTGs faced stiff competition from solar power systems—which were cheaper and avoided the complexities of the RTG safety procedures. A selling point with military users was the reduced vulnerability of RTGs to enemy countermeasures, as compared to solar-cell arrays. Remaining commitments to NASA, however, were for planetary missions that could not use solar cells because the missions went too far from the sun. Missions logged by the program during the last half of the decade were:

	Launch Date
Viking 1 (SNAP-19)	20 August 1975
Viking 2 (SNAP-19)	9 September 1975
LES 8 (MHW)	14 March 1976
LES 9 (MHW)	14 March 1976
Voyager 2 (MHW)	20 August 1977
Voyager 1 (MHW)	5 September 1977

A summary of American space launches in the last half of the decade reveals how selective were the uses of RTGs. According to NASA figures from 1975 to 1980, the United States launched: 77 applications satellites; 23 scientific payloads; and 11 space probes. Of this total, only six carried RTGs. Two RTG launches (the earth-orbital LES military communications satellite launches) are included in the total applications satellites. The other four all flew on space probes—and thus RTGs supplied power for over half of the missions.[18] Clearly, as in earlier applications, the RTGs were reserved for special uses.

Amid the uncertainties of organizational change and public controversy, those heavily involved in space missions persisted in addressing primary technical problems. Many of the RTG people, especially those assigned to facilities away from headquarters, did not experience the "changed climate" that Carpenter recalled. They remained relatively insulated from the changes in the parent organizations of the RTG program. At least on Viking, they were caught up in the excitement of teams of professionals who were realizing life-long dreams.

Viking to Mars

No space missions after Apollo recaptured the dynamism and public interest generated by the race to put a man on the Moon. However, Viking unmanned missions to Mars had a special fascination of their own. A select audience found Mars an exciting frontier for human exploration; some of this excitement carried over to a larger public that, even as it turned away from the space program, had become caught up in the Space Age. Audiences captured by "Star Trek" and "2001, a Space Odyssey" were among those enchanted by close human examination of the mysterious red planet.[19]

Mars was considered a prime candidate for hosting life in some form. The Viking missions to Mars would put down unmanned "Lander" probes from orbiting vehicles. These Landers would carry experiments whose primary purpose was to search for evidence of life. For a long time, mission planners had argued that the Landers could not rely on solar power and would require isotope power systems in order to perform in the extreme temperatures, winds and nights of Mars. Jerry Soffen, NASA Viking project scientist, contributed to early planning of biological experiments to search for evidence of life on Mars. When NASA's Langley facility became involved in the soft Mars landing, Soffen left the Jet Propulsion Laboratory (JPL) in Pasadena, California, and went to Langley as project scientist. Langley, with Jim Martin as project manager and Tom Young as mission director, assumed responsibilities for the total Viking mission and for the Lander, while JPL retained responsibility for the Orbiter subsystem. "Viking was pretty big," Soffen said. "Of course nothing came close to the magnitude of Apollo—which absorbed almost everyone at NASA. But in its day, I would say Viking had some 20,000 people across the country working on it."[20]

The original Viking mission was scheduled to fly in 1973, but budget cuts caused a slippage to 1975. The creation of instrumentation and software were distinctive challenges. Round trip communication at the speed of light required about 45 minutes, so the automated spacecraft had to interrogate itself and self-determine its actions, because corrections sent from Earth would be greatly delayed. The Martian night and dust worried planners. "When we were still considering solar power," said Soffen, "we even thought about ways to tilt solar panels while the Lander was on the surface to shake off dust from dust storms. But actually we always wanted RTGs and we put a lot of effort into keeping the AEC in line to provide them." Viking's design ended with RTGs as the only power source for the Lander and all its experiments.[21] Each of the two RTGs on the mission was required to produce a minimum of 35 watts for 90 days on the Martian surface.

There were significant problems in adapting the SNAP-19 to the requirements of the Viking mission. Thermal integration of the RTG with the Lander was a major difficulty. The RTGs were to furnish all the electricity for the Lander and the heat to control the Lander's temperature.[22] The cold nights and relatively hot days on the Martian surface led to concern about controlling the heat of the instruments. A thermal switch was installed under the two RTGs. As the internal temperature of the Lander became high, a bellows would open a pair of plates to prevent heat from the RTGs from entering the Lander compartment; when the temperature became cold, the bellows would close the plates and allow heat from the RTGs to be conducted into the Lander compartment.

Two other problems led to special design features for the SNAP-19s on Viking. The Martian winds caused designers to construct wind screens over the RTGs—and the wind screens, too, were part of the thermal control system. Even more distinctive was the problem of contamination which required the Lander and all its components to be sterilized before launch. The Viking experimenters wanted to ensure that the landing vehicle was carrying no contamination from Earth to the Martian surface—and they especially wished to guard against carrying life there that might be detected by their Martian-life-seeking instruments. The entire Lander, including the RTGs, was sterilized—"encased in a cocoon which was sealed," according to Bob Brouns, RTG program representative at Langley for Viking. There were concerns that the RTGs might get too warm during the bake cycle, so a cooling coil was placed at the top of the RTG before it was capped with a dome. Water was run through this tube to take heat out of the RTGs during the sterilization cycle.[23]

The two Viking launches on 20 August and 9 September, 1975, although not heralded or publicized like Apollo, received increasing media and public interest as the days neared for the actual landings on Mars. The landing of Viking 1 was planned as a 4 July 1976 Bicentennial event. After the Orbiter began to send back pictures of potential landing sites, the journals became lavish in their coverage. Soffen explains the interest and publicity regarding Viking: "For one thing, it was a Bicentennial event. The new Smithsonian Air and Space Museum was opened by a signal beamed back from Viking to cut the ribbon. But I think people got interested because they were fascinated by Mars—and Viking stayed there taking pictures for a long time."[24]

The landing of Viking 1 was delayed beyond the original target date of July 4 to permit the location of better landing sites. The delay only added to the suspense of the scientists, mission principles, newsmen, and selected laymen gathered at JPL. Mark Washburn, who was there, recorded the moment of touchdown in his book *Mars At Last!*

> The final seconds were agonizing. Years of work and decades of dreaming were about to be fulfilled—or smashed on an unseen Martian rock.
>
> And then—at 5:12:07 A.M. PDT (ERT), 20 July 1976—*touchdown!*
>
> Von Karman Auditorium erupted in an orgy of cheers, hugs, and tears. In mission control, the controllers shouted and whooped, tore off their headphones and danced by the light of their computers...
>
> *Viking* was on Mars.[25]

The life-detecting experiments on the two Vikings turned up no positive evidence of life on Mars. In fact, no organic chemicals, the building blocks of life, were found; yet meteorites contain organic chemicals. According to Soffen, one explanatory theory holds that the atmosphere of Mars allows penetration of ultraviolet rays to the planet's surface so that organic chemicals on the planet's surface are oxidized. Soffen added that the Viking's search for life was "a high stakes gamble" and many scientists lost their interest in Mars after Viking.[26]

The RTGs performed perfectly. "Considering what Viking did," said Soffen, "it was remarkable how the power worked."[27] A status report of 4 December 1976 on the RTGs indicated that on Vikings 1 and 2, requirements for 70 watts of electrical power for 90 days were fulfilled.[28] Plans for Viking '79 and other Mars missions were cancelled, nevertheless.

A Return to Military Applications

Before the Vikings reached the Martian surface, another mission carried RTGs into space. Two LES 8/9 missions,* flew on 14 March 1976. Reports of the success of these communications satellites were issued before the news from Mars began to come in, although the LES mission was kept low key from the beginning. A defense mission for the Air Force, LES 8/9 was the first defense application of RTGs since the Navy Transit launched four years earlier—and only the second use of RTGs by DOD in 12 years.

The two LES 8/9 spacecraft were launched simultaneously aboard one launch vehicle, placed in separate synchronous orbits, and intended to have a useful life of five more years. The two satellites were designed to communicate crosslink with one another and with surface terminals as well. The single pair, spaced thousands of miles apart, could "provide communications among terminals anywhere in an area covering more than ¾ of the surface of the Earth."[29] As experiments, LES 8/9 were "designed to demonstrate and evaluate techniques to help satellites survive and continue dependable operation in a hostile environment."[30]

There had been a series of LESs, all designed and built by Lincoln Laboratory in the course of a continuing Space Communications Program conducted for the Air Force. None of the other LESs had been powered by RTGs. Phil Waldron, Associate Progamming Manager for LES 8/9, said that five years of planning preceded the launch. But once committed to the RTGs, Lincoln Lab stayed with its decision. Waldron explained: "At Lincoln Lab, we're in the business of R&D for the military. We're not in competition with anyone; we are learning things that improve space communications systems. We try to be low key."

All the simulations and testing, as well as installation of the RTGs on the spacecraft, took place at the laboratory. No major problems or crises arose. Minor engineering problems mainly concerned the amount of fuel and heat

*Lincoln Experimental Satellites (LES) were named for Lincoln Laboratory of MIT, responsible for system integration for this Air Force mission.

generated. A long string of trailers (referred to as the circus train) carried the air conditioning for the spacecraft and its RTGs whenever they were moved at Cape Kennedy.[31]

LES 8/9 also carried a new generation of RTGs into space. The MHW (Multi-Hundred Watt) RTG, more high powered than previous RTGs, had been under development by General Electric for several years. The basic generator was a 130-watt modular unit; the two generators on an LES were designed to provide over 260 watts of power continuously for five years.[32] Higher levels of power were achieved by using multiple units. Fuel for the MHW was in the form of a plutonium dioxide sphere, with each RTG containing 24 of those spheres "protectively packed into a cylindrical graphite [re-entry] aeroshell... in turn encased in a metallic clad."[33] Thus, new precautions for safety were taken because the MHW-RTGs would carry 146,000 curies compared to 80,000 on Pioneer and 41,200 on Viking.[34] Instead of lead telluride thermocouples the MHW used silicon germanium thermocouples, which could operate at higher temperatures to produce more watts per pound.[35]

Pitrolo recalled how some of the changes came about in the MHW. He had moved to the MHW program and worked closely with Lincoln Laboratory in early development work for LES 8/9. The AEC state-of-the-art had progressed from the microsphere fuel form to plutonia-molybdenum cermet. According to Pitrolo, his team at General Electric insisted on a solid fuel form. "I went to Los Alamos and asked a guy to press me a solid oxide ball," he recalled. Then, because molybdenum was degrading the fuel form, a search began to find a material that could survive re-entry and be compatible with the fuel form and the graphite in the container cask. A search of the literature revealed that the iridium could be used instead of molybdenum. So the developers of the MHW learned to weld and work with iridium.[36]

The LES 8/9 mission met a basic Air Force requirement for development work on communications satellites, but did not lead to other DOD contracts or missions for the RTGs, although the mission contributed to the state-of-the-art for military use of RTG power in satellites. In addition to exploring and extending military applications of RTGs, the LES mission made contributions to the development of RTG technology. Lessons learned in developing the MHW were applied on the Voyager space probes, which also used the MHWs. Developers of Voyager sat in on LES safety meetings, observed operations, and watched LES activities at Cape Kennedy, according to Waldron. Waldron also believes that the dollar cost per watt for RTGs, including about $10 million for safety, was a factor that inhibited Air Force uses.[37]

Before he left the RTG program, Carpenter played a very active role in pursuing RTG uses on DOD missions. He was a member of the DOD/ERDA Space Nuclear Applications Steering Group. The September 1976 issue of *Aviation Week* discussed the problem created by cuts in the budget and the need to pinpoint requirements before initiating development. Reporting that a joint DOD/ERDA committee hoped to select several types of future military satellite missions that could use high-power non-solar-cell energy sources in the 10 to 100 kw. range, the journal quoted Carpenter that "we cannot afford anymore false starts." It concluded:

> Carpenter is hopeful that, after the joint Defense Dept./ERDA committee has selected several space military missions that are potential candidates for nuclear power sources, funds will be made available for design studies by experienced spacecraft contractors.[38]

In the following six years, however, this hope was not fulfilled.

Voyager to the Outer Planets

The Voyager program began as a plan for a $2 billion program to send exploratory craft to Mars. This plan was cancelled and the NASA outer-planet mission received the recycled name "Voyager." NASA's planetary mission plans of the 1960s recognized that by the late 1970s Jupiter, Saturn, Uranus, Neptune and Pluto would all be lined up on the same side as the sun—an event that occurs once in a hundred years—and a multiplanet mission could be designed to visit all of the outer planets. NASA initially planned separate Grand Tours—each with twin launches—to visit, respectively, Jupiter-Saturn-Pluto in 1976 and 1977 and Jupiter-Uranus-Neptune in 1977. Because of budget cuts, NASA's planners dropped Uranus, Neptune, and Pluto from immediate plans.[39]

Plans for missions to the outer planets included consideration of RTGs. During the planning stage, Vincent Truscello came to JPL from Martin-Nuclear in Baltimore; he and Gerhard Stapfer of JPL recalled that in the earliest planning for the Grand Tours, there was recognition of the need for a nuclear power source. "In the early 1960s," Truscello said, "I was writing position papers that said that there were no other options than RTGs for our planetary missions. The intensity of light decreases by $1/r^2$ as you get away from the sun. So once you get beyond Mars, the size of solar panels you would need is huge."[40]

Although JPL had never worked with nuclear power sources, as the result of many years of planning and execution of planetary missions, the laboratory acquired a great deal of knowledge about RTGs. JPL also conducted a great deal of materials and lifetime testing. The laboratory's role was not to develop RTG systems, but to integrate them on planetary spacecraft. The misson's name, "Mariner Jupiter/Saturn 1977," was changed to "Voyager" shortly before its launch; it was scheduled to have an RTG power source. "You can't easily shift schedules on a mission like Voyager," said Truscello, "the launch window occurs with much less frequency than for missions like Apollo." The abbreviated missions to the outer planets, finally defined in 1972, had stayed on schedule, but not without some technical problems.

Each Voyager spacecraft was powered by three Multi-Hundred Watt generators having a combined output in the order of 475 watts per spacecraft. Thus, the total nuclear power for the Voyagers was about equal to that of all previous missions still in space in 1977.[42] As launch time approached for the two Voyagers, which would depart within a few weeks of one another, an ERDA announcement stressed the magnitude of this latest space exploration:

> Nuclear power generators provided by the Energy Research and Development Administration (ERDA) will make possible the longest space mission ever planned—a 10-year voyage starting with closeup television pictures of Jupiter and Saturn—then perhaps a look at our Sun's distant planets, Uranus and Neptune.[43]

Rod Mills, NASA program manager on Voyager, explained, "Because the mission went so far out, we decided to send two spacecraft to insure against failure." A boom extending out from the spacecraft carried the RTGs. Instruments for the spacecraft were mounted on another boom located 180 degrees from the RTG boom.[44] Voyager was launched on schedule, in 1977. The launching of Voyager 1 took place on 5 September 1977. Although Voyager 1 was actually launched two-and-a-half weeks after Voyager 2, it was designated

"1" because it followed a trajectory that brought it to Jupiter before Voyager 2's arrival.

Carl Sagan, among others, hoped for significant information from Jupiter and anticipated that "abundant biota" might be found in the planet's clouds. At the time of launch, a space journal referred to the mission as "running a planetary post pattern": Voyager would "'run straight' for Jupiter, then head toward Saturn, then fly toward Uranus and, finally, streak into the solar system's end zone—beyond the leading edge of the solar system." The impressive tour would fly by Jupiter, rendezvous with Saturn's rings and make close-up observations of eleven of the two planets' twenty-four satellites. Ballistics of the trajectory of Voyager 1 called for it to use Jupiter's gravity to sling it toward Saturn—thereby saving almost three years in flight time. Voyager 2 would use Saturn's gravity to accelerate and change its course toward Uranus and possibly on to Neptune.[45]

In their distant travels, the Voyagers, even more than the Vikings, had to be able to run themselves. Communication time to Jupiter and back is 80 minutes, and to Saturn and back, about twice that amount. The Voyagers were able to transmit 115,200 bits of data per second from Jupiter and 44,600 bits per second from Saturn.[46] So again, the RTGs powered versatile and complex instruments, including independent computer brains, and thereby insured the success of a mission to the edge of the solar system.

The planetary encounters elicited rapt attention from space scientists and considerable interest from the general public. As with the Vikings, information came to a central control center at JPL and from there to an eagerly awaiting audience at the Von Karman Auditorium. Mark Washburn documented impressions of the encounter with Jupiter in early 1979 as the atmosphere of the planet was revealed in vivid color:

> There had never been anything like it. For two weeks in late February and early March, 1979, Voyager I plunged through the Jovian system, shattering theories and changing forever the way in which earthlings look at the universe. The high-tech, soberly scientific Voyager mission turned into something different, something more—it was an interplanetary freak show, an expedition to the other side of the looking glass, where the Merry Prankster Imaging Team provided the pictures

> and Lewis Carroll explained the science. . . . Magnificent, majestic Jupiter, king of Olympus, sultan of the solar system, grand Poo-bah of the planets, at last revealed its true Day-Glo colors, . . .Jupiter—the psychedelic planet.[47]

Enthusiasts were ecstatic about the achievements of the Voyager spacecraft. Few in the lay public who saw the pictures remained unmoved by them as the returns came in from Jupiter—and then from Saturn. As the ten-year voyages continued, however, most people forgot about Voyager as other news eclipsed the long periods of travel between planetary encounters. As the Voyager reached Saturn in November 1980 and August 1981 and beamed back breathtaking pictures in color of that planet's rings, space exploration once again commanded the public's attention. The rings of Saturn provoked awe and wonder. The response was not enough, however, to generate support for the revival of a manned planetary program or even an expanded non-manned space exploration program.[48] If support were forthcoming in the future, the RTG program, whose devices were a necessity for such ventures, was determined to be ready at the launch pads.

A Program Needing Missions

As the last space launchings carrying RTGs took place in mid-1977, the RTG program received some mention in the nation's newspapers for its contributions. The *New York Times* said that the Voyager launching to Jupiter, Saturn and beyond "is the latest adventure for a little-noted power technology that has made possible much of the last decade's dramatic extension of knowledge of the solar system." Citing information obtained in a telephone interview with Bernard Rock, at the time assistant director for space application for ERDA's Division of Nuclear Research and Applications, the *Times* said:

> According to Mr. Rock, development of even larger future nuclear power systems for space is supported by a $30 million annual research program. Among its plans is the use of advanced selenide thermoelectric units along with plutonium 238 heat sources aboard a spacecraft that is to carry an orbiter and a probe to Jupiter. Launching is scheduled for 1982.[49]

Developmental work also proceeded on radioisotope-dynamic systems that would harness the plutonium heat source to drive an electricity-generating turbine. With improved spacecraft and gyro mechanisms to compensate for rotating equipment, space-nuclear power developers no longer avoided the isotope-heat-to-turbine option. Radioisotopic-dynamic systems, then competing for selection, would generate 1,000 to 2,000 watts of power; the anticipated outcome of the competition was a system qualified for space flight by early 1982 in the next satellite program of the U.S. Air Force.[50]

Neither of these projected schedules for NASA and DOD missions was met. The Jupiter orbiter/probe, named Galileo, was rescheduled for a 1985 launch and then for 1986. The Air Force satellite using a dynamic isotope power system also was delayed greatly. Selection between competing dynamic isotope technologies for the Air Force's Space Based Surveillance Spacecraft (SBSS) was anticipated to occur "some time in 1986/1987."

The competing dynamic systems were Brayton Isotope Power System (BIPS) and the Organic Rankine Isotope Power System (KIPS). In the early 1980s, the RTG Program Plan said: "It is...necessary to update the 1978-1979 work completed on KIPS and perform comparable studies on BIPS in the integrated spacecraft configuration to provide information to candidate SBSS system contractors.[51]

In the few missions where commitments for supplying RTGs still remained, there were many scheduling delays. A new NASA program named Solar-Polar, sponsored jointly by NASA and the European Space Agency—each of which was to supply one spacecraft—was scheduled for launch in 1983, then delayed, and finally discontinued under U.S. budget re-evaluations. The United States retained commitments, however, to launch the European spacecraft from the U.S. space shuttle, to provide tracking and data services for the mission, and to supply RTGs for the spacecraft.[52]

With mission schedules slipping and new missions extremely hard to pin down, the RTG program continued its work of technology improvement. While costs of the MHWs used on LES and Voyager were approximately $25,000 per watt of electric power, program officials expected to achieve a 60 percent reduction, to approximately $10,000 per watt by 1981, and to less than $7,000 per watt by the mid-1980s, through the introduction of an improved radioisotope heat source. Economies were achieved by increasing RTG output per pound Earliest units had an output of approximately 1 8 watts per pound nearly 4 watts per pound by the mid 1980s were projected [53] The new generation of RTGs that would provide power on the Galileo and Solar Polar missions was called General Purpose Heat Source (GPHS) It was to be a modular system similar to the MHW, produce 285 watts of power in the RTG under initial space operational conditions, use Silicon Germanium thermocouples, and attain a heat to-electric power conversion efficiency of 6 8 percent (compared to 6 7 for the MHW, 6 3 on SNAP 19, and 5 0 on SNAP 27) [54]

Prospects for new missions were not good in the 1980s President Reagan advocated a strategy of converting the agency's role to one which encouraged private enterprise demonstrations of the commercial viability of technologies, while the federal government assumed the role of supporting "long term, high risk energy research and development in which industry would not invest "[55] Reagan's administration seemed much more friendly to nuclear energy in immediately affirming the nuclear power option and later breaking ground for the Clinch River Breeder Reactor The administration also expressed its intentions to stimulate growth and productivity of many energy technologies [56] Thus, the climate improved for advocates of technology development, but the quiet technology relied on development and applications opportunities in space, and the climate for space programs was uncertain

Space and nuclear scientists and technicians continued to seek glimmers of hope A Harris survey in 1980 revealed that a majority of those surveyed* believed the advantages of technology far outweighed the risks "Even on the emotional subject of nuclear power," it was reported, "while 75% agreed that there could be no guarantee against a catastrophic nuclear accident, most felt that the risks were justified And most respondents seemed to have reasonable confidence in the judgment of scientists and engineers "[57]

On the space front, although the shuttle captured public attention and received much acclaim, a long-range and well-supported space program—especially for space science and space exploration—languished in the uncertainties of budget cutting and mixed signals about the value to the nation's strength and confidence of non terrestrial enterprises In 1981, NASA and its scientific advisory groups took steps to salvage the planetary program A new

*The survey was based on 1 500 interviews of a national cross section of the adult population plus an additional 600 Congressmen and business and financial leaders policy maintained the earlier scientific objectives for solar system exploration but extended the time for obtaining the data for satisfying those objectives. New plans also envisioned spreading the return of data over more limited and less expensive planetary spacecraft.[58]

Missions under the new policy would have much more limited science objectives than the Viking and Voyager projects of the prior decade. The members of NASA's Solar System Exploration Committee were concerned about possible effects of Reagan administration budget cuts on the Galileo Jupiter orbiter/probe mission. At the same time, the National Academy of Sciences expressed concerns about a proposed 12 percent reduction in federal research and development expenditures, and the head of MIT's Department of Physics expressed fears that such a cut would diminish manpower in the physical sciences to pre-Sputnik levels.[59]

Space technology supporters searched for positive intepretations of President Reagan's 4 July 1982 welcome to the astronauts returning from the fourth shuttle orbiter at Edwards Air Force Base, before a crowd estimated at 500,000. The most promising Reagan statement was: "we must look aggressively to the future by demonstrating the potential of the shuttle and establishing a more permanent presence in space." The president appeared to recommit the nation to the shuttle program, to more options for military uses of space, and to continued planetary exploration if the budget problems eased. "While the president did not say yes to anything," reported a trade journal, "neither did he say no."[60]

In the RTG program at this juncture, technical developments went forward methodically while space-mission schedules continued to slip. The problem was how to turn the "maybes" of potential users to "yeses." Even more important, was a need to generate a climate for "yeses," reinforced by successes, that represented a space program with purpose, continuity, and momentum. This could not be done by a program alone. As Webb had stressed in the days of Apollo, the larger environment was an important determinant of opportunity and action in the operations of large-scale endeavors. Key leaders of such endeavors must be sensitive to the larger environment and engage in relationships to influence decisions. For a component program of a large-scale endeavor in space the most appropriate axiom was: Be ready when opportunity appears.

Chapter VIII
Past Lessons and Future Challenges

Lessons from a Program Lineage

The space-RTG program spans a period of less than three decades, although its antecedents can be traced back over a half-century more. There were many technical improvements and successes in the program despite cycles of budgetary growth and decline. Managed by a small core of dedicated professionals, the program persisted through numerous organizational changes and shifts in the climate for space exploration and nuclear-power applications. As a component of modern-day endeavors that require large allocations of public resources and support from many sectors of society, the program accumulated extensive experience concerning survival and continuity in the modern environment for technical research and development. Moreover, the RTG program activities cut across two technological fields—atomic energy and space exploration—that have been the focus of tremendous attention and controversy in the second half of the twentieth century.

Significant lessons stand out in this history of a technology developed in a relatively small program managed and fostered by a relatively small group of people.

Advantages of Being Small and "Quiet." In an era when there are mixed emotions about technology (especially "supertechnologies"), there may be advantages in being both small and quiet. Many RTG program people would probably agree that it is not always best to be big—especially when bigness is accompanied by pressures of high expectations. For many years the space reactor-power and nuclear space-propulsion efforts drew far more resources, as well as far more attention and pressures, than the RTG program. When the reactor-power and space-propulsion efforts were curtailed by extreme budgetary pressures and growing discontent with nuclear power and space, the quiet technology not only continued, it gathered increased support. Modest funding also meant less pressure from private sector contractors seeking a piece of the action and fostered conditions for a hard core of technicians and advocates to take shape—a core of people who, both among government employees and private-sector contractors, became zealous about proving and improving their technology.

Importance of Solving Early, Basic Technical Problems. When the RTG technology first was made public, it was presented as a field where a "breakthrough" had been achieved—enabling electric power to be obtained directly from isotopic heat by thermocoupling, making space applications possible immediately. The breakthrough was nurtured and capitalized upon; opportunities for applications became building blocks for accumulating knowledge and experience around a proven technical capability. Through the years, improvements were sought and achieved in heat sources, materials, thermocoupling processes, conversion processes, and safety procedures. Moreover, the technology persisted to the day when the original breakthrough was no longer of definitive importance. Improvements in related technologies made the isotopic-dynamic option feasible; improvements in cost-per-watt-delivered were sought in systems where isotope heat turned rotating equipment. Thus, RTG development cycle had continuity that carried beyond original breakthroughs and earlier barriers.

Importance of Being Safe and Responsible. The RTG program people would agree that one can never be too careful, or too concerned with safety in the nuclear field. Fearful that one accident could destroy the whole program, they began early to address safety problems. They also maintained a procedure of providing public information about potential hazards and follow-up information when mission aborts did occur. Safety research and development went hand-in-hand with research and development in the RTG technology and was wedded to specific spacecraft. Changes in safety concepts, procedures, and testing kept pace with new hazards associated with new mission requirements, new RTG configurations, and increased fuel loadings. Although the safety program added to the users' costs for RTG power, it helped to bring the program through years that were difficult for nuclear power.

Importance of Having Missions. Technical research and development may be greatly constrained and difficult to perform when it must be justified by and linked to mission requirements. This complaint was voiced early by the Martin-Nuclear developers; and it continued to be sounded throughout the program's history, as complaints about a "job shop" role were expressed in the program. In retrospect, though, key program managers saw that it was the ability to find missions and obtain mission commitments that kept the program alive and enabled technical developments to proceed, for development wedded to missions greatly facilitated dealing with the larger environment and the capricious forces operating there. Program needs and responsible budgetary expenditures were demonstrated in line with developments to meet mission schedules, while pressures for justifying missions and for meeting the schedules of costly missions, fell on those outside the program. RTG program people often commented that a slipped mission schedule was a help because "we would never have made that earlier launch date." Thus, the program sometimes benefited from slipped schedules in that this did not reflect badly on the program itself but instead left intact its record of always "being ready at the launch pads." Of course, mission slippage, curtailment, or—worst of all—cancellation, can be very negative aspects of mission dependence if the program itself has to cut back or "stand down" from an effort, and thereby lose momentum and continuity.

Importance of Flexibility—and Continuity. Flexibility is extremely important in accomplishing modern large-scale endeavors and helps in dealing with the larger environment. But positive flexibility requires competence with, and confidence in, a technology. The program's people must know what they have to offer and be ready to interpret that product to others while accommodating to changing priorities, perceptions, and concerns. In the story of the RTG program, the many changes in larger organizations were not vital largely because they remained extraneous for a long-term, dedicated, experienced program core caught up in missions and determined to prove and improve their technology. Today's RTG program manager, Bernard Rock, can look back on more than 20 years of his own participation in the program. Still close at hand are key personnel, George Ogburn, one of the "originals" from the late 1950s, who now functions as safety nuclear officer on Galileo and Solar-Polar, and Ted Dobry, now in a higher level safety role at DOE. One of Rock's two key directors today is James Lombardo, who joined the program in 1971, and was manager on missions such as LES 8/9 and VOYAGER, and now is director of Nuclear Systems Development. The other is Gary Bennett, who earlier was nuclear power flight safety manager on LES 8/9 and Voyager, and later took over program safety functions from Ted Dobry*. Thus continuity contributed greatly to competence, flexibility, and the ability to persist, learn, and adapt.

Seizing Opportunity. In a large-scale endeavor, it is vitally important to actively engage forces in the larger environment in order to influence change. In contrast, a component program, which has less leverage for influencing the larger environment, must be able to wait out the tides of public and political changes while avoiding being swamped by them. The public, the president, and the Congress can be ambivalent and change their attitudes. They can ignore and neglect a space program yet be caught up in the Space Age; for example, they can fear nuclear power in its "big technology" forms yet accept and support the quiet nuclear technology in its medical and healing applications—and be ready to support new "miraculous" applications that open new vistas on uncharted frontiers. A program embedded in space and nuclear developments and applications must be ready to capitalize on opportunities, especially those that arise from captivation of the human imagination.

Whither the RTG Program

Many in the space business believe that an American space program will gather momentum in this century. NASA's Soffen predicted the possibility of manned missions to Mars: "The astronauts would have to stay a year so the planets would line up properly for the return. The Soviets have stayed in orbit 211 days."[1] Mills, also of NASA, sensed a change in the climate of the space agency, reflecting a general change in the larger environment. He spoke of the start-up, in 1985, of a Mars geo-chemical observer that would begin a more methodical examination of the planet and believed that NASA was not as concerned, compared to recent years, with Earth applications. Mills felt, "there is fairly strong support for space exploration just for the value of the knowledge gained. We can't get anything as large as Viking going anymore. But a year or so ago a committee was created to look at a planetary program for the next 20 years. It is getting good support from the scientific community." Plans of the committee were for a new start in the space science program every year, with $1 billion now in NASA's science applications budget. "Anytime these missions

*Mike Dix, still a consultant to DOE, recalled that he and Ted Dobry go back to the Pied Piper days at Martin Baltimore when the then-classified nuclear work was done in the closed "boiler room" of that company's Nuclear Division go far out from the sun [in their explorations]," he said, "we will probably use RTGs "[2]

At JPL, where Truscello and Stapfer were involved in the rescheduled Galileo and Solar Polar missions, more caveats are expressed about the future of the RTGs RTGs were a must for space explorations away frm the sun—and would be used on Solar-Polar because the spacecraft on that mission would go all the way out to Jupiter, using the planet's gravity for a slingshot effect, before swinging back into orbit around the poles of the sun But Stapfer cautioned "The big problem with RTGs is the cost, and the days of big, costly space missions may be numbered RTGs are a big chunk of the cost of a mission " Moreover, RTG fuel costs were low in the past because DOE assumed most of these costs, soon the user would have to pay the full costs of the fuel On the hopeful side, Stapfer said that RTGs could fit in with the future approaches to mission design "To save costs the idea now is to design spacecraft for multiple missions RTGs look good for this approach You don't have to do a lot of redesign of them "[3]

The RTG people at Teledyne, however, who had lost out in the later space missions, were less optimistic about the future of RTGs in space They were confident that terrestrial applications had a better future than space applica tions "There are really only two commercial firms in the RTG business any more," according to Linkous "GE has all the space RTG work, and we [Tele dyne] essentially have all the terrestrial RTGs GE picked up the bigger contracts for space RTGs, but I really feel our future is better developing the terres trial ones NASA put half of its budget into the shuttle in trying to capture the public eye for the future I'm in favor of the shuttle program, but I think it may take a lot away from a deep space exploration program that would need RTGs "[4]

Carpenter, now working for a private aerospace firm, saw future possibilities for space RTGs mostly in defense applications He acknowledged there were frustrations in getting the military to move on missions, the LES mission came about, he reported, because of one Air Force colonel who was enthusiastic and wanted to see it through Although LES flew in 1976 and there have been no defense missions using RTGs since then, Carpenter maintained that the great future for space RTGs was with the military, particularly when the civilian attitude toward nuclear matters was considered "The military tradionally feel they must control all aspects of what they are doing. They can't allow it to be said the defense of the country depends on things the military can't control." So there are special problems in military applications of nuclear power-involving resources that have been kept under unique civilian controls in this country. In addition, Carpenter indicated, "It's hard to get a requirement out of the military until they are sure something will work. They will tell you: 'We won't fly it first.'"[5]

In the larger organizational environment surrounding the RTG program, dismantlement of the Department of Energy went forward under President Reagan, although slowed by compromises in Congress over issues of assignment of DOE functions to other agencies. For example, Senator John Tower of the Armed Services Committee expressed concern that weapons programs might be overshadowed if placed in the Commerce Department.[6] A changing climate regarding energy as a crucial problem further slowed plans to abolish the DOE. Outgoing Secretary of DOE James B. Edwards said in his farewell at the National Press Club in October 1982 that the era was behind us when energy was one of our most serious national problems. The in-coming Secretary, Donald Hodel, did not strongly advocate dismantlement of DOE although he expressed the view that the Department's functions could be performed by another existing agency.[7]

As he considered the future, Rock reviewed the many technical accomplishments of recent years:

> We have been making steady advances. Our heat sources are more advanced. The thermoelectric materials are more advanced. Some materials in the generator are more advanced. Our earlier converters were all low temperature devices. Today we have very high temperature converters—and this required advances in metallurgy .... Our efficiency [electrical output from heat input] levels are now up to 6 to 7 percent; and the future looks like 9 to 10 percent . . . . Solar-Polar will give us 2.3 watts per pound, while our earliest units only gave about 1 watt per pound. In the future, we expect to be up to 4.5 watts per pound.

Rock expected the dynamic systems using rotating equipment to play a large part in the future.[8]

The 1984 program plan of the Office of Special Nuclear Projects, Space and Special Radioisotope Systems Applications, set forth the two principal objectives guiding current RTG operations: (1) "To provide the U.S. with a viable nuclear isotope option for space power by continuing development of technology and qualification of static and dynamic isotope power systems"; and (2) "To develop and deliver qualified isotopic energy systems for use on approved U.S. space missions."[9] The plans cited two missions, Galileo and Solar-Polar, both scheduled for launch in May/June 1986. Budget projections in this plan showed marked increases in proposed funding.[10]

Rock was optimistic about the future: "Our forecasts are for growth. A NASA planetary series is pretty well defined. The military are showing increased interests. Beyond Galileo and Solar-Polar, NASA is set to start work in 1987 for launches in the 1990s. The military are looking at missions in the early 1990s. We are in a period of planning and development for these missions." Rock indicated that the latest developments in static RTGs for such missions were concentrating on a new device beyond the General Purpose Heat Source (GPHS) RTG to be used on Galileo and Solar-Polar. The latest generation RTG was called "Modular Isotope Thermoelectric Generator" (MTG), and the modules for this device—which facilitated fine tuning on lower-power modules—were 20 to 25 watt units.[11]

The supportive thrust of an overall long-range national endeavor was missing from the larger picture of space programs. Space advocates recognized that demonstrations of a quick, dollar and cents, return on investment were not feasible in space explorations and felt the need for visionary leadership willing to take political risks for potential long-term payoffs.[12]

Few in the lay public, or in the technical inner circles, expected or wanted another race in space. Those with an abiding interest in the space-RTG program hoped that past experiences would lead to a better appreciation of the value of space exploration. In *Distant Encounters,* Mark Washburn quoted one project scientist as saying that Voyager had made us "human beings [that] now measure a billion kilometers in dimension." Washburn concluded:

> Voyager gave us a glimpse of all that lies beyond us, and the experience of Voyager gave us a new appreciation of what is within us . . .[13]

As RTG technical developments went forward, the program was prepared to make new space achievements possible.