

Atomic Power In Space

A History

March 1987

DOE/NE/32117--H1

DE87 010618

Prepared by:
Planning & Human Systems, Inc.
Washington, DC 83
Under Contract No. DE-AC01-NE32117
A

Prepared for:
U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Deputy Assistant Secretary for Reactor Systems
Development and Technology
Washington, DC 20545

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

gse

CONTENTS

Forward

Preface

iv

Chapter I

Introduction 1

Chapter II

The Beginnings 4

Chapter III

Recognition of Potential 14

Chapter IV

Golden Days at the AEC 28

Chapter V

Momentum from the Lunar Race 56

Chapter VI

A Maturing Program 72

Chapter VII

Persistence Amid Change 83

Chapter VIII

Past Lessons and Future Challenges 99

FOREWORD

On December 8, 1953 President Dwight D. Eisenhower, in his famous "Atoms-for-Peace" address, proposed that the United Nations establish an international agency which would promote the peaceful uses of atomic energy. The President's purpose was to take a small step toward adapting the atom "to the arts of peace." Within a few years his small step had grown into a number of peaceful atomic activities, among them an International Atomic Energy Agency, bilateral agreements for cooperation in peaceful atomic development, research reactors built in foreign countries, two international peaceful uses conferences, the creation of special schools with curriculums centered on nuclear technology, and the expanded use of radioisotopes in medicine, agriculture, and industry. One such peaceful use developed late in the decade was the "world's first atomic battery." Unveiled for the first time in President Eisenhower's office on January 16, 1959, the "atomic battery" was a radioisotope thermoelectric generator, a special device which converted the heat created by the natural decay of a radioactive isotope directly into useable electric power. The President was gratified to learn that the generator, developed under the aegis of the Atomic Energy Commission's Space Nuclear Auxiliary Power program, could provide sufficient power to run the instruments aboard a satellite.

Characterized as a part of "Atoms-for-Peace" programs, radioisotope thermoelectric generators did not provide power for satellites until after the nation had entered the space age. The U.S. Navy launched the first radioisotope thermoelectric generator-powered satellite on June 29, 1961, a month after President John F. Kennedy committed America to put a man on the moon. The power unit, called a SNAP 3A device, supplied electricity for instruments on a Navy navigational satellite. Despite extensive safety tests which the Atomic Energy Commission performed on the device, the Kennedy Administration had some qualms about launching the SNAP 3A device, resulting in a last-minute approval and some extraordinary effort to get the device to the launch pad on time.

Although a small, self-contained unit might seem an obvious power source for a satellite, radioisotope thermoelectric generators actually powered only a few of the many satellites the United States placed into earth orbit. Altogether they provided electric power for six Navy navigational satellites, two Nimbus meteorological satellites, and two communications satellites. Solar panels provided a more suitable power source for most earth satellites.

The race to the moon and the requirements of space exploration, however, created more varied and challenging uses for radioisotope thermoelectric generator power units than did satellite missions. Because they were relatively rugged, light weight, and compact, contained no moving parts and did not depend on the sun for power, the National Aeronautics and Space Administration decided that radioisotope thermoelectric generators should power instrument packages and probes which must survive severe environments with little or no sunlight. Radioisotope thermoelectric generators therefore were developed to supply electricity to instrument packages left on the moon during the long lunar night. Astronauts deployed five Apollo Lunar Surface Experimental Packages on the moon between November 1969 and December 1972. Not only did the radioisotope thermoelectric generators survive the lunar night but they also continued to supply power until shut down on command from the earth years later.

The ability to supply power in severe, sunless environments also prompted the National Aeronautics and Space Administration to select radioisotope thermoelectric generator units to power the Viking unmanned Mars lander and the Pioneer and Voyager space probes to Jupiter, Saturn, and beyond. The Viking lander sent back the first pictures taken from the surface of another planet, correcting many misconceptions about the red planet. Although Mars was considered a prime candidate for supporting some form of life, Viking found no evidence of it on Mars. Surviving the Jovian radiation belts, the Pioneer and Voyager spacecraft provided a wealth of data about Jupiter, Saturn, and their moons, surprising scientists with unexpected discoveries. Overnight our conception of these worlds changed from planetary systems frozen in cold storage for eons to dynamic systems with swirling clouds of gases, tempestuous storms, ever-changing rings, and moons with active volcanoes

and one with an atmosphere of methane.

Entitling his work *Atomic Power in Space*, Dr. Richard Engler has taken us on satellite launches and to the outer reaches of the Solar System. Characterizing radioisotope thermoelectric generator technology as a "quiet technology," he has aptly pointed out that the generators have been a smaller part of larger shows, albeit a vital part. Although creating a small, "quiet" product, the radioisotope thermoelectric generator programs of first the Atomic Energy Commission, then the Energy Research and Development Administration, and finally the Department of Energy, have nevertheless grown and prospered while the rest of the nuclear space effort has been abolished. Dr. Engler has woven the contrast of prosperity and decline into his story while vividly capturing through oral history the views of radioisotope thermoelectric generator developers and users. Organizational change as well as ever-vigilant attention to safety has also characterized the program and Dr. Engler has discussed these themes in detail. Most thought provoking are the lessons he drew from the program. Regardless of the scale of the radioisotope thermoelectric generator program efforts, the lessons gleaned from such a successful program should be of value to anyone involved in technological development.

PREFACE

A tomic Power in Space," a history of the Space Isotope Power Program of the United States, covers the period from the program's inception in the mid-1950s through 1982. Written in non-technical language, the history is addressed to both the general public and those more specialized in nuclear and space technologies.

The Space Isotope Power Program has been highly successful and has made major contributions to the overall space program of the United States. It has been part of notable technical triumphs and large-scale organizational endeavors of the space and nuclear age and offers lessons from the program perspective on the problems of modern-day research and development. It is important to document the history now, while key participants can be located to relate their first-hand experiences.

The story is told at a number of levels: developments and achievements at the technical level; major events in the key institutions closely involved in RTG technology, and the larger milieu of the time. A chronology (see Appendix) presents important events in these different lines of action for the period covered by the history. A Bibliography indicates major sources used in developing the different lines contributing to the total story; of course, classified documents were not used.

Illustrations, diagrams, charts, and budgets are shown in Appendices. A table of isotope power systems for space is also appended, as is a chronological listing of launchings and an annotated chart on the different RTGs developed.

Acronyms used frequently in this narrative include:

AEC	Atomic Energy Commission
NASA	National Aeronautics and Space Administration
RTG	Radioisotopic Thermoelectric Generator
SNAP	Systems for Nuclear Auxiliary Power

In the series of SNAP devices developed for space and terrestrial use, odd-numbered SNAPS were RTGs while even-numbered SNAPS were nuclear reactor systems, not isotopic ones.

The following outline of chapter coverage may be helpful in following the chronology of this history and of the program it describes:

Chapter One: Introduction provides an overview of the story, notes how the RTG program reflected a merging of space and nuclear technologies, and identifies major themes.

Chapter Two: The Beginnings covers the 1950s but flashes back from a significant public announcement in early 1959 to trace the beginnings of radioisotope power discovery and development.

Chapter Three: Recognition of Potential describes developments in 1960 and 1961, years of transition from the Eisenhower Presidency to that of Kennedy when the first RTGs were used in space satellites, and notes early safety concerns.

Chapter Four: Golden Days at the AEC covers the years 1962-1965 when a small group of people were intimately involved in the program, a reorganization which created the Space Nuclear Systems Division at the AEC, and the beginning of major growth in the program as it prepared to support APOLLO and other missions of the National Aeronautics and Space Administration (NASA).

Chapter Five: Momentum from the Lunar Race describes the years 1966-1970 when NIMBUS and the first APOLLO launchings occurred, with RTG developments and applications spurred by NASA's major space exploration goals while international and domestic unrest increased.

Chapter Six: A Maturing Program describes developments in the years 1971-1974, the PIONEER and last APOLLO missions, and technical accomplishments before major reorganizations at the AEC.

Chapter Seven: Persistence Amid Change completes the historical narrative by taking the program from 1975 to 1982, describes the VIKING missions and the Lincoln Experimental Satellite (LES) and VOYAGER missions, and covers major organizational changes within the AEC.

Chapter Eight: Lessons and Challenges presents important lessons in the history of a space-age R&D program and future projections for radioisotopic power in space.

Planning & Human Systems, Inc., wishes to thank the many people who participated in developing this history. While not all who contributed their time to this project can be cited here, special thanks go to Bernard Rock and Orrice Murdock of the Office of Special Nuclear Projects, who gave initial impetus to this project, and to Jack Holl and Roger Anders of the History Division of the

Department of Energy for providing guidance throughout the project and for making available archival materials. George Ogburn from the RTG program was an invaluable source of information on important contacts as well as a guide to budget and organizational materials. Finally, all those program participants and technology pioneers who gave their time for interviews made it possible to capture the personal recollections important for the history.

Any errors in fact or interpretation found in this history are the responsibility of Planning & Human Systems, Inc.

Richard E. Engler, Ph.D.
Planning & Human Systems, Inc.
Washington, D.C.

Chapter I Introduction

Technological change has accelerated tremendously in recent decades. Today's new breakthroughs are disseminated almost immediately to the lay public via television and soon become tomorrow's routine occurrences. No technological developments of this accelerated age have captured more attention than those in space and those relating to nuclear energy. The technology which provided nuclear power for space missions cuts across these two broad fields of technical and scientific development.

In spite of their many spectacular triumphs, both the space age and the nuclear age have very recent beginnings. They date from the period following World War II when America assumed worldwide responsibilities. Throughout the 1950s, the two technological revolutions gained momentum, and in the decades which followed they brought amazing technological feats to the senses of many people throughout the world. They also influenced, and were influenced by, other events in the world.

The first man-made satellites, launched in 1957 by the Russians, led to a searching reassessment of American science and education. Eventually they triggered the race to the Moon of the 1960s and astronaut Neil Armstrong's "giant leap for mankind." Subsequently, unmanned Mars landings, missions to fly by Saturn and Jupiter, and other space probes punctured old beliefs and led to revised theories among space science specialists, while providing a view of the universe never seen by previous generations.

Dramatic developments in nuclear energy also unfolded during those years, although their appearance frequently was accompanied by public concern after the earlier cheers had subsided. From the beginnings at Stagg Field and Alamogordo, awe was mixed with foreboding, and efforts to generate peaceful uses of nuclear energy have been burdened by fears of the uncontrollable. Growing concerns about ever more destructive bombs and fears of fallout contamination led to concerted efforts to control testing and find peaceful uses for nuclear energy. As a consequence, the Atomic Energy Commission (AEC), successor to the greatest weapon development project of all time, began to

devote more of its developmental efforts to civilian applications of nuclear energy. According to a history of the AEC, in 1966 “the AEC budget for the first time was divided about equally between weapons and peaceful uses.”¹ Yet even the peaceful applications of nuclear energy were to face some barriers.

The radioisotopic program, a part of the overall effort to develop systems for nuclear auxiliary power for space missions, was a participant in these events. It benefitted from the plutonium produced and made available in sizable amounts by the many years of nuclear weapon development under the AEC. The space uses of isotopic power received their greatest boost from the highly-publicized missions conducted by the National Aeronautics and Space Administration (NASA), in America’s participation in the space race.

The space isotopic power program, however, has been a quiet program, somewhat shielded from evolving public concerns about nuclear power and rarely the star of the space spectacles. Space isotopic power has developed quietly because it is indeed a quiet technology. For example, it does not involve explosive power; nor does it require human interventions in nuclear processes to induce nuclear fission or fusion. It is a battery-like thermal power emanating from the natural decay of radioactive elements; when used in and applied to space missions, the technology operates far from the terrestrial environment.

The history of the radioisotope power program is basically a success story, although it is certainly not one of linear success. The program was initiated by the AEC under impetus from the Department of Defense but first went public late in that decade as part of the “atoms for peace” movement, with President Eisenhower showing an atomic battery to the world and extolling its peaceful potential uses. Subsequently, while the Defense Department supported mostly test applications of the radioisotopic power devices in space, the program reached its pinnacle of success through uses by the civilian space agency NASA.

The program never became truly big but was a vital part of larger programs while outliving its “big brothers” in the space-nuclear field. In the spring of 1961, as the first radioisotopic thermoelectric generator (RTG) space missions were about to be launched, proponents of the use of nuclear energy in space were projecting the future technologies that would enable Americans to achieve the goal set by President Kennedy—a man on the Moon by the end of the decade. They proclaimed: “Nuclear Rockets will get him there... Nuclear

Power will sustain him there.”²

The story told here will show how the second part of that prophecy came to fruition through the use of radioisotopic power.* It will describe how the RTG program matured in the 1970s to deliver RTGs that were vital components of missions to distant planets and beyond. It will look at the human, organizational, political, and social factors contributing to the survival and continuing achievements of the space isotopic power effort throughout its history.

The history of the space isotopic power program is essentially one of opportunities, perseverance, and attentiveness to detail—especially regarding safety measures and public communications about them. In its ultimate measure, space isotopic power is a program sustained throughout its history by a team of people who, in spite of changes in the larger organizations surrounding them, were ready at the launch pads when opportunities arose to demonstrate the technology in which they believed.

The story begins with the first glimmerings of opportunities for this space and atomic age technology.

*The faltering of the nuclear propulsion and space nuclear reactor power efforts is a secondary theme in this history.

Chapter II

The Beginnings

An Auspicious Debut

The radioisotopic power program made an auspicious public debut. A banner headline in the Washington, D.C. *Evening Star* of 16 January 1959 announced:

PRESIDENT SHOWS ATOM GENERATOR¹

An accompanying photograph showed President Eisenhower examining the “world’s first atomic battery” as it sat on his desk in the Oval Office of the White House. The president had personally ordered the display of the device shortly after seeing it himself for the first time.

The small, lightweight device on the president’s desk was a radioisotope-fueled thermoelectric generator (RTG)—a companion effort to nuclear reactor developments in the Systems for Nuclear Auxiliary Power (SNAP) program. Ready for space missions, the RTG could provide the necessary auxiliary power to operate the instruments of a space satellite. The RTG displayed for the public in that historic moment had been designated SNAP-3 by the AEC. In later years, especially on missions to the Moon and beyond, the RTG role as a bit player in space spectacles, kept it out of the headlines, but on that day it was the star of the show.

Although the isotopic power device was not made public until January 1959, the AEC had briefly discussed its development a year earlier before the Joint Committee on Atomic Energy (JCAE). The hearings before the JCAE had focused on “Outer Space Propulsion by Nuclear Energy,” but Colonel Jack Armstrong, chief of the AEC Aircraft Reactors Branch, also introduced Committee members to the small isotope power program. The program had been spurred, he said, by indications that the Russian Sputnik, with its long-lasting signals, used something other than conventional battery power for its transmitter. Efforts to develop space-nuclear power for the electrical equipment in the Air Force reconnaissance satellite 117L had led to research and development in both reactors and isotopes for space-power uses. Funds were found in

the nuclear propulsion appropriation for 1958 to finance a low-key, low-cost effort in isotopic power development “to provide an extremely light, an extremely small source of power...”²

Only four months before the televised display on Eisenhower’s desk, the Martin Company of Baltimore, Maryland received a contract for producing an isotopic generator. The Minnesota Mining and Manufacturing Company developed the conversion system by which heat from radioisotopic decay of polonium 210 was transformed into electricity. The five-pound experimental unit which developed five watts of power had been developed soon after the Martin contract was signed. Armstrong was reported as saying that “the cost of the model was \$15,000 exclusive of atomic material.” He estimated the cost of fueling with 3,000 curies of polonium at \$30,000.³

The men from the AEC meeting with President Eisenhower hailed their small generator, which had no moving parts, as a “significant breakthrough” for its efficiency in producing electric energy from the heat of decaying radioactive isotopes through a method called “thermocoupling.” According to Armstrong, until the breakthrough in conversion methods, American scientists exploring isotope technology used rotating machinery driven by radioactive power sources to produce electricity. The new generator achieved its efficiency, stated to be 8 to 10 percent of electrical energy output from heat energy input,* through a radiating system of metal spokes, with each spoke in contact with a container that shielded the radioactive polonium and heat from the decaying polonium radiating up the outside ends of the spokes as electrical energy. The new RTG technology was not intended as propulsion for nuclear powered airplanes; Armstrong said that immediate uses were for NASA to decide, adding, “We can tailor the product to fit the customer.”⁴

Although NASA soon became the major user of RTGs in space, it was the Department of Defense that first capitalized on isotopic power technology for space—in satellites. Defense uses dominated nuclear energy developments throughout the 1940s and 1950s, with developments in the “big” nuclear technologies coming to public attention with the “world-shaking events at Hiroshima and Nagasaki. While opportunities for uses of isotopic power in the 1950s were linked to the “big” nuclear technologies and the new atomic age, the

*Later accounts reduced estimates of this efficiency to about 5 percent.

development of isotopic power itself has a history that goes back many decades.

The Quiet Nuclear Technology

Glenn Seaborg, Nobel laureate in chemistry and pioneer in the discovery of radioactive elements, has noted that while nuclear power plants generate headlines and engender debates about potential dangers, “the atom works away quietly, as it has for half a century, in medicine, industry, agriculture, and science.”⁵ Radioisotopes and atomic radiation, used in medicine since the early 1900s, marked the first phase of the atomic revolution, a phase which Seaborg believed was already over. He described the quiet technology:

The ‘silent’ atomic tools are varied; most depend not upon fission and fusion but upon more subtle properties of the atom, such as its precise clockwork, the high-speed projectiles it emits, and the vivid, distinctive label it provides.⁶

Behind these quiet tools was the discovery, in 1896, of radioactivity by Henri Becquerel. Investigating the phosphorescence of certain minerals after their exposure to light, the French physicist accidentally discovered that phosphorescent uranium salts affected a photographic plate. Most startling was his observation that uranium’s phosphorescent property did not depend on prior exposure to light, but was an inherent characteristic of the element. He had detected the disintegrating nucleus of the atom of an unstable element and had shattered the assumptions of classical physics, which viewed the atom as the irreducible building block of matter.⁷

Pierre and Marie Curie later used electrical methods to pursue the phenomena of radioactivity, building on the discovery that uranium and its compounds rendered the air near them a conductor of electricity. Their research into the radioactive properties of elements led them to the discovery of radium and polonium in 1898. They also detected, in their experiments with radium, the buildup of a voltage difference that was used in 1913 by English physicist H.G.J. Moseley in constructing the first nuclear battery. Moseley’s battery consisted of a glass globe silvered on the inside with a speck of radium mounted on a wire at the center. The charged particles from the radium created a flow of electricity as they moved quickly from the radium to the inside surface of the sphere.⁸

As late as 1945 the Moseley model guided other efforts to build experimental batteries generating electricity from the emissions of radioactive elements.⁹ These devices converted the motion energy of the charged particles from a radioisotope directly into electricity, without first converting the motion energies to heat, and thus generated very low powers (thousandths of a watt). At that time neither converters for transforming heat to electricity nor materials exhibiting sufficient efficiency in thermoelectric properties were available. The route that finally led to the RTG—obtaining heat from radioisotopic emissions and converting this heat to electricity—was not followed for some time.¹⁰ Before describing how that route was finally taken, it would be useful to describe the basic nuclear radiation process that is the essence of the quiet atomic tools.

An isotope is “any of two or more varieties of the atoms of a chemical element.”¹¹ Isotopes of the same element have different numbers of neutrons in their nuclei, although they otherwise display the same characteristics of the element. The isotopes of elements that exhibit radioactive decay properties are called radioisotopes. Radioisotopes are unstable elements that produce usable energy in the natural process in which one chemical element is transformed into another. Thus, within a family of radioelements such as uranium, change through decay to another element of the same family is constant and spontaneous.¹²

A radioactive isotope, then, possesses unique and valuable properties that are the basis of the quiet atomic technologies: “It spontaneously emits... nuclear particles... It decays exponentially in time at a rate which cannot be altered by known physical forces.”¹³ It is a potential source of usable electricity; its lifetime in generating energy for that purpose can be calculated exactly in terms of the half-life of the particular radioisotope as it decays.

International Confrontations and Vistas for New Applications

Before the Manhattan Project developed the atomic bomb, only very small quantities of radioisotopes were available. The AEC-sponsored reactors that continued to turn out large quantities of fission products brought about a great increase between 1940 and 1950 in radioisotopes and in the decay heat available to engineers. Moreover, in 1950 the need for small and reliable electrical power supplies was becoming manifest in the infant space program.¹⁴

As the 1950s opened, the wedding of the quiet technology to early space efforts was spurred by cold war confrontations that dictated developments in both atomic and space science.

The United States' monopoly of nuclear weapons ended in 1949 when the Soviet Union exploded a nuclear device of its own. The decision by President Truman to proceed with the development of a hydrogen bomb (H-bomb) followed within five months. Great power tensions reached a new high in June 1950 with the beginning of the Korean War. New military demands and the development of the H-bomb led to a tremendous expansion of AEC production facilities in the fall of 1950. New plants for producing plutonium were a major part of this expansion. Nuclear weapon testing increased also, and America's first experimental thermonuclear device was detonated at Eniwetok in the fall of 1952. In the years 1950 to 1953 the AEC created a vast complex dedicated almost totally to military purposes.¹⁵

During the cold war years, when the weapons race among the super powers intensified, the adversaries also pursued ever more sophisticated methods for learning about each other's technological advances. Surveillance satellites became major elements in the early space race, and radioisotopes had the potential for providing power for these military satellites. An early study by the North American Aviation Corporation had considered radioisotopes for space power.¹⁶ Then a RAND Corporation report in 1949 discussed options for space power in "Project Feedback," strategic satellite reconnaissance the corporation was studying, and concluded that a radioactive cell-mercury vapor system was feasible for supplying 500 watts of electric power for up to one year.¹⁷ These assessments and the growing recognition of power requirements in Project Feedback led the AEC in 1951 to commission studies of a 1-kilowatt electrical space power plant using reactors or radioisotopes. Several companies who performed these studies recommended the use of isotopes for space power. In 1952, the RAND Corporation issued a Project Feedback summary report with an extensive discussion on radioisotopic power for space.¹⁸ The interest in isotopic power for space satellites increased.

A significant achievement for the quiet technology occurred in early 1954 at Mound Laboratory in Miamisburg, Ohio. It was at this laboratory, which in future years prepared the fuel packages for succeeding generations of isotopic devices, that scientists pioneered the design of a thermocouple to convert

isotopic energy to usable electrical energy. Mound scientists Kenneth Jordan and John Birden had been frustrated in efforts to use decaying radioactive materials as heat sources to boil water to drive a steam turbine and generate electricity. They hit upon the idea of applying the thermocouple principle, using metals that differ markedly in electrical conductivity, to create a thermopile that would conserve and harness the heat from radioactive material and generate electricity.* Within a few days of working out the calculations, the Mound scientists constructed a working model of the technology. The principle of using the thermocouples was patented by Jordan and Birden, and today remains the basis for all radioisotopic-power thermoelectric generators.²⁰

A Program Takes Form in an Atmosphere of Challenge

With the need for space reconnaissance being given high priority and nuclear power now viewed as feasible for uses in surveillance satellite systems, the Department of Defense requested in August 1955 that the AEC perform studies and limited experimental work toward developing a nuclear reactor auxiliary power unit for the Air Force satellite system under study.²¹ In agreeing to undertake the development of such auxiliary nuclear power systems, the AEC stated that it intended “to explore the possibilities of using both radioisotopes and reactors as heat sources.”²² This was the birth of what became the SNAP program of the AEC.

The title “SNAP” replaced an earlier title of the program. In the 1958 hearings before the JCAE, Senator Clinton Anderson asked, “Is SNAP by any chance kin to the Pied Piper?” Armstrong’s reply was: “It is Pied Piper renamed, sir.”²³

That exchange occurred after momentous events had shocked American defense planners, space scientists, and the public at large. In October 1957 the Soviet Union launched its first Sputnik into orbit. That same month, the editor of *Aviation Week* stated:

The Soviet satellite... now orbiting around the earth approximately 16

*The thermoelectric conversion was discovered in the early 19th century by the German physicist Seebeck. The Seebeck principle of thermocouples indicates that “an electrical current is produced when two dissimilar metals are joined in a closed circuit and the two junctions are kept at different temperatures.”¹⁹

times every 24 hours...offers incontrovertible proof of another Russian scientific achievement. . . .

We believe the people of this country have a right to know the facts about the relative position of the U.S. and the Soviet Union in this technological race which is perhaps the most significant single event of our times. They have the right to find out why a nation with our vastly superior scientific, economic and military potential is being at the very least equalled and perhaps being surpassed by a country that less than two decades ago couldn't even play in the same scientific ball park.²⁴

In the same issue of *Aviation Week* an article surmised that success of the Soviet Sputnik would give new impetus to a Lockheed project for a satellite reconnaissance project called "Pied Piper" being developed for the U.S. Air Force. The project referred to was the one for which the AEC took the responsibility of developing nuclear energy as a possible source of auxiliary power. Repercussions at the AEC came quickly.²⁵

"Pied Piper" was the code name for the advanced reconnaissance system for which the AEC was preparing a nuclear auxiliary power unit. Since the publicity in *Aviation Week* compromised the term, the AEC issued instructions on 27 October 1957 to all field offices and contractors involved in the AEC part of the program to discontinue using the code name. The unclassified title "Systems for Nuclear Auxiliary Power," or "SNAP," became the authorized reference for AEC's work on nuclear auxiliary power units.²⁶

Technical work on SNAP devices went on, perhaps in an atmosphere of greater urgency—not so much due to immediate mission needs, but because of the challenge to American technological capabilities that Sputnik represented. The nation was caught up in self-doubt and questioning such as it had never known in the modern age. New institutions were being created to revitalize American science, especially space science. President Eisenhower, after presiding over a confident if turbulent era in the 1950s, was besieged for answers about the apparent decline in America's preeminence in modern technology.

In response to this concern, Eisenhower created a President's Science Advisory Committee in November 1957, with James R. Killian becoming the first Science Advisor in the Executive Office of the President. Killian described the atmosphere of that time as America strove to recapture lost prestige:

On December 6, the first test of the US *Vanguard* space vehicle, carrying a three-and-one-half pound satellite, seemed to the world an ignominious flop. This spectacular failure, coming as it did after the successful *Sputnik II*, increased the hysteria and embarrassment in the United States and the ridicule abroad. In England, the press revelled in caricaturing *Vanguard*, calling it, among other things, *Puffnik*, *Flopnik*, *Kaputnik*, or *Stayputnik*.²⁷

Later that month, however, Killian prepared a memorandum for the President containing the judgment of a Science Advisory Committee panel chaired by George Kistiakowsky. Taking on the implications of competitive space (and therefore missile) capabilities in light of the Russian *Sputnik*, the panel expressed the judgment that “technically our missile development is proceeding in a satisfactory manner,” and although the United States was behind the Soviets in the space race, having started much later, the nation’s technological progress in the missile field was, in fact, “impressive.”²⁸

Another panel of the Committee recommended outlines of an American space program and the organization to manage it. As a result, NASA was established in July 1958 to conduct civilian aeronautical and space research. The first administrator of NASA, Keith Glennan, recalled the subdued tone of the president as he asked Glennan to take on the task of furthering America’s advances in space science and technology:

The meeting with President Eisenhower was brief and very much to the point. He stated clearly his concern over the development of a program which would be sensibly paced and prosecuted vigorously. As I recalled it, he made no mention of any great concern over the accomplishments of the Soviet Union although it was clear that he was concerned about the nature and quality of scientific and technological progress in this country.²⁹

To calm the public concerns and deflect Department of Defense strategies to mobilize U.S. space efforts primarily on a military basis, the president and his advisors set a course for civilian leadership in space. The president sought to further calm matters in the international nuclear contest by announcing, in August 1958, a moratorium on nuclear weapons testing to begin October 31 of that year.

Soon after it accepted the space nuclear assignment requested by the Defense Department, the AEC began parallel power plant efforts with two private corporations: odd-numbered SNAP programs using radioisotopes were spearheaded by contractual work at the Martin Company; even-numbered SNAP reactor power systems were developed through contractual work with the Atomics International Division of North American Aviation, Inc. The work by the Nuclear Division of Martin-Baltimore progressed through an early SNAP-1 effort to use the decay heat of cerium 144 to boil liquid mercury and drive a small turbine. In the course of following this development path, the Martin Company also let subcontracts to develop generators that would not require rotating equipment and the introduction of gyroscopic action to space vehicles. In 1958 work began on two thermoelectric demonstration devices at different companies, Westinghouse Electric and Minnesota Mining and Manufacturing (3M), while AEC contracts with other companies explored the development of demonstration thermionic units.*

The program to develop advanced energy conversion techniques that did not require rotating equipment (as in SNAP-1) was given the designation SNAP-3. It yielded results quickly; the 3M Company delivered a workable thermoelectric generator to Martin in December 1958. Using polonium 210 (capsuled by Mound Laboratory), the generator, quickly assembled and tested by Martin, was delivered to the AEC as a proof-of-principle device, producing 2.5 watts with a half charge of polonium 210 fuel. The AEC thus had at hand a capability for producing units that would generate 120 watts of electricity continuously for a year.³⁰

Echoes of “Atoms for Peace”

President Eisenhower, shown this breakthrough in the quiet technology in January 1959, was eager to share the success story with the American public and the world at large. There was a sense of calm and composure about the debut of the proof-in-principle RTG. The event around President Eisenhower’s desk emphasized “peaceful uses” for this technology. The president’s eagerness to display the device openly testified to such purposes and provided an

*Thermionic conversion is the transformation of heat to electricity by the process of boiling electrons off a hot surface and collecting them on a cooler surface.

opportunity to issue a challenge to NASA, then a fledgling civilian space agency, to develop missions appropriate to the potential of the device. The small package that was the RTG appeared and was represented as harmless and non-threatening.

Perhaps the president saw an opportunity to use this example of American technical capabilities to publicize calming themes for space research much as he attempted to tone down the nuclear contests throughout the decade. Eisenhower attempted early in his first Administration to turn world attention away from nuclear confrontations and toward peaceful uses of atomic energy. His "Atoms for Peace" address to the United Nations came in his first year in office. The Atomic Energy Act which soon followed made possible private development of nuclear power in the United States, and at the close of Eisenhower's first term the AEC made large amounts of U-235 available for use in power reactors in the United States and abroad. * President Eisenhower showed great determination throughout his Presidency to turn nuclear science and technology away from international confrontations and races for technological superiority. On the threshold of a new international race—the quiet nuclear technology was not a powerful booster for such a race but a tool for sustaining people and their machines in the space ventures, whatever the purposes of those ventures. The momentum of a race eventually would open the greatest opportunities for applications of the quiet technology.

*Sales of radioisotopes at Oak Ridge National Laboratory increased from 5,389 curies at the beginning of Eisenhower's Presidency to nearly 150,000 in the first year of his second term in office.³¹

Chapter III

Recognition of Potential

A Time of Transition: 1960-1961

Throughout his eight years in office, President Eisenhower strove to project attitudes of calm and of confidence in the future, but events worked against him. Early in his first term, the nation's sense of innate superiority was weakened by the realization that the Korean conflict was ended by a negotiated settlement rather than a clear cut military victory. Nine months into his second term, that sense was severely shaken by Russia's orbiting of Sputnik I. At that point, Eisenhower had already initiated programs to revive scientific, technological and organizational energies. In 1955, for example, he had approved plans for launching an American satellite as part of U.S. participation in the International Geophysical Year. After Sputnik's launch there was a greater appreciation of the political significance of such accomplishments.¹ Existing programs were accelerated and new ones undertaken. Eisenhower saw the need to match and surpass these achievements. He saw also a need to prevent the U.S. response to this challenge in space from being equated by other nations as being limited solely to military needs and objectives.² It was to avoid this interpretation that from the outset, in planning for NASA, the emphasis was on scientific objectives, and on the peaceful, civilian pursuit of scientific goals.

Homer Newell, a NASA administrator, and later an historian of the agency, wrote of the circumstances that helped shape its mission:

A majority of those who would finally make the decision soon became convinced that the most effective way of proving U.S. leadership in space would be to demonstrate it openly. Moreover, a space program conducted under wraps of military secrecy would very likely be viewed by other nations as a sinister thing, a potential threat to the peace of the world. . . . It seemed important, therefore, that the U.S. space program be open, unclassified, visibly peaceful, and conducted so as to benefit, not harm, the peoples of the world.³

NASA's philosophy was thus in accord with the President's reservations about the power of the nation's military-industrial complex. He "was not disposed to foster further growth by adding still another very large, very costly enterprise to the Pentagon's responsibilities."⁴

The content of the space program of the new civilian space agency was not specifically prescribed by Congress in the NASA Act passed in 1958. The charter provided only the framework for coordination and cooperation between NASA and other agencies. Under its first administrator, the new agency moved vigorously in the direction of a civilian space science program, setting "a strong but measured pace," according to Newell. The pace on serious commitments to a lunar science program was slow at first, and "Glennan for a while showed a reluctance to discuss planetary missions except as plans for later, for the more distant future."⁵

On the nuclear side of the nation's space efforts, two important aspects were forcefully addressed in that transition year of 1960: safety problems and organizational needs.

A few months earlier, the AEC had established an Aerospace Nuclear Safety Board "to analyze and project the possible effects of nuclear space devices upon the health of the peoples of the world...and recommend standards of safe practice for the employment of nuclear powered space devices proposed by the U.S."⁶ In May 1960, Glennan and AEC Chairman John McCone assessed the problems of safety along with the potential benefits in the use of nuclear components in space programs. In that early speculative period, Glennan wrote:

In respect to the use of nuclear sources for power generation in spacecraft, it is our belief that for certain missions the use of nuclear components may be the only way in which the mission requirements can be fulfilled.... Here again, however, there is considerable question as to the acceptability of the hazards involved. The hazards to personnel and equipment on the surface of the earth, the radiation problem incident to manned space flight, the interference with experimental measurements in spacecraft, and the radiological contamination of extra terrestrial bodies, are all moderating influences on the use of nuclear systems.⁷

Glennan suggested that the AEC begin to define the conditions for safe use of nuclear auxiliary power systems in space missions and propose the safeguards which would have to be provided. He assured McCone of NASA's willingness to work closely with the atomic agency on these matters.⁸

In August 1960, the two agencies formalized arrangements for working together more effectively on all aspects of space nuclear efforts. A "Memorandum of Understanding between Atomic Energy Commission and National Aeronautics and Space Administration" affirmed "that Mr. Harold Finger will serve as the manager of the joint AEC-NASA project office and Mr. Milton Klein will serve as the deputy manager."⁹ The new joint AEC-NASA Nuclear Propulsion Office reported to the Director of the Division of Reactor Development in the AEC and to the Director of Launch Vehicle Programs in NASA. As joint office manager, Finger wore two hats: he headed the joint office of nuclear propulsion and retained direction of the NASA office for space power. Finger thus exercised responsibilities for integrating AEC-developed RTGs into any NASA missions.

Both the early safety concerns and the organizational effort to bring the AEC and NASA together for joint efforts in the space nuclear field had enduring effects on the future of nuclear auxiliary power and the progress of the quiet space-nuclear technology. Safety concerns led to new organizational mechanisms for handling and anticipating safety problems as opportunities were sought to prove the usefulness and value of isotopic technology in space. At the same time, the new joint AEC-NASA Office, while it dealt with nuclear *propulsion*, prepared the way for merging the SNAP program with NASA projects. NASA's missions eventually came to lead in using RTGs for power in space.

The nuclear propulsion effort, designated Project Rover, now came under the single management of the new joint AEC-NASA office. The SNAP program continued as an AEC effort in the agency's Division of Reactor Development. When the AEC-DOD Aircraft Nuclear Propulsion Office (ANPO) was disbanded, its director, Armstrong, became Assistant to the Director of the Division of Reactor Development at AEC. Lieutenant Colonel G.M. Anderson, formerly SNAP project officer in ANPO, became chief of the SNAP Branch in the new division.

Before the momentum of the race into space increased, the SNAP program, particularly its quiet technology, was developing momentum of its own. At the

end of the Eisenhower Administration, radioisotopic power stood on the threshold of its first mission applications. The RTG technology was ready. Its proponents were looking for opportunities to put it to use. On Capitol Hill, in JCAE hearings, the pressure was on Project Rover. Committee members pressed for a flight schedule that would test nuclear propulsion in space.

The JCAE was also manifesting an interest in the SNAP program and its potential for providing long-lasting power to expensive satellite systems. In early 1961 hearings on "Development, Growth and State of the Atomic Energy Industry," JCAE Chairman Holifield told AEC officials that some committee members felt the SNAP program promised a payoff in continuing performance, perhaps for a year or two, from satellites costing hundreds of millions of dollars. Asked by Holifield if he was satisfied with the way the SNAP program was going, the Director of the Division of Reactor Development, Frank R. Pittman, replied: "As far as the technical aspects of the SNAP program are concerned, I am satisfied that it is . . . progressing quite well." Pressed, however, for information on whether progress had reached the establishment of requirements by user agencies, Pittman replied that such requirements had been established at that point only for certain even-numbered (reactor) SNAP systems. "We have requirements on the SNAP 2, the SNAP 10, and SNAP 8, with time requirements for testing."¹⁰

Potentials and Precautions

The SNAP-3, which was demonstrated to President Eisenhower in 1959, later came to be known as "the salesman of our working SNAP devices."¹¹ The first proof-of-principle SNAP was shown at several foreign capitals as part of the American "Atoms for Peace" exhibits. Reactions from academicians and students attending seminars held in conjunction with the exhibits were highly positive, although sometimes questions regarding safety were raised.¹²

In the U.S., one of the first public expressions of concern followed the demonstration in Eisenhower's Oval Office. According to George Dix, then responsible for safety at the Martin Company's isotope power project, and later head of the total space nuclear safety program under Finger at the AEC, nuclear critic Ralph Lapp complained that a highly lethal item had been placed on the President's desk. RTG engineers were attuned to reactions regarding safety and in a matter of days they developed a safety evaluation which

apparently satisfied Lapp. The report, which covered handling procedures and all other matters regarding the safety of RTGs, thereafter accompanied SNAP-3 when on display in foreign capitals.¹³

Dix also pointed out that it was President Eisenhower who pressed for the use of the new technology in space satellites as soon as possible. According to Dix: "This successful demonstration came along about the time we had lost a Vanguard on the pad. Ike said, 'Let's fly this thing. [The Russians are] beating us on other things. Let's beat them on power.'"¹⁴

During 1960, technical journals continued to make a case for nuclear auxiliary power in space, but they also expressed reservations over the safety factor.¹⁵ Despite the president's enthusiasm, the first RTG flight came two and a half years after the White House demonstration. The prevailing attitude was summed up by *Nucleonics*: "Isotopic Power Ready for Space But Caution Delays Use." Describing the comprehensive safety program of the Martin Company for SNAP-3, the journal noted that the "devices are being designed so they will remain sealed in any abort prior to leaving the earth's atmosphere but...will disintegrate to molecular-size particles on re-entry." These particles were described as so small they "will reside in space until long after the contained radioactivity has decayed to meaningless levels."¹⁶

Despite the conscientious safety programs at AEC and NASA, the Defense Department continued its preference for solar devices over isotopic power because the former presented no radiation problem. A series of solar device failures, attributed to leakage of storage batteries, forced a reconsideration of this policy. A need was seen to rely on isotopic power while industry worked at perfecting solar cell batteries. One unmanned source at DOD's Advanced Research Project Agency was quoted as saying RTGs could be "here to stay, particularly for missions where there is no sunlight."¹⁷

The AEC approach was to face the safety issue head on and to take steps to systemize safety reviews and safety procedures shaped to criteria that left no apparent margin for error. These criteria were developed in June 1960 at a three-day meeting of the AEC's Aerospace Nuclear Safety Board,¹⁸ and spelled out in a September 1960 report to McCone. The criteria for the safe use of radioisotopic units, according to the report, provided that:

The isotope material should be contained and the capsule present no hazard in the event of a launch abort.

The above conditions should obtain in the event of failure to reach orbit, and in addition the capsule should fall in broad ocean areas.

In the event of failure to obtain a stable orbit, or in re-entry from a successful orbit for any planned time, the capsule and contents should be burned and dispersed in the upper atmosphere.¹⁹

Citing results of tests already conducted, the Board indicated that a definitive program of further tests was being planned. An initial step in this program would involve placing pods on Atlas test vehicles launched from Cape Canaveral.²⁰

At the end of 1960, the Chairman of the Aerospace Nuclear Safety Board, Lieutenant Colonel Joseph A. Connor, Jr., of the United States Air Force, announced an AEC position on safety in the nuclear space program. Addressing the Atomic Industrial Forum, he stated that SNAP isotope and reactor devices had been thoroughly tested and found capable of burn-up on re-entry into the atmosphere at speeds above 24,000 feet per second, for a burn-up time of 300 seconds or more. Connor concluded: "the use of nuclear powered devices sufficient to meet all space requirements expected to be developed by 1980 would release but a small fraction of the radioactivity considered by the Federal Radiation Council to be tolerable for the general population."²¹

Firming a Base for Accelerated Space-Nuclear Achievements

President Kennedy had defined sharp views on new approaches to atomic energy and its control in the international arena at the outset of his Administration. Glenn Seaborg, then Chancellor of the University of California at Berkeley, recalled being in the university's Radiation Laboratory on 9 January 1961 when President-elect Kennedy called to ask him to accept the post of Chairman of the AEC. Upon his acceptance, Seaborg found himself "plunged into a new kind of chemistry, that of national and international events."²²

Seaborg was to find out that President Kennedy wanted a scientist as the AEC Chairman, and although he wanted a Democrat for that job, he was not interested in the party affiliation of those named to fill the other senior level positions within the agency. "I felt my job as chairman was nonpartisan," said Seaborg, and he added that it became clear to him that in the nuclear field the new president wanted most to mobilize the scientific community and involve its

members in the pending crucial decision on atomic energy.²³

Seaborg's heading the AEC proved a boon to the isotopic power program. In the course of his career prior to entering government he had been involved in the discovery of plutonium and many of the transuranium elements. He was co-discoverer of certain isotopes, including Pu-239 and U-233. As the AEC Chairman, he kept abreast of developments in isotopic power, arranging to be briefed on RTG programs soon after his arrival at the agency.²⁴

Together with Seaborg, another man crucial to a growing space-nuclear partnership was James Webb, who was called on by the Kennedy Administration to head NASA as it stood on the threshold of the space age. Webb had held several key administrative positions in Washington. He had been Executive Assistant to the Secretary of the Treasury in the early Truman years, and the Director of the Bureau of the Budget when the AEC was formed. In 1952 he had served as Undersecretary of State. Noted for his expertise in administration, Webb saw the New Frontier being faced by NASA as a venture in both space science research and development and administrative research and development.²⁵

When it was behind him, Webb saw the experience at NASA as a lesson in the role of political factors in essentially scientific programs. He observed that:

If NASA program managers, scientists, engineers and top officials had not thought of their work in political... terms... if they had not arranged their activities to gain support from other NASA divisions, Congress, the Bureau of the Budget, the scientific community, etc.—Apollo would not have met its goals...

...political relationships are not... something added on to the work of line managers or program officials as less important than other duties; these relationships are an integral part of their work, inasmuch as personal relationships and a sensitivity to the total environment are essential parts of leadership responsibilities if the system is to work at all.²⁶

A second basic lesson was the importance of being able to adapt to continuous change. This, Webb found, was permitted by a feedback mechanism in the form of an executive secretariat established at NASA* to provide senior

*The secretariat at NASA consisted of Administrator Webb, his Deputy Administrator, Hugh Dryden, and Associate Administrator, Robert Seamans, Jr.

management with reliable information, as well as the systematic exchange of officials between headquarters and decentralized offices. In addition to keeping senior management on top of things, the executive secretariat worked to insure a flow of information to other levels so that all NASA employees could grasp with greater clarity their specific roles in the accomplishment of established missions.²⁷

Webb and Seaborg had not been close associates before they accepted their assignments in the Kennedy Administration. Seaborg met with Webb on his first Sunday after arriving in Washington and recalled that the two "hit it off from the start."²⁸ Their working relationship strengthened as they ushered their agencies' joint programs through many congressional hearings on Capitol Hill and through budget sessions within the Executive Branch.

Webb recalled that soon after his assignment at NASA there were pressing problems with the military which required immediate resolution. The Pentagon had not given up completely on its desire to be the lead agency in the space program. It saw the inauguration of a new president as a possible opportunity to swing the space effort from NASA to the Air Force. Defense Secretary McNamara, however, felt NASA should keep the space program, and key scientists around the country backed this support for civilian control.²⁹ McNamara's position was consistent with NASA's mandate by the Space Act to develop extensive relationships with universities and corporations and undertake a major cooperative effort to develop the scientific, technical, and administrative capabilities of the nation and its institutions. NASA was also mandated to share this effort with other nations, and therefore wanted the space program to be as open and non-secretive as possible. Webb later explained that he wanted to be able to "say to the press and the scientists and engineers of the eighty nations cooperating, 'Come and bring your camera.'"³⁰

The "open" approach of NASA would lead to some problems in AEC-NASA relationships, since the mandates and the traditions of the two agencies differed in significant ways. A firm basis for cooperation was set by the two men who headed these agencies. The need for cooperation increased greatly once President Kennedy announced his challenging goal for space.

It was four months after Kennedy assumed the presidency before he stirred the nation with his startling and exciting goal of landing a man on the Moon by

1970. Seaborg recalled that he was present by special invitation³¹ when the president, in a special message to Congress on 25 May 1961, announced:

Now it is time to take longer strides—time for a great new American enterprise—time for this nation to take a clearly leading role in space achievement, . . . I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to earth.³²

Webb understood the significance of a “race” to put a man on the moon and he welcomed Kennedy’s introduction of this concept. “It meant we had a target. I kept reminding Congress that we were committed to putting a *man* on the Moon and to demonstrating our technical capabilities in that achievement. Getting to the Moon would be proof positive that we had developed our capabilities in a full range of disciplines. If we could get man to the Moon and back with our technology, we could do anything.” There were times, however, as NASA’s program and budget quickly grew, when President Kennedy would question whether the full range of NASA’s activities was necessary to carry out the landing on the Moon. “I told him we have to bring along the universities and the other institutions and push the total concept of development,”³³ Webb recalled. One NASA task was to orchestrate the combined efforts of many universities and other institutions whose common goal was to make the fantasies of centuries become a reality within a few short years.

It was in the first year of the race to the Moon that the quiet technology got its chance to take its steps into space. Its proponents were impatient, but they too were learning about the importance of the chemistry of national and international events combining with technology in a total environment.

First Success in Space

The first successful use of RTGs in space occurred in a Navy satellite program. The Navy’s Transit program had been underway for some time. It was a system for orbiting a navigation satellite that would provide accurate sightings for ships and planes in all weather conditions. The effort began at the Applied Physics Laboratory (APL) of Johns Hopkins University in 1957. The first link between the Transit developers and the isotope people at the AEC

(and their Martin Company contractors) came about almost fortuitously, as John Dassoulas of APL recalled.

"I had been looking into the possibilities of isotopic power since we first began the Transit program. We had a five-year goal for the life of the operational Transit, and we weren't confident that the hermetic seals on batteries would hold up for five years. But I wasn't aware of the SNAP program at all."³⁴

In 1958 the Department of Defense sponsored a big meeting in Pasadena, California about space (satellite) power. Dassoulas attended the conference but did not meet with any of the nuclear power people until, on his return flight, he found himself sitting next to Anderson, who headed the isotope SNAP work at the joint AEC-DOD office. Anderson responded to Dassoulas' expression of interest in isotopic power for the Transit program with an invitation for him to visit the Martin Company's Baltimore facility and to become acquainted with the work there on SNAP.³⁵

Following the visit, Dassoulas returned to APL and asked for and received permission to use an isotopic SNAP device on Transit. Plutonium, however, was then unavailable because of AEC restrictions, and APL refused to permit the use of strontium-90 because of the excessive weight of the necessary shielding. The AEC eventually relaxed its policy and agreed to provide the plutonium fuel and SNAP-3A, as a result, was converted from polonium-210 to plutonium-238, permitting a power life of five years.³⁶

At the request of DOD a development program was initiated by AEC in February 1961 "to provide two plutonium-238 isotope-fueled generators for TRANSIT satellites to be launched in June and July." The AEC, looking beyond the Transit mission itself, held that "a primary purpose of the flight test is to demonstrate the performance of a SNAP...generator under actual space conditions."³⁷

Tests for the safe use of SNAP devices on Transit had been conducted the previous fall. The next spring "safety" remained a critical issue, although both the Transit people at APL and the RTG people at the AEC and Martin looked forward hopefully to a chance to fly the isotopic generator. The planned trajectory of the launch vehicle from Cape Canaveral was to take the Transit over Cuba and South America. This added further qualms to those advising caution because of anxiety about possible Cuban reactions to a fly-over after the Bay of Pigs incident.

In March, the Martin Company completed a comprehensive safety analysis of the Transit generator, focusing on potential hazards that might result if launch or re-entry failures were to occur. Martin concluded “that if the radio-isotope generator considered is launched in the trajectory proposed for Transit vehicles, it will not produce a significant radiation hazard.”³⁸

In April, there were impact tests against granite at the Aberdeen Proving Ground to assess whether isotope containment would be maintained in the event the core experienced a crash landing.³⁹ That same month a hazards analysis report was prepared by the Division of Licensing and Regulation.⁴⁰ Later in the month this report and the Martin final safety report were shared at a joint meeting, attended by Navy, Air Force, DOD, and AEC personnel, where agreement was reached on the responsibilities of the various agencies.⁴¹ In May, Seaborg and his fellow commissioners undertook extensive efforts to ensure the SNAP-3A’s launch would be approved. Commissioner John Graham, Acting Chairman of the AEC, wrote to McNamara seeking his support and urging him to intercede at the State Department with Chester Bowles, who had expressed concern about the Transit trajectory over Cuba and South America.⁴²

Seaborg’s May 6 bi-weekly report to the president announced the AEC’s approval of the SNAP-3 devices on pending Transit launches. His report urged Space Council and presidential approval of the missions, citing the findings of the hazards study that “any danger to the public is extremely unlikely.” Seaborg told the president: “I call this to your attention since this first application of a nuclear auxiliary power source in space is likely to have a wide public impact.” He then outlined the suggested procedures for a joint submission of the proposed plan by AEC and DOD to the Space Council for review. Were that not feasible, he said, a meeting could be arranged with Secretary McNamara, Secretary Rusk, and himself. Seaborg concluded: “It may be necessary to present the matter to you directly for your approval.”⁴³

In spite of Seaborg’s efforts, the plan for a SNAP-3 demonstration on the forthcoming Transit launch was rejected by the National Aeronautics and Space Council, primarily because of objections from the Department of State. The Department of Defense, however, reassured Seaborg that it expected “provision will be made for a SNAP unit to be included in the next TRANSIT shot after the one scheduled in June.”⁴⁴

Reporters were quick to pick up on high-level government concern over

radioactive material in space. On 16 May 1961, the *New York Times* pointed out that “cautious officials” had split with scientists on use of nuclear devices and that the “problem confronting the Administration...is not so much a technical decision as one of diplomatic, political and psychological considerations.”⁴⁵ On May 19 the *Times* was more specific about the misgivings in certain U.S. government agencies—one article indicated that concern was evident at high levels. While officials believed the vehicle to be safe, concern had arisen, particularly in the State Department, “that in event of an unsuccessful launching, the satellite, with its radioactive parcel, could fall on Cuba or some other Latin-American country” provoking an international incident. Even a successful launch could lead Latin-American countries to “take offense about having radioactive materials flown over their territory.”⁴⁶

In early June hopes of the RTG proponents were high again; and throughout the month, right up to the June launch of Transit-4-A, hopes rose and fell. On June 8, Seaborg reported that he hoped for a reversal of the Space Council's decision but that he was not optimistic that a reversal could be achieved.⁴⁷ By June 23, however, hopes were high as Gilpatric of DOD told the AEC that the Defense Department was making a last attempt to get the State Department to go along with using the SNAP-3 device on Transit-4-A, scheduled for launch on June 27. Finally on the 23d, word came from Gilpatric that approval had been received.⁴⁸

At the working level, perceptions of how it all came about varied. Robert T. Carpenter of the AEC thought that Seaborg asked the JCAE to intercede with the Space Council. Dassoulas believed that the go-ahead came about because Seaborg had dinner with President Kennedy one evening in June and persuaded him to approve the mission. All agreed that lead time was short and the situation hectic as the small RTG team found ways to get their device on the vehicle at Canaveral on time for the scheduled launch.⁴⁹

According to Dassoulas, a fueled SNAP-3A device had already been shipped to the Cape sometime in June when, because of fears it might be launched without approval, an order came: “Return that thing to Washington and store it at the Martin Company.” When the last-second go-ahead was received, the little team scurried to meet the deadline. “One of our people was a Marine Corps pilot, and he checked out a small plane so that he and Carpenter could fly that

RTG out of Andrews to the Cape,”* recalled Dassoulas. The device was kept overnight at the APL in Laurel, Maryland, after Carpenter obtained it from Martin. “We decided he should just bring it over here to APL in his car. I met him in the lobby and we put it in one of the labs, with the rooms on each side vacated.” The guards were all instructed what to do and how to handle safety and security. The generator was in Florida the following evening, flown down by Carpenter and the pilot.⁵⁰ Finally, on 29 June 1961, after a 24-hour launch delay, a Thor-Able rocket launched three satellites simultaneously—including the first orbiting of an RTG in space.

Thus, two-and-a-half years after its debut on President Eisenhower’s desk, the quiet technology made the front page headlines again. The *New York Journal American* of Thursday, 29 June 1961 announced:

U.S. ORBITS ATOMIC BATTERY

According to the newspaper “The successful orbiting of the nuclear device... gives American scientists a significant lead over Russia in the race to harness atomic power for space exploration.”⁵¹

The AEC made efforts to capitalize on that first space-nuclear success by announcing in September that the “World’s First ‘Atomic Battery’ In Space Continues to Operate Successfully” after ten weeks in orbit.⁵² In October, Seaborg promoted the atom in space and advocated future applications of nuclear power in space before an international symposium of space scientists and engineers looking back on the success of SNAP-3A on Transit:

The presence of the ‘atomic battery’ in the satellite is a symbol of a ‘marriage’ that was bound to occur—between Space and the Atom. We have known for some time that the two were made for each other. No one would be tempted, at the present time, to abandon other sources of energy for space. However, the atom has made greater strides toward coming of age for space application in the past few years than many of us could have hoped. The day is not far off when atomic energy will be available in many different packages for practical use in space vehicles.⁵³

*Both Carpenter and Dassoulas recalled that the device was flown to Florida on Saturday for an expected Sunday night launch which was delayed until Monday night. Official records show, however, that the launch occurred on Thursday 29 June 1961.

As plans went forward for a second SNAP launching on another Transit in November, the political and environmental lessons learned were being applied. Seaborg addressed a letter to Vice President Johnson, who also served as chairman of the Space Council, lauding the Council's role in the June launch. He provided information about the new launch mission, and he said that he was anticipating that the Space Council would again play a critical role.⁵⁴ The Vice President replied that he was appreciative of this reference to the assistance of the Space Council in the June 29 launch and that the Executive Secretary would be asked to perform the coordination necessary for inclusion of a nuclear power source in the Transit-4-B launch.⁵⁵

A second successful launching of a SNAP-3A, aboard a Transit-4-B navigational satellite, took place on 15 November 1961. The RTG team, this time with plenty of lead time and operating without the uncertainties of the pioneering launch, was ready at the launch pad. In the wake of this success would come a period of search by this small team for opportunities for the RTGs, which now had demonstrated their capabilities as power sources for space missions.

Chapter IV

Golden Days at the AEC

A Close Community

Many of the original RTG team thought of the early years after Seaborg came to the AEC as the “golden days” of the AEC—before the big and costly space systems and missions of NASA involved increasingly large numbers of people and organizations in the RTG program.

From 1962 to 1965, the antinuclear movement was not yet vociferous, the future of nuclear power and its widespread uses looked promising, and the chairman of the AEC was a scientist who believed strongly in nuclear power and its wedding to space ventures. Moreover, Seaborg inspired loyalties and a sense of common purpose in the people of the AEC.

Carpenter* recalled that it was common to meet the top man in the halls at AEC’s Germantown building and to be greeted by name and asked questions about the program: “We had a personal relationship with Seaborg, and we also had a close arrangement with the Commissioners.” He added that problems on the Hill were few and that the program received support from both the AEC and the Congress, whose members pressed for a flight schedule on space nuclear propulsion, eager to see the SNAP-isotope technology get its chances to fly. In those years, according to Carpenter, the AEC allowed engineers to do everything from start to finish on their programs—at least on the small isotopic power program. The RTG group chose to have just a few hands holding all the reins. Carpenter recalled: “I prepared budget documents, defended them before Congress, ran my program and participated in the launches.”¹

Carpenter explained that few contractors were involved in the early days because the program was small and there wasn’t a great deal of money available for space-isotopic power development. He indicated that SNAP-3 was built on a purchase order from the Martin Company to the 3M Company

*At that time head of the isotope office of the SNAP program under Armstrong, who reported to Pittman, director of the Reactor Division at AEC.

for a very small amount. Martin got involved in isotopic power, while others held back, because “they were into space in a big way and their programs were long range. A lot of other firms that got involved later came in when there was more money in the budgets. Like when we got going on Apollo.”²

In the initial development period, the circle was limited, encompassing the small group at the AEC and small groups in other institutions: the isotope power experimenters and developers at Martin-Baltimore and their subcontractors at 3M; the fuel packagers at Monsanto’s Mound Laboratory; and users such as the Applied Physics Laboratory of Johns Hopkins University which developed the Transit navigational satellite system for the Navy. This team proceeded to develop the SNAP-9A with its increased power requirements for the operational Transit scheduled for flight in late 1962. At the same time, a series of SNAP-7 devices were under development at Martin for use by the Navy, Coast Guard, and Weather Bureau for navigation lights and weather stations on earth.

NASA began to enter into contracts with the AEC to study possible applications of isotopic SNAPs to future space missions. Even before Apollo, NASA recognized that there would be unusually severe power system requirements for lunar missions “due to the weight and space limitations of payload, the 14-day lunar nights, and the variety of the intended experiments.”³ By the fall of 1961, NASA reconfirmed its requirements for an isotopic power unit for the Surveyor soft lunar landing mission and the AEC prepared to provide two SNAP devices—designated SNAP-11s—to NASA for missions scheduled to take place two years later.⁴ In mid-1962 NASA began preliminary discussions with the AEC on the possibility that an RTG could provide primary power requirements for one of a series of satellites called Interplanetary Monitoring Probes. Along with foreseen technical advantages, NASA hoped to use the RTG to enhance its own “capability and experience in the use and application of nuclear devices.”⁵

Reporting to the JCAE in September 1962 on space nuclear power applications, Commissioner Hayworth of the AEC stated “Nuclear power not only will enhance space exploration; its use, both for propulsion and for auxiliary power, is the key to extensive outer space exploration.” He reviewed the developments and tests in the Rover program to develop nuclear rocket propulsion and admitted that there had been disappointments causing delays. Turning to the

isotopic power side of the SNAP program, Hayworth reported with “considerable satisfaction” on program successes: launchings in June and November of the previous year of isotope power devices on Navy Transit navigational satellites. Looking to the future, he said, “We are continuing to work closely with DOD and NASA to satisfy their requirements for space SNAP devices, and... we have developed a plutonium 238 fueled 25 watt unit, SNAP-9-A, for use in the Navy’s operational prototype Transit satellites.” Hayworth also spoke of the work with NASA on the development of the SNAP-11, a 25-watt curium-242 fueled thermoelectric generator planned for powering the Surveyor soft landing lander.⁶

Thus NASA readied itself for the time when it would become the major user of the isotope units and the small RTG group would open its membership to growing numbers of people and organizations.

A Climate of Renewed Determination and Hope

Great Power confrontations affected the RTG program. The Soviets broke the nuclear atmospheric test moratorium that had been honored by the United States, Great Britain, and the Soviet Union since November 1958. President Kennedy ordered the resumption of underground testing. In April 1962, while the nation still hailed the triumph of John Glenn’s first orbit of the Earth by an American, the president authorized the resumption of atmospheric tests off Christmas Island. The tests provoked considerable adverse public reaction around the world as well as at home.⁷ The Cuban Missile Crisis in October marked the height of international tension. By the summer of 1963, Kennedy seemed determined on a course that would bring the Great Powers back from the brink of war and start them on a road of cooperation, at least on the issue of nuclear testing. Perhaps benefiting from international tensions, NASA and AEC research moved ahead while Great Power confrontations unfolded.

In June 1963, the president chose the occasion of a commencement address at the American University in Washington, D.C., to lay out a new course for the Great Powers to follow in the search for peace and accommodation of their differences. Was peace possible? “Our problems are man made—therefore, they can be solved by man” the president believed. Was it possible to be at peace with an aggressive communist Super Power? “No government

or social system is so evil that its people must be considered as lacking in virtue." Moreover, the peoples of both countries shared a mutual abhorrence of war and had never been at war with each other. Finally, turning to arms control, the president made two announcements:

First: Chairman Khrushchev, Prime Minister Macmillan, and I have agreed that high-level discussions will shortly begin in Moscow looking toward early agreement on a comprehensive test ban treaty....

Second: To make clear our good faith and solemn convictions on this matter, I now declare that the United States does not propose to conduct nuclear tests in the atmosphere so long as other states do not do so.⁸

The discussions which began in Moscow in July led before the summer was over to a "Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under Water." This Limited Test Ban Treaty was approved by the U.S. Senate, 80 to 19, on September 24 and ratified by the Praesidium of the Council of Ministers of the U.S.S.R. on September 25.⁹

In a congressional reassessment of the nation's space program, the president's moves toward accommodation with the Soviet Union were seen not only as slowing the lunar race but also as undercutting overall support for the space program. In an address at the United Nations in September, the president proposed that the two Great Powers conduct a joint manned lunar landing program. Space technology advocates said this had "provided new arguments for further cuts in an already reduced space budget, and left the public puzzled as to whether Project Apollo still is an urgent national goal." *Aviation Week* expressed similar concerns:

President Kennedy has dealt his own national space program its hardest blow....

The immediate effects of the President's ill-conceived invitation to the Soviets to join the U.S. Apollo program are twofold:

First, it will provide congressional opponents of his space program with the well-sharpened ax they need to cut its Fiscal 1964 budget drastically and retard U.S. space progress even more than the restric-

tions of technical development . . .

Second, it will induce a psychological drag into the vast program that has just begun to build promising technical momentum. . . .¹⁰

By early November, the space journal pressed for a new national space policy and a Fiscal 1965 space budget “based on solid elements of national self-interest. . . .”¹¹ A week later Khrushchev put Russia back into the manned lunar landing race by his statement that Russia had not given up on its lunar program and that his previous statements of being ready to “consider” a joint manned lunar landing program had been misinterpreted.¹²

After Kennedy’s assassination, editorialists tended to stress the positives of this “truly modern president.” In his last major speech, at the U.S. Air Force School of Aerospace Medicine in San Antonio, the day before his assassination in Dallas, Kennedy related an anecdote of the Irish boys who, when in doubt about trying to get over an orchard wall on their treks across the countryside, tossed their hats over the wall and then had no choice but to follow them. The president had said: “This Nation has tossed its cap over the wall of space, and we have no choice but to follow it.” One editorial concluded that “when the first American astronauts return safely from the moon, as they surely will, we should remember that it was John F. Kennedy. . . . who tossed our caps over the wall of space and made us surmount it successfully.”¹³ The RTG program benefitted both from Kennedy’s support of technology and from the national optimism.

Other events competed for attention during the last summer and fall of the Kennedy Administration. The massive “March on Washington” against poverty, the rioting of blacks for their civil rights, and the repercussions of the assassination of President Diem¹⁴ of Vietnam predominated in the media. The next steps in moving the isotopic power devices toward space flight tests on an operational prototype satellite went almost unnoticed that fall. In late September, a Navy Transit 5B navigational satellite powered completely by an isotope power generator was launched from Vandenberg Air Force Base. Space journals in October¹⁵ briefly recounted this flight debut of the SNAP-9A. Clearly, the headline-grabbing days of the pioneering SNAP devices were over. A successful SNAP-9A launch on another Transit on 5 December 1963 did not even receive mention in either the space journals or the popular news magazines.

The Technology Goes Forward

On the first anniversary of nuclear power in space, AEC Chairman Seaborg reminded the public through the press of this historic milestone for the Atomic Age. The SNAP-3A device was still operating successfully after one year, its plutonium fuel, which had half a life of 90 years, had the potential for powering a space transmitter for decades. Seaborg projected this vision of future uses for nuclear power in space:

I firmly believe that nuclear energy provides the most feasible means of accomplishing long voyages in space and many other ambitious missions of our national space program. . . .

Because of the exciting panorama of applications, the development of nuclear energy for space is most important. Mankind is only on the verge of the space age. Nuclear power will take us into this age—and close to the planets.¹⁶

High hopes and expectations in Congress still rode with nuclear propulsion and space reactor power generators. The quiet technology already had proven itself and the AEC made plans to explore other possible applications for the RTGs.¹⁷

In late 1962, NASA's ten-year forecast of potential requirements for RTGs for space missions included Interplanetary Monitoring Probes, Orbiting Astronomical Observatories, and Nimbus—a satellite system for providing 24-hour weather coverage on a global basis.¹⁸ Preliminary work on RTGs for these systems began. Meanwhile, work proceeded on the SNAP-9A that would power the Navy's operational prototype navigational satellites. In the spring of 1963 Pittman, the head of AEC's Division of Reactor Development, reported to a Senate Committee that "...our most dramatic success has been with the relatively small isotopic SNAP devices...especially suited for space applications because they are able to operate under extreme environmental conditions of temperature and electromagnetic radiations, and are not dependent upon sunlight to generate power."¹⁹ The AEC *SNAP Fact Sheet* of 1 September 1963 set down program developments to that date:

The SNAP-7 program developed "prototype isotopic units fueled with strontium-90...for the Coast Guard and the Navy for use in coast

navigational aids, deep sea sonar devices and automatic weather stations.” All of the devices in this series were for terrestrial uses in severe environments.

SNAP-9A was under design for use by the Department of Defense in the operational navigational satellites—formerly Transit, which flew in 1961 SNAP-3As. The SNAP-9A, like the 3A, was fueled by plutonium-238 and was designed for a life of five to ten years. It generated 25 watts of electrical power and weighed 27 pounds.

NASA’s inquiries about using RTGs for Project Surveyor—the unmanned soft lunar exploration program—had led to work at the AEC on SNAP-11. This device, to be filled with curium-242, would weigh 30 pounds, and would provide “a minimum of 18.6 watts of power continuously for 90-day lunar missions.”

Also under development for the NASA Surveyor mission was the SNAP-13, which would demonstrate the feasibility of using an RTG in a cesium-vapor-thermionic-generator. This generator would produce 12.5 watts, in line with Surveyor requirements.

Under development for a classified mission was a SNAP-15—the smallest generator currently in the total program. It would use plutonium-238 and supply .001 watt of power for a design life of five years.

NASA’s interest in RTGs for the Interplanetary Monitoring Probe stimulated work on a unit similar to the 9A but allowing “for easier fabrication and lower system weight.” Designed for a satellite to chart the magnetic field between Earth and the Moon, these generators would produce approximately 25 watts and be fueled with plutonium-238.

Finally, the AEC noted that proposals had been invited “for development of an isotopic generator for space using strontium 90 as the fuel,” a device to supply electric power for the Medium Altitude Communications Satellite of the Air Force.²⁰ Contracts for these devices were awarded in November to General Electric and the Martin Company, and provided for conducting the first phase of a program assessing strontium-90 as a fuel for RTGs in space.²¹

Gradually other companies were drawn into RTG development, but the Martin Nuclear Division remained the major developer. Martin felt the tight funding squeeze of the program and the restrictions of "hardware-oriented research" even as the company extended its work to new devices for both DOD and NASA. In a briefing of the AEC Commissioners in late 1962, R.D. Bennet, general manager of Martin, complained that funding was limited, that the development of SNAP devices was restricted to specific missions, and that the program lacked a broad research and development effort that should be directed particularly toward increasing power-to-weight ratios and insuring reliability as power requirements increased.²² In retrospect, however, in spite of continuing complaints about lack of funding, proponents of the RTGs at the AEC realized that the strength of the program was in mission oriented research and development which focused on the requirements of specific missions.

Experiences in preparing for the launch of the SNAP-9A second generation RTGs during 1962 and 1963 were repeated many times in the following years as the developers of the quiet technology became accustomed to uncertain lead times and strove to be ready at the launch pads whenever the signal on a mission finally was "go." Changes in load requirements for the Navy satellites affected the converter design. Other problems arose in thermal cycling: in the course of long term vacuum testing, air entered into one of the units and oxidized the thermoelectric package. Moreover, the launch vehicle had been modified in October 1962 and a first launch date, originally set for December, was postponed to February and then to mid-May 1963.²³ Other postponements occurred. With launches finally scheduled for September, October, and November 1963, a process was instituted in August for receiving the Commission's and the president's approval for using the plutonium-238 fueled SNAP-9A generators on Navy navigational satellites flown out of the Pacific Missile Range.²⁴

In response to last minute disagreements regarding safety, information on safety was developed and provided to reviewers almost up to launch time.²⁵ Following the Commission's approval a few days before the first launch, the Space Council advised the AEC of the president's approval. An AEC press release on the late September launch announced that the Navy navigational satellite launched from Vandenberg was the "First To Be Wholly Powered By Nuclear Energy."²⁶ In early December another AEC press release was headlined

“Second Satellite Wholly Powered By Nuclear Energy Launched Recently; Operating Successfully.”²⁷ A February 1964 status report, however, recorded that useful doppler signals from the first launching were no longer being received, although the second SNAP-9A, launched two months earlier, continued to perform perfectly.²⁸

As plans matured for the launch of the third and last SNAP-9A in the series, attention to safety issues was even more concentrated. A mission abort occurred on that launch, indicating that this attention was well placed. Procedures and mechanisms for handling potential hazards had placed heavy demands on resources throughout the development and use of the RTGs. Safety procedures became highly formalized before the manned lunar flights which required larger power supplies and multiplied the potential hazards of mishaps.

Evolution of a Safety Program

Dix, Finger’s nuclear safety officer, commented “We always proceeded on the assumption that if we had one abort resulting in the release of radioactivity the program would be lost.”²⁹ Tom Kerr, who came to the Joint Space Nuclear Propulsion Office in June 1962 as NASA’s coordinator of safety reviews for all space nuclear systems, also reflected this determination to keep failures from destroying the program. Kerr documented the story of procedures for safety clearances following DOD and the AEC informal reviews of the two SNAP-3A launches:

In preparation for the SNAP-9A launches in 1963, an expanded review group and procedures were implemented. NASA was invited to participate in the reviews; although the launches were for DOD navigation systems. At that time the responsibility for these reviews was made a part of the responsibilities of the joint AEC/NASA Space Nuclear Power Office. . . . It was during these early reviews and launches that efficient and comprehensive review and approval procedures were developed.³⁰

Specialists were not prepared initially to work with the space nuclear environment. Procedures used for ground based systems could not be followed; the RTGs were lightweight and heavy shielding had to be avoided. Moreover, a number of situations had to be considered: launch failure on or near the launch

pad; re-entry following an unsuccessful launch; and short orbital lifetime leading to re-entry and terrestrial impact in unknown and uncontrolled areas. In addition, approval had to be obtained at the highest level. Kerr noted: "It was critical for the Department of State and the president and his staff to understand the potentials of these launches. The potential for political repercussions was great in case of failure with impact and possible fuel release on foreign territories."³¹

During the period of SNAP-9A preparations, representatives from the AEC, DOD, and NASA outlined areas and procedures for improving the consistency and efficiency of the review and approval process. They decided to use an *ad hoc* panel representative of the concerned agencies, rather than creating a standing interagency committee. One factor influencing this decision was that a standing committee which included public participation would have difficulties handling classified information. As early as January 1963 a model charter had been developed for a possible interagency review committee.³² Eventually the safety review panel was given the name "Interagency Nuclear Safety Review Panel" (INSRP). Although these panels were always newly constituted *ad hoc*, through many years of safety reviews Dix was the assigned AEC coordinator and Kerr the assigned NASA coordinator.

In the spring of 1964 a report to the Commission by the General Manager and the Director of Regulation set down an interagency safety review mechanism close to the one that eventually was adopted.³³ The procedures agreed upon relied on the creation of an *ad hoc* panel for each mission and included development of a public information package and safety report. These prepared packages anticipated the mishaps that might occur and contained appropriate safety information for distribution.

Basic considerations on safety began with the fuel used in the devices. The AEC selected plutonium-238 as the fuel for the first SNAP space missions because it emitted primarily "alpha" particles (the least penetrating type of particles) and had a relatively long half-life, could not support a chain reaction, and even in large masses presented no danger of nuclear explosions. The danger lay in its poisonous qualities if inhaled or ingested by living organisms. The AEC described the many tests, conducted on plutonium-238 fuel capsules for SNAP devices, that examined ability to survive launch pad accidents safely, to withstand impact, and to burn up on re-entry in the atmosphere.³⁴ Dix said: "We went with a 'burn-up on re-entry' concept in the early days because those

in authority believed that the release from a high altitude abort was an improbable event and if it did occur would only add a very tiny increment to the plutonium that was in the atmosphere from weapons testing.³⁵ The “burn-up” aspects of safety considerations, however, caused the most problems in obtaining approval for the 9A launches.

The Division of Licensing and Regulation of the AEC expressed strong reservations about the safety of the forthcoming SNAP-9A launches and challenged assumptions regarding burn-up on re-entry. It reminded the Commissioners that the SNAP-9A devices contained ten times the amount of plutonium fuel that had been flown in the SNAP-3A. These concerns were never completely dispelled even though the launch went ahead with Commission approval. Approval was accompanied by the acknowledgement that safety review by the Division of Reactor Development and the Division of Licensing and Regulation was to continue and that throughout the Transit series the Commission would be advised of any “untoward events” that occurred.³⁶

The failure of the third Navy 5B satellite to achieve orbit caused some flurry and placed pressures on the safety team. A.R. Luedecke, AEC General Manager, reported to Chairman Seaborg:

Preliminary data on the April 21, 1963 SNAP-9A abort indicate that the payload reached a high altitude (over 1000 miles) over the South Pole and re-entered over the Mozambique Channel at a steep angle. . . .³⁷

A press release from Seaborg reassured the public:

From previous safety analysis and tests it had been concluded the re-entry will cause the plutonium-238 fuel to burn up into particles of about one millionth of an inch in diameter. These particles will be widely dispersed. . . and would not constitute a health hazard.³⁸

There were few negative repercussions. In June the AEC Commissioners were reassured by Duncan Clark, Director of the AEC Division of Public Information, that “the USSR is the only country to voice reaction to the news of the SNAP-9A failure to orbit.”³⁹ The issue stayed alive; inquiries from U.S. Senators seeking information and reassurances were received and answered at the AEC as late as October.⁴⁰ In the fall a review of the failure of the April launch was presented to the Space Council.⁴¹ As results from high altitude balloon samples

continued to be received, the AEC prepared and distributed a reassuring press release stating that the recently collected data “clearly indicates that the fuel of a space nuclear generator burned up as expected last April after its spacecraft failed to achieve orbit.”⁴²

Carpenter remembered: “We looked at aborts as ‘good tests.’”⁴³ Dix recalled proudly: “We had done an analysis which spotted just where that RTG would go down—in the Mozambique Channel;” (he also indicated that this predicted burnup analysis had been published in the open literature prior to the launch).⁴⁴ Strengthened by the “test” provided by the 9A abort, the safety program went forward as an integral part of the growing technology. As Kerr explained, the safety program pre-mission reviews and tests contributed to the design of the SNAP devices and thus contributed to a phenomenal record of successful missions while also predicting and controlling the hazards from the few failures.⁴⁵

The 9A abort led to a change in the fuel form, according to Kerr.⁴⁶ Eventually, with larger radioisotopic fuel loads, the basic safety concept changed from burn-up and dispersion” to “intact re-entry.” By the time that new concept was integrated into an RTG-powered space mission, however, the mechanisms for interagency review and meticulous safety analysis were well established and in operation.

Crossroads for New Thrust and Directions

In late 1963, space and nuclear scientists and technologists attempted to foresee how the new President, Lyndon Johnson, would proceed with the space program. Johnson came to his new position with considerable legislative experience in space and military activities as a result of his committee assignments while a member of Congress and his chairmanship of the National Aeronautics and Space Council after his election as vice president. In his first address to a joint session of Congress on 27 November 1963, Johnson pledged to continue Kennedy’s ideas and ideals including “The dream of conquering the vastness of space...”⁴⁷

Johnson’s first decision in space priorities was viewed positively by Aviation Week: “The national space program has taken a significant step forward with President Lyndon B. Johnson’s decision to develop a military orbital space station.”⁴⁸ Two weeks later, however, the president trimmed the FY 1965

budget, which led to the cancellation of nuclear flight programs. The AEC/NASA Joint Office estimated that 1,300 employees at Aerojet, Lockheed, and Westinghouse were affected by the cancellation of the reactor-in-flight test project and the stretch-out on Nerva, the nuclear engine for rocket vehicle application.⁴⁹

Reasons for the budget cut became apparent as the months passed. In April 1964, space journals devoted much attention to the Vietnam War. Although Defense Secretary McNamara had said no decision had been made to extend the war, he rejected any suggestions that the United States withdraw from Southeast Asia.⁵⁰ Tensions on Capitol Hill surfaced, engendered by Secretary McNamara's defense of his program to develop weapons. An attack by Congressman Laird on the military budget indicated that "guns and butter" was an issue of partisan contention. Laird challenged Secretary McNamara for using dollar amounts to justify the classification of each program as major:

Using this criteria, perhaps we should classify the war on poverty as a major new weapons system. After all, the requirements of a new weapons system all seem to have been met in this program. The cost is certainly high enough. And the war on poverty, like the weapons systems Secretary McNamara claims as new, is obviously a combination of already existing programs. And, of course, the program has been given a new name.⁵¹

Administrators of NASA and the AEC took steps to maintain the momentum of their programs and to cope with this threatening environment.

In January 1964 President Johnson asked Webb to review NASA's future space exploration plans with the object of relating hardware and development programs to prospective missions. The president also stressed the importance of coordinating research and development programs with the DOD and the AEC. Webb conferred with Seaborg and incorporated Seaborg's views regarding joint work between the two agencies into his report. Detailing the programs, their missions, and hardware, Webb laid out the panorama of development in which NASA was engaged, "a ten-year \$35 billion program aimed at developing a national capability for operations in space." Attempting to save the broad programs, he discussed the many missions being considered and their coordination with other agencies.⁵²

Seaborg had begun over a year earlier to prepare a case for the SNAP program and, as budget battles approached,⁵³ invited private contractors, the military services, and other government agencies to attend seminars about the SNAP program.⁵⁴ In response to the president's request, a draft report on the SNAP program was ready by January 1964. Commissioner Ramey criticized the report's apparent efforts "to lean over backwards to be fair to other types of systems like solar cells" and expressed reservations about the emphasis placed on nuclear safety.⁵⁵

Distributed in February 1964, the report stressed the unique advantages of nuclear auxiliary power to a wide variety of space missions and maintained that the "*performance of ambitious space missions will require amounts of reliable power so large that they can be achieved only from nuclear systems.*"⁵⁶ Welsh, at the Space Council, offered to help defend the program vigorously, but made clear the priorities of the Council regarding the total SNAP program:

My staff recognizes the usefulness of the isotope SNAP devices, but if anything is even more interested in the range of nuclear reactor work entailed in the total program. They feel very strongly that we must give every encouragement now to power development needed to support future missions. The Apollo landing will not be an end. Future possibilities include manned planetary explorations, a growing lunar base, and multi-mission advanced earth orbiting stations. All of these will have to have power sources of...magnitude above any available now. Only nuclear energy has this potential.⁵⁷

Throughout 1964, the AEC and NASA moved toward closer coordination of both agencies' efforts in the space-nuclear field. The move was a response to many forces, including the economic squeeze; the emphasis on non-duplication of effort; the increasing need to justify mission requirements for research and development; and the anticipation of higher power requirements for future missions. In January 1965 a proposed agreement between NASA and the AEC to create a joint Space Nuclear Systems Division circulated for review in those agencies. The agreement stated the purpose and rationale of this reorganization:

Recognizing that the development of nuclear energy systems and their application in space missions requires the technical and management capabilities, and involves the responsibilities, of both the National

Aeronautics and Space Administration and the Atomic Energy Commission, these agencies agree that these activities require a joint effort and a joint organization to insure effective system development and to insure that the responsibilities of each agency are properly fulfilled. It is, therefore, the purpose of this agreement to establish such a joint organization and to define its functions.⁵⁸

Negotiations and preparations for the new division, which would include research and development on power systems and integration of the conversion system with the isotope source, continued through the spring of 1965. In June the new Space Nuclear Systems Division, headed by Finger, was established. In his first meeting with the JCAE, Finger stated that very large ranges in power were needed, but it was inconceivable that money would be available to develop a unique system for every particular mission. Therefore, he proposed:

It is...important I think that in the Commission program, we try to develop systems that bracket as broad a range of potential mission uses as possible, and parallel with this, continue to push the technology into more advanced areas in order to try to improve the performance and life capability of these systems.⁶⁰

In the fall, at the annual conference of the Atomic Industrial Forum, Finger described the new AEC-NASA organizational arrangements, which included the coordination of Space Nuclear Systems programs among and between the AEC and NASA, as well as the AEC's Space Electric Power Organization (Figures 1 and 2.) A new juncture had been reached. As the small, self-confident, and persevering RTG group prepared to launch their devices on vehicles to go to the Moon and beyond, they found the drama of space nuclear power filled with growing numbers of actors—both individuals and organizations.

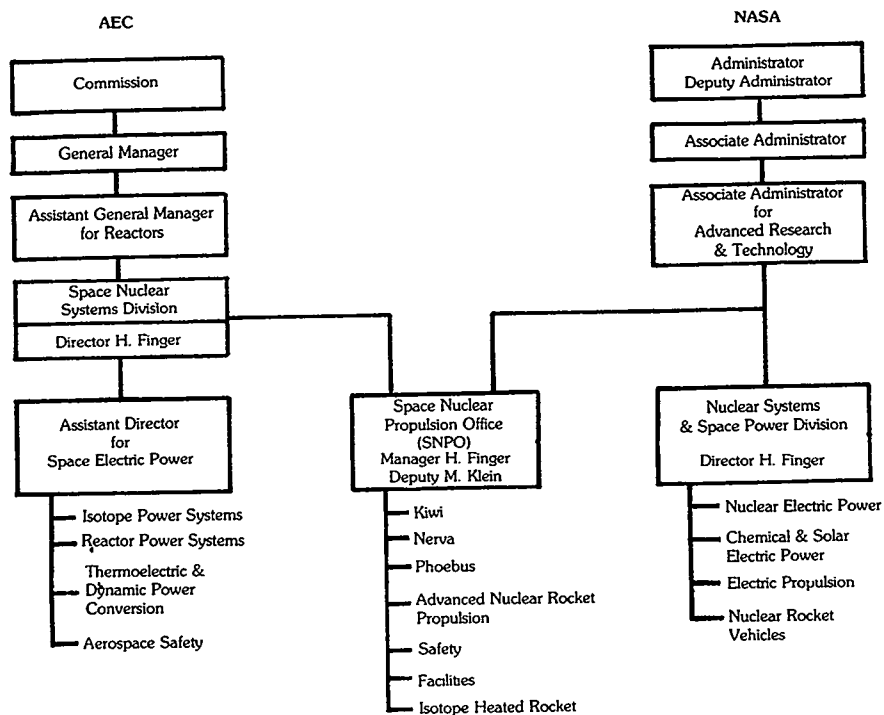


Fig. 1. Organization of Space Nuclear Systems Programs

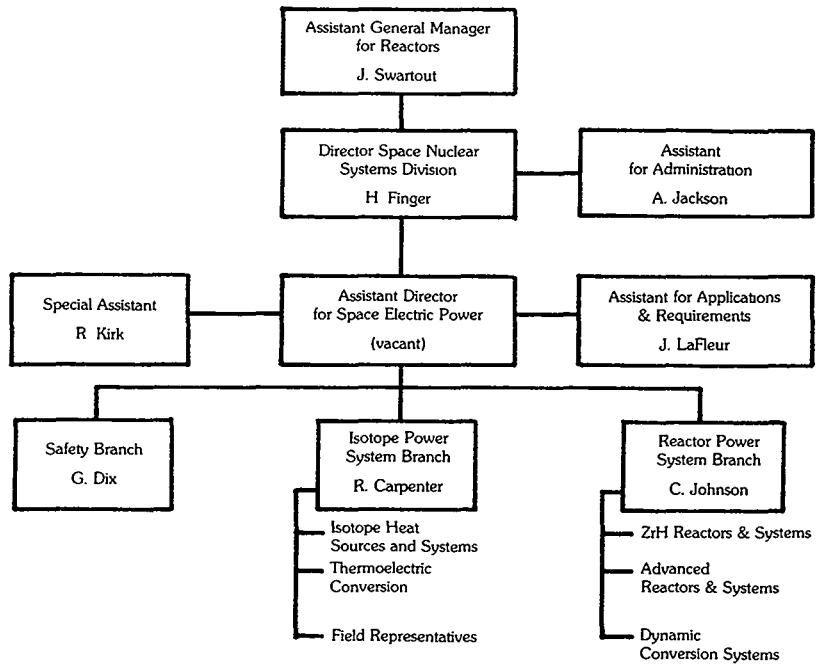
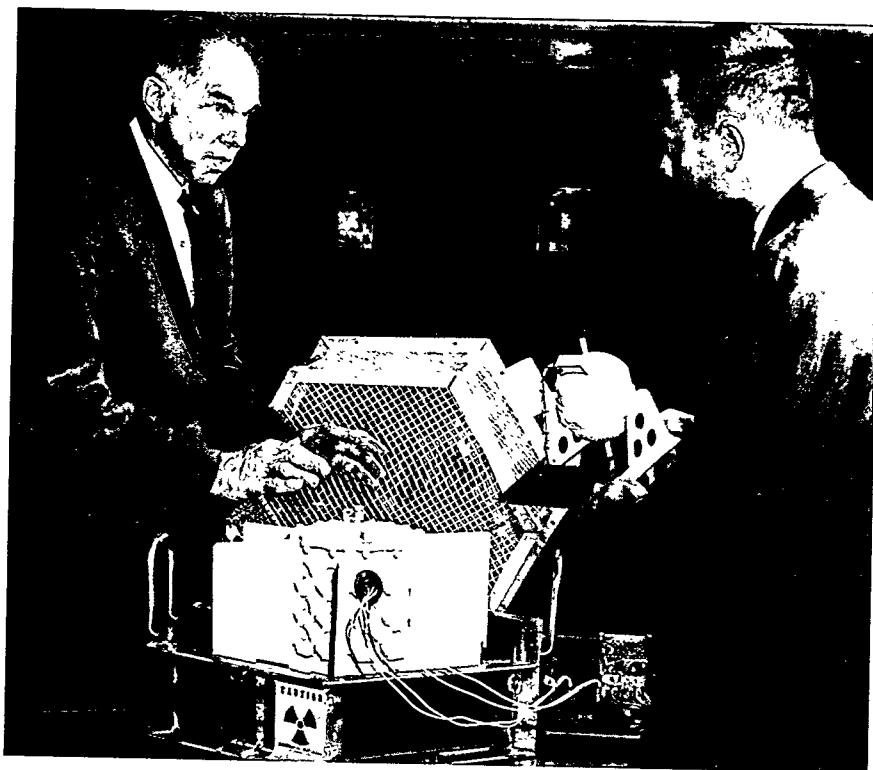


Fig. 2. SNS — SEPO Organization



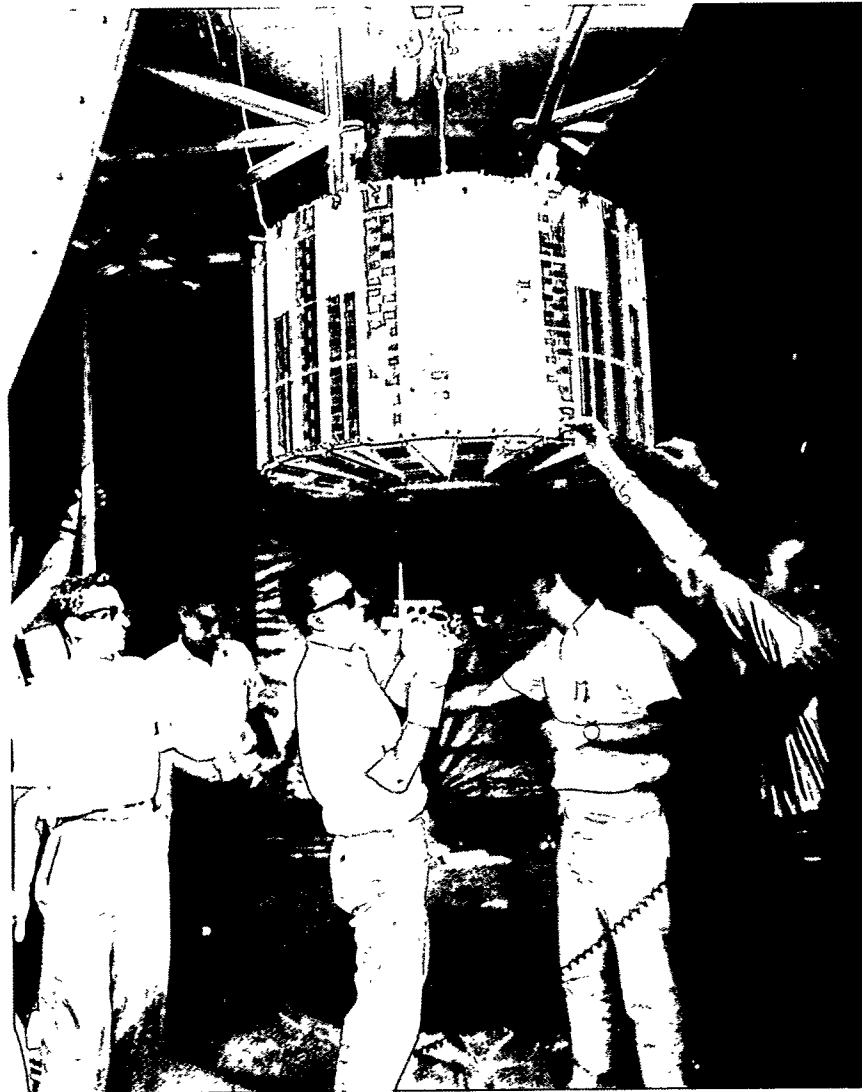
1

Public debut of the RTG technology, 16 January 1959. Viewing the SNAP-3 demonstration device displayed on President Eisenhower's desk are (left to right): President Eisenhower and (from the Atomic Energy Commission) Major General Donald J. Keim, Assistant Director for Aircraft Reactors, Division of Reactor Development; John A. McCone, Chairman, AEC; Colonel Jack L. Armstrong, Deputy Assistant Director for Aircraft Reactors, Division of Reactor Development; Lt. Colonel Guveren M. Anderson, Project Officer, Missile Projects Branch, Division of Reactor Development. (Source: Department of Energy Archives.)



2

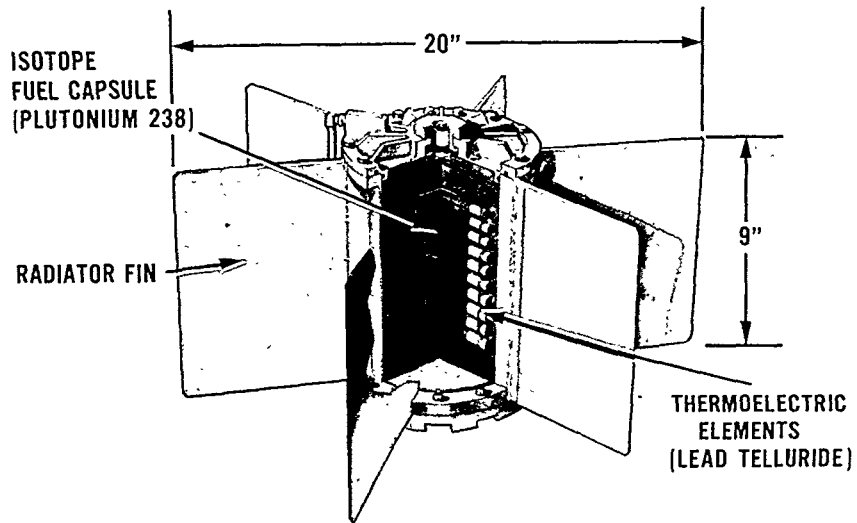
Glenn Seaborg (on the left) is shown the SNAP-9A by Robert Carpenter, of the RTG program, shortly after Dr. Seaborg took over as Chairman of the AEC early in 1961. (Source: Department of Energy Archives.)



3

Paul J. Dick of the Martin Marietta Nuclear Division prepares to attach the SNAP-9A generator to the base of the Navy's Transit satellite prior to the launch on 29 June 1961 which marked the first use of atomic power in space. (Source: Teledyne Corporation.)

SNAP 19 RADIOISOTOPE ELECTRIC GENERATOR



DESIGN POWER OUTPUT 25 WATTS
 DESIGN WEIGHT 30 LBS

NASA R-12-1273
 7-27-66

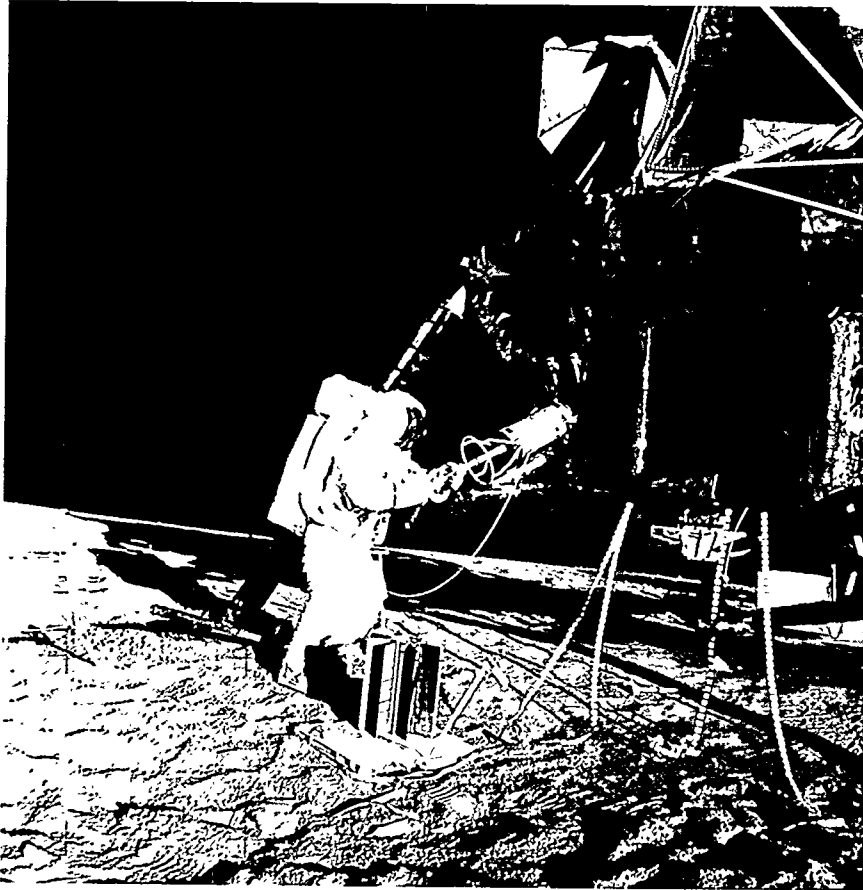
4

Cutaway illustration of essential features of the SNAP-19, developed by the Martin Marietta Nuclear Division and used, with modifications, on NASA missions beginning with the Nimbus weather satellite and including Pioneer to Jupiter and Viking to Mars. (Source: Department of Energy.)



5

SNAP-19 heat sources photographed on the ocean floor of the Santa Barbara Channel after abort of the Nimbus weather satellite mission (launched on 18 May 1968) testing the first use by NASA of RTGs. Heat sources were recovered and re-used and a subsequent Nimbus launch provided a successful test of the RTGs. (Source: Department of Energy Archives.)



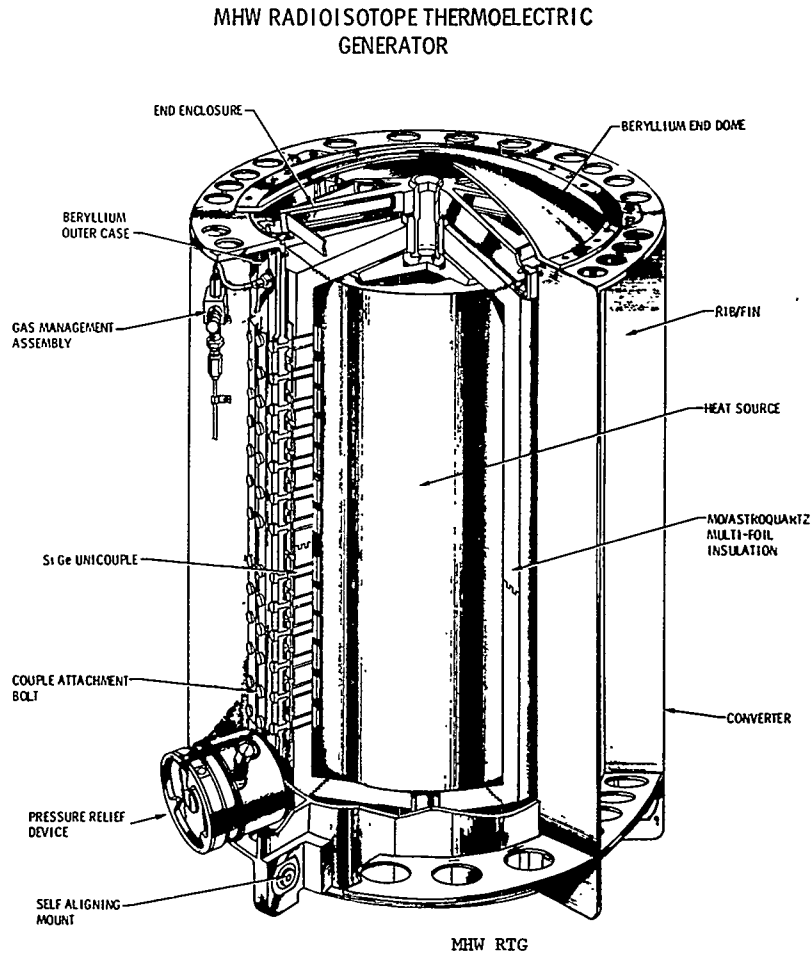
6

On the Apollo 12 mission (launched 14 November 1969) Alan Bean removes the heat source from its carrying cask in the LEM prior to inserting it into the SNAP-27 sitting at his feet on the surface of the Moon. Beginning with Apollo 12, SNAP-27s powered scientific experiments left behind on the lunar surface by Apollo astronauts; the experiments were finally shut down after many years although the RTG power was still meeting operational requirements. (Source: NASA Archives.)



7

Dr. John A. Simpson (left) and Dr. James A. Van Allen, principal investigators involved with NASA's Pioneer 11 mission to Jupiter (using SNAP-19s for power), discuss preliminary estimates of Jupiter's intense radiation belts received at NASA's Ames Research Center at Moffett Field, California. Pioneer 11 entered and survived the region of Jupiter's most severe radiation on 2 December 1974. (Source: NASA Ames Research Center Archives.)



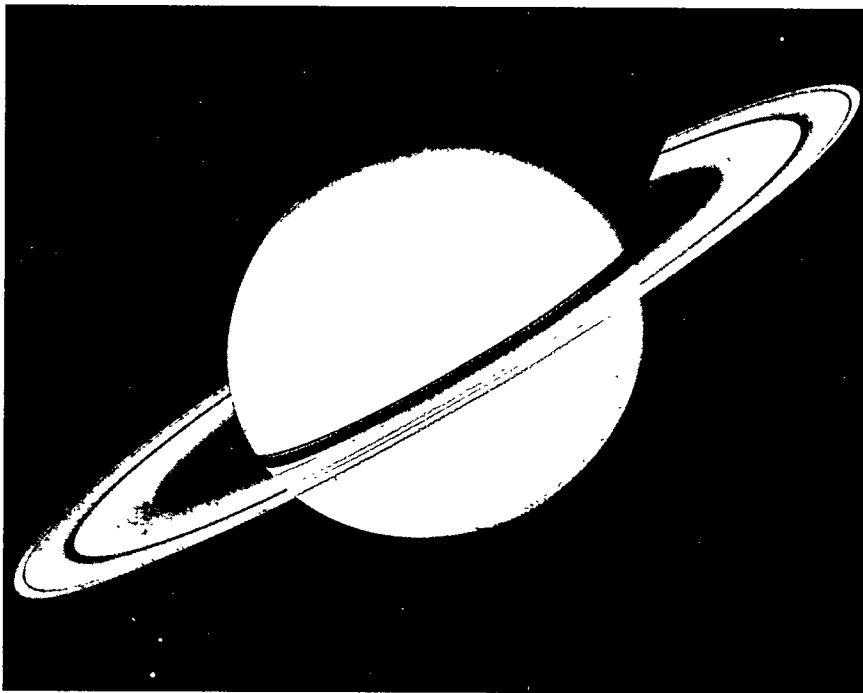
8

Cutaway illustration of essential features of the MHW RTG, the most advanced RTG used to date on space missions. The MHW is designed to meet power requirements in the multi-hundred watt range and was used on the LES 8/9 satellite missions of the Department of Defense and on NASA's Voyager missions to the outer planets. (Source: Department of Energy.)



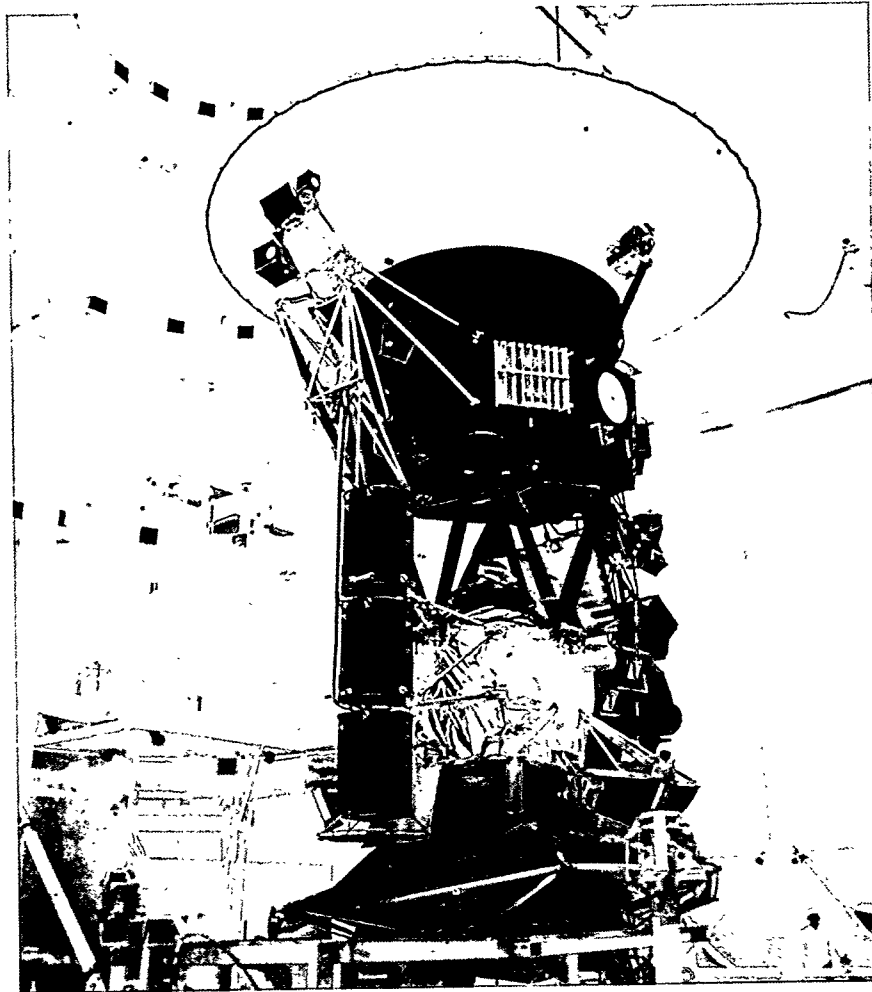
9

Sand dunes and rocks on the surface of Mars, photographed by Viking 1's camera on 23 July 1976. The American flags that can be seen are located on the two RTG wind screens, specially designed to protect the SNAP-19 RTGs from dust storms on the surface of Mars. (Source: NASA Archives.)



10

Saturn and its rings photographed from a distance of 11 million miles by NASA's Voyager 1 (powered by MHW RTGs) on 30 October 1980. Such spectacular views of distant space phenomena are made possible by RTG power which can operate regardless of the distance of a spacecraft from the sun. (Source: NASA Jet Propulsion Laboratory Public Information Office.)



11

The Voyager spacecraft awaiting encapsulation in the Spacecraft Assembly and Encapsulation Center at the Kennedy Space Center. The extendable boom on the left bears three MHW RTGs (stacked black cylinders), while the boom on the right carries science instruments shrouded in black thermal blankets. After launch, booms are extended to their full lengths and the RTGs providing electrical power are kept as far away as possible from the instruments they power. (Source: NASA Jet Propulsion Laboratory Public Information Office.)

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-238³

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 discussion 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 characteristics 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 million¹⁰ 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 re-entry.' 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. Pitolo 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 twenty

General Electric's SNAP-27s were designed for lunar missions, but the momentum of the Multi-Hundred Watt contract and the Apollo program ended, an unmanned

century.¹⁸

designed uniquely for manned space exploration. Apollo experience carried them to the deep-space applications. Before the unmanned mission found uses for RTGs.

The Challenge of PIONEER

Charles Hall, Pioneer Project Manager at NASA-Ames in Sunnyvale, California, managed the program first defined as an interplanetary probe to be as a "rowboat" compared to the Apollo. He did not scrutinize his program as much as Apollo. Because of its comparatively small budget, it could be pulled along in the wake of Apollo. Program directors sold on RTGs by Apollo experiences further proved the technical capabilities of the RTG program and its contractors.

Hall had reservations about using RTGs because the first Nimbus carrying an RTG degraded too fast on the RTG that accompanied the Nimbus launch in 1969. On the other hand, he was not sure if solar cells would be used. The scheduled launch of Pioneer 10, was early 1972, and the decision was undecided three years before the launch. Hall convinced NASA headquarters to negotiate with TRW. This was done. "The design was pretty limited," Hall said, "but it was better than going through all the hassles of solar cells."

NASA headquarters favored the use of RTGs, as did AEC's Space Nuclear Systems Division. At about the same time of the completion of the solar power study for Pioneer, Carpenter at 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

at NASA-Ames in Sunnyvale, the time it was moved to Ames and later. He refers to the Pioneer program as "battleship." This meant that people did not scrutinize it because of its comparatively small budget. Hall was one of the marketing of the RTG people.¹⁹ His technical capabilities, under pressure, of the RTG program and its contractors.

RTG on a three-year space mission failed on launch and, also, the power source accompanied the successful Nimbus launch. He was not sure whether a mission to Jupiter could be done. To expedite system development, a sole source contract should be awarded. TRW proposed the use of solar cells. "The design was pretty limited," Hall said, "but it still looked better to me than going through all the hassles of solar cells."²⁰

of the RTGs, as did AEC's Space Nuclear Systems Division. At about the same time of the completion of the solar power study for Pioneer, Carpenter at 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 March 1972, 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 telluride 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.

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 tech-

nical 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 $\frac{3}{4}$ 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 Programming 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 mission'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 interpretations 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 from 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 applications. “There are really only two commercial firms in the RTG business anymore,” according to Linkous. “GE has all the space RTG work, and we [Teledyne] 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 terrestrial 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 traditionally 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 objec-

tives 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." 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.

BIBLIOGRAPHY

A Note on Information Sources

Various types of materials were used in preparing this history. At the outset, an extensive computer search of the Department of Energy (DOE) library, including the data base at the Oak Ridge Laboratory, revealed that the type of technical reports there would not be helpful in developing this history. Primarily, three other sources of information were relied upon: materials from DOE Archives, which were identified and assembled by Roger Anders of DOE's History Division; the data bases of the Library of Congress, which led to a review of newspapers, periodicals, technical journals, and books; and interviews.

Three classes of information were used: technical events and developments, institutional developments, and related events in the milieu. The five categories of materials used are discussed below.

Printed reports and government documents were used to identify particular facts about the RTGs and the program. Some of the materials provided relevant facts covering broad time periods; other sources pinpointed narrow time periods and revealed program status at a time, or presented important decisions or statements relevant to the program. A few of the materials focused on particular aspects of the program.

Books and pamphlets provided a breadth and depth of understanding. Several stand out for an understanding of the technology and the broad and changing issues of the time period covered: the historical documents about the AEC, ERDA, and the DOE, and the energy chronology produced by the history staff of DOE (Buck, Dean, and Holl) were invaluable in succinctly presenting relevant events in the institutional environment. The work on radioisotopic power generation by Corliss and Harvey was a valuable primer in the technology. For background on the times and glimpses of the views of top-level scientists and administrators, the cited books by Seaborg, Webb, Killian, Kistiakowsky, and Levine were profitable. The Newell book also proved helpful in tracing the history of NASA. Detailed information on specific space missions was found in several NASA documents on Apollo, Viking, and

Voyager; the books by Washburn added an emotional dimension. The books by Rolph and Ford aided in understanding the changing milieu at the time the AEC was disbanded.

Articles from newspapers, periodicals, and technical journals were used to obtain insights into the changing technical, political, and social milieu during the period covered by the history. The articles used in the text are presented in chronological order since the chronology of changing foci and issues was most significant to the history. All of the newspaper articles came from the DOE archives; "Other Articles" cited were uncovered in a topical search for specific facts.

Unpublished materials encompass a number of different types of items uncovered during the research, ranging from documents prepared by program participants, such as Mike Dix and Tom Kerr, to remarks of key functionaries on particular occasions. It is possible that some of this may have been published at a later date.

It should be noted that archives materials were extremely helpful throughout the research and writing of this history. "Letters", "memos", and "news releases" are not cited in the Bibliography although they are cited with full dates in the chapter notes; such materials were invaluable in obtaining insight into day-by-day issues discussed and acted upon by key administrators during particular time periods. They were most numerous in the archives for the AEC years but much less so for ERDA and DOE.

Interviews were emphasized throughout the research, to preserve an oral history of the program on tape. All interviewees were cooperative, helpful, and for the most part eager to share their recollections. Some are now retired but made themselves available for interviews; others took time from busy work schedules to be interviewed. The list of those interviewed represents coverage of differing but important perspectives on and involvements in the program.

Printed Reports and Government Documents

Bennett, Gary L., James J. Lombardo, and Bernard J. Rock. *Nuclear Electric Power For Space Systems: Technology Background and Flight Systems Program*. Published paper delivered at 16th Intersociety Energy Conversion Engineering Conference, Atlanta, Georgia, August 9-14, 1981.

Bennett, Gary L., James J. Lombardo, and Bernard J. Rock. *U.S. Radioisotopic Thermoelectric Generator Space Operating Experience (June 1961-December 1982)*, paper presented before the 18th Intersociety Energy Conversion Engineering Conference, Orlando, Florida, August 21-26, 1983.

Craig, Carol. *RTG Source of Power: A History of the Radioisotopic Generators Fueled at Mound*. Miamisburg, Ohio: Mound Public Relations, 1983.

Eisenhower, Dwight D. *Public Papers of the Presidents of the United States: Dwight D. Eisenhower, 1953*. Washington: U.S. Government Printing Office, 1960.

Harvey, D.G. and T.J. Dobry. *Safety Analysis of the Transit Generator*. The Martin Company, MND-P-2479, March 1961.

National Aeronautics and Space Administration. *Aeronautics and Space Report of the President: 1980 Activities*. Washington: National Aeronautics and Space Administration, 1980.

U.S. Atomic Energy Commission. *Snap Nuclear Generator Press Kit*. Washington: Atomic Energy Commission, June 26, 1961.

U.S. Atomic Energy Commission. *Systems for Nuclear Auxiliary Power: A Report by the Commission — 1964*. TID-20103. Washington: U.S. Atomic Energy Commission, February 1964.

U.S. Atomic Energy Commission. *Twenty-third Semiannual Report of the U.S. Atomic Energy Commission*. Washington: U.S. Government Printing Office, January 1958.

U.S. Congress. *Hearings Before Subcommittees of the Joint Committee on Atomic Energy (Outer Space Propulsion By Nuclear Energy)*. Eighty-Fifth Congress, January 22, 23, and February 6, 1958. Washington: U.S. Government Printing Office, 1958.

U.S. Congress. *Hearings Before Subcommittees of the Joint Committee on Atomic Energy (Development, Growth, and State of the Atomic Energy Industry)*. Eighty-Seventh Congress, February 21, 23, 24, 27, 28; March 1, 2,

and 3, 1961. Washington: U.S. Government Printing Office, 1961.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (Development, Growth, and State of the Atomic Energy Industry)*. Eighty-Seventh Congress, March 20, 21, 22, and 23, 1962. Washington: U.S. Government Printing Office, 1962.

U.S. Congress. *Hearings Before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy (Space Nuclear Power Applications)*. Eighty-Seventh Congress (Second Session), September 13, 14, and 19, 1962. Washington: U.S. Government Printing Office, 1962.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (Development, Growth, and State of the Atomic Energy Industry)*. Eighty-Eighth Congress, February 20 and 21, 1963. Washington: U.S. Government Printing Office, 1963.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (First Session on Space Nuclear Power Generators)*. Eighty-Ninth Congress, August 6, 1965. Washington: U.S. Government Printing Office, 1966.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (Authorizing Legislation Fiscal Year 1967)*. Eighty-Ninth Congress (Second Session), January 25, February 15, and March 4 and 8, 1966. Washington: U.S. Government Printing Office, 1966.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (Authorizing Legislation Fiscal Year 1968)*. Ninetieth Congress (First Session), Part 3, February 28, March 2 and 3, 1967. Washington: U.S. Government Printing Office, 1967.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (Authorizing Legislation Fiscal Year 1969)*. Ninetieth Congress (Second Session), Part 1, January 30 and 31, February 5 and 6, 1968. Washington: U.S. Government Printing Office, 1968.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (Authorizing Legislation Fiscal Year 1970)*. Ninety-First Congress (First Session), Part 1, April 17 and 18, 1969. Washington: U.S. Government Printing Office, 1969.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy (Authorizing Legislation Fiscal Year 1971)*. Ninety-First Congress (Second Session), Part 1, February 18 and 19, 1970. Washington: U.S. Government Printing Office, 1970.

U.S. Congress. *Hearings Before the Joint Committee on Atomic Energy*

(*Authorizing Legislation Fiscal Year 1972*). *Ninety-Second Congress (First Session), Part 3, March 9, 16, and 17, 1971*. Washington: U.S. Government Printing Office, 1971.

U.S. Congress. *Joint Hearing Before the Joint Committee on Atomic Energy Congress of the U.S. and the Committee on Interior and Insular Affairs of the U.S. Senate (Nomination of Dr. Robert C. Seamans, Jr., To Be Administrator, ERDA)* Ninety-Third Congress, (Second Session), December 11, 1974. Washington: U.S. Government Printing Office, 1974.

U.S. Congress. *Hearings Before the Subcommittee on Legislation of the Joint Committee on Atomic Energy (ERDA Authorizing Legislation Fiscal Year 1977)*. Ninety-Fourth Congress (Second Session), Part 2, February 4, 1976. Washington: U.S. Government Printing Office, 1976.

U.S. Congress. *United States Code: Congressional and Administrative News*. Eighty-Third Congress — Second Session, 1954, Vol. 2. West Publishing Co. and Edward Thompson Company, 1954.

Books and Pamphlets

Allardice, Corbin and Edward R. Trapnell. *The Atomic Energy Commission*. New York, Washington: Praeger Publishers, 1974.

Buck, Alice L. *A History of the Atomic Energy Commission*. Washington: U.S. Department of Energy, July 1983.

Buck, Alice L. *A History of the Energy Research and Development Administration*. Washington: U.S. Department of Energy, March 1982.

Chapman, Richard L. *Project Management in NASA*. Washington: National Aeronautics and Space Administration, 1973.

Corliss, William R. and Douglas G. Harvey. *Radioisotopic Power Generation*. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964.

Cortright, Edgar M. *Apollo Expeditions to the Moon*. Washington: National Aeronautics and Space Administration, 1975 (NASA SP-334).

Dean, Prentice C. *Energy History Chronology From World War II to the Present*. Washington: U.S. Department of Energy, August 1982.

Dempsey, John C and Paul Polishuk. *Radioisotopes For Aerospace, Part I: Advances and Techniques*. New York: Plenum Press, 1966.

Ford Daniel. *The Cult of the Atom*. New York: A Touchstone Book Published by Simon and Schuster, Inc., 1982.

- Gantz, Kenneth F. *Nuclear Flight*. New York : Duell, Sloan & Pierce, 1960.
- Hewlett, Richard G. and Oscar E. Anderson, Jr. *A History of The United States Atomic Energy Commission (Vol. I): The New World, 1939/1946*. University Park, Pa.: The Pennsylvania State University Press, 1962.
- Hogerton, John F. *The Atomic Energy Deskbook*. New York: Reinhold Publishing Corporation, 1963.
- Holl, Jack M. *The United States Department of Energy: A History. Washington: U.S. Department of Energy, November 1982.*
- Killian, James R. *Sputnik, Scientists, and Eisenhower*. Cambridge & London: The MIT Press, 1976.
- Kistiakowsky, George B. *A Scientist At The White House*. Cambridge: Harvard University Press, 1976.
- Klass, Philip J. *Secret Sentries in Space*. New York: Random House, 1971.
- Levine, Arnold S. *Managing NASA in the Apollo Era*. Washington: National Aeronautics and Space Administration, 1982.
- Logsdon, John M. *The Decision to Go to the Moon: Project Apollo and the National Interest*. Cambridge, Mass., and London, England: The MIT Press, 1970.
- Mazuzan, George T., and Walker, J. Samuel. *Controlling the Atom: The Beginning of Nuclear Regulation, 1946-1962*. Berkeley, Los Angeles, London; University of California Press, 1984.
- National Aeronautics and Space Administration. *Voyager To Jupiter and Saturn*. Washington: National Aeronautics and Space Administration, 1977 (NASA SP-420).
- Newell, Homer E. *Beyond The Atmosphere*. Washington: National Aeronautics and Space Administration, 1980.
- Pedersen, Erik S. *Nuclear Energy in Space*. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964.
- Rolph, Elizabeth S. *Nuclear Power and the Public Safety*. Lexington, Mass: Lexington Books, 1979.
- Schell, Jonathan. *The Time of Illusion*. New York: Alfred A. Knopf, 1976.
- Seaborg, Glenn T. *Kennedy, Khrushchev, and the Test Ban*. Berkeley: University of California Press, 1981.
- Seaborg, Glenn T. and William R. Corliss. *Man and Atom*. New York: E.P. Dutton and Company, Inc., 1971.

Washburn, Mark. *Distant Encounters*. San Diego: Harcourt Brace Jovanovich, 1983.

Washburn, Mark. *Mars At Last!* New York: G.P. Putnam's Sons, 1977.

Webb, James E. *Space Age Management: The Large-Scale Approach*. New York: McGraw-Hill, 1969.

Wilford, John Noble. *We Reach The Moon*. New York, Toronto, London: Bantam Books, 1969.

Articles

"Sputnik in the Sky" (by Robert Hotz). *Aviation Week & Space Technology*, October 14, 1957, p. 21.

"USAF Pushes Pied Piper Space Vehicle." *Aviation Week & Space Technology*, October 14, 1957, p. 26.

"5-Lb. Device Hailed as Big Breakthrough." *The Evening Star* (Washington, D.C.), January 16, 1959. (page number not discernible.)

"President Shows Atom Generator." *The Evening Star* (Washington, D.C.), January 16, 1959, p.1.

"First Atom Battery Developed by U.S." *The Washington Post*, January 17, 1959, p.1.

"Isotopic Power Ready for Space But Caution Delays Use." *Nucleonics*, July 1960, pp. 26-27.

"Nuclear Power in Outer Space." *Nucleonics*, August 1960, pp. 58-63.

"Special Report on Nuclear Energy in Space." *Nucleonics*, April 1961 (Special Issue).

"Nuclear Power Is A Space Issue." *New York Times*, May 16, 1961. (page number not discernible).

"U.S. Wary of Using Atom Device in Satellite Flight Across Cuba." *New York Times*, May 16, 1961, p. 2.

"3-in-1 Satellite Is World's First." *New York Journal American*, June 29, 1961, p. 1.

"The March on Washington." (Cover Story), *Newsweek*, September 2, 1963.

"Test Ban: 16 to 1." *Newsweek*, September 9, 1963, p. 23.

"Kennedy's Offer Stirs Confusion, Dismay" (by Alfred P. Alibrando). *Aviation Week & Space Technology*, September 30, 1963, p. 21.

"Kennedy's Space Boomerang" (Robert Hotz). *Aviation Week & Space Technology*, September 30, 1963, p. 21.

"Snap 9-A Isotope Generator Powers Navy Navigation Satellite." *Aviation Week & Space Technology*, October 7, 1963, p. 21.

"What The White Man Thinks Of the Negro Revolt." *Newsweek*, October 21, 1963.

"Vietnam: The Showdown." *Newsweek*, November 5, 1963.

"An Indelible Mark" (by Robert Hotz). *Aviation Week & Space Technology*, December 2, 1963, p. 21.

"Continued Space Effort." *Aviation Week & Space Technology*, December 2, 1963, p. 28.

"John Fitzgerald Kennedy." *Newsweek*, December 2, 1963.

"Johnson Familiar With Aerospace Facilities." *Aviation Week & Space Technology*, December 2, 1963, p. 26.

"Johnson Stress on Military Space Seen." *Aviation Week & Space Technology*, December 2, 1963, p. 26.

"Another Step Forward" (by Robert Hotz). *Aviation Week & Space Technology*, December 16, 1963, p. 25.

"Nuclear Flight Programs Cancelled As President Trims FY '65 Budget." *Aviation Week & Space Technology*, December 30, 1963, p. 22.

"Options in Vietnam." *Aviation Week & Space Technology*, April 6, 1964, p. 19.

"South Vietnamese Raiders Extending War" (by Larry Booda). *Aviation Week & Space Technology*, April 6, 1964, pp. 16-18.

"Washington Roundup." *Aviation Week & Space Technology*, April 27, 1964, p. 25.

"The Long War" (by Robert Hotz). *Aviation Week & Space Technology*, January 3, 1966, p. 11.

"AEC Doubles Space Radioisotope Efforts." *Aviation Week & Space Technology*, January 10, 1966, p. 78.

"Washington Scene: AAP-Wednesday's Child" (by Henry Simons). *Astronautics and Aeronautics*, February 1966, p. 5.

"Nimbus Snap-19 Generators Recovered." *Aviation Week & Space Technology*, October 14, 1968, p. 16.

"Washington Roundup." *Aviation Week & Space Technology*, April 6, 1969, p. 17.

"Exuberance Sets Tone of First EVA." *Aviation Week & Space Technology*, November 24, 1969, pp. 20ff.

"Scientists Concede Value of Man in Lunar Experiment Deployment." *Aviation Week & Space Technology*, December 1, 1969, pp. 20-21.

"Crew Describes Apollo 13 Crisis." *Aviation Week & Space Technology*, April 27, 1970, p. 20.

"Fly on the Flypaper" (by Robert Hotz). *Aviation Week & Space Technology*, May 11, 1970, p. 13.

"Outlook for 1971" (by Robert Hotz). *Aviation Week & Space Technology*, January 11, 1971, p. 9.

"Overlooked Space Program Benefits" (by Robert Hotz). *Aviation Week & Space Technology*, March 15, 1971, p. 11.

"Aerospace Business in the Seventies" (by Abraham Hyatt, North American Rockwell Corp.). *Astronautics and Aeronautics*, July 1971, p. 49.

"Sounder Planning Required" (by Robert Hotz). *Aviation Week & Space Technology*, December 11, 1972.

"The Last Liftoff" (by Robert Hotz). *Aviation Week & Space Technology*, December 11, 1972, p. 17.

"Pioneer 10 Blazes Path to Jupiter, Beyond." *Aviation Week & Space Technology*, December 10, 1973, p.21.

"Pioneer's Successes Buys Saturn Hopes." *Aviation Week & Space Technology*, December 9, 1974, p. 16.

"Layoffs at Cape Total 2,000." *Aviation Week & Space Technology*, July 21, 1975, p. 18.

"Electric Power Systems for Space: A Progress Report." *Astronautics and Aeronautics*, December 1975, pp. 26ff.

"DOD, ERDA Seek Space Power Focus." *Aviation Week & Space Technology*, May 30, 1977, p. 13.

"Carter Discourages Major New Space Efforts." *Aviation Week & Space Technology*, May 30, 1977, p. 13.

- "VOYAGER: Running a Planetary Post Pattern" (by Mark D. Zimmerman). *Machine Design*, August 25, 1977, pp. 26ff.
- "Technology: Plutonium Power for Space Exploration." *New York Times*. August 31, 1977. (page number not discernible.)
- "Space Nuclear Power Gains Foreseen." *Aviation Week & Space Technology*, January 1978, p. 129.
- "NASA's Loss of Thrust" (by George C. Wilson). *Aviation Week & Space Technology*, January 1978, pp. 6-10.
- "Technology's Brighter Image." *Machine Design*, July 24, 1980, p. 67.
- "NASA Moves to Salvage Planetary Program." *Aviation Week & Space Technology*, November 2, 1981, p. 16.
- "Science Academy Asks Caution in Research, Development Cuts." *Aviation Week & Space Technology*, November 2, 1981, p. 16.
- "Bean-Counting the Solar System" (by William H. Gregory). *Aviation Week & Space Technology*, December 14, 1981, p. 11.
- "Solar Polar Plans Advance Despite Pullout by NASA." *Aviation Week & Space Technology*, December 28, 1981, p. 12.
- "Better Than Nothing" (by William H. Gregory). *Aviation Week & Space Technology*, July 12, 1982, p. 13.

Reference Books

- "Glenn T. Seaborg." *Who's Who in America*, 42nd Edition, 1982-1983, p. 2997.
- "Isotope." *Collier's Encyclopedia* (1982), Vol. 13, p. 320.
- "James E. Webb." *Who's Who in America*, 42nd Edition, 1982-1983, p. 3494.
- "Radioactivity." *Collier's Encyclopedia* (1982), Vol. 19, pp. 604-607.
- "The Challenge of Space Exploration" (by Robert C. Seamans Jr). *Annual Report of the Board of Regents of the Smithsonian Institution 1961*. Washington: U.S. Government Printing Office, 1962, pp. 260-263.
- "Vietnam War." *The Encyclopedia Americana* (1983), Vol. 28, pp. 112a-112b.

Unpublished Documents/Materials

Connor, Lt. Col. Joseph A. *Safety Aspects of the Nuclear Space Program*. Remarks before the Annual Conference of the Atomic Industrial Forum, San Francisco, California, December 15, 1960.

Dix, George P. *Nuclear Safety of Space Nuclear Power Systems*. Washington: Atomic Energy Commission, undated.

Dix, George P. and Susan S. Voss. *The Pied Piper — A Historical Overview of the U.S. Space Power Reactor Program*. Paper presented at the First Symposium on Space Nuclear Power Systems, Albuquerque, New Mexico, January 11, 1984.

Holifield, Chet. *Remarks By Congressman Chet Holifield, Chairman JCAE, On The Occasion Of Presenting A SNAP 27 Generator To The Smithsonian Institute* (sic), December 9, 1970.

Kerr, Thomas B. *Procedures for Securing Clearance*. Washington: National Aeronautics and Space Administration, undated.

Morse, J.G. *Summary of Attitudes Encountered in Brazil Toward Operational SNAP Devices*. The Martin Company, Nuclear Division, June 5, 1961.

Roberts, Dr. Richard W. *Statement for The FY 1976 Appropriations Hearings U.S. Congress*. No date.

Roberts, Dr. Richard W. *Statement for The FY 1977 Authorization Hearings Before the Committee on Aeronautical and Space Sciences U.S. Senate*, February 3, 1976.

Seaborg, Glenn T. *Nuclear Power And Space*. Remarks prepared for delivery at International Symposium on Aerospace Nuclear Propulsion, Las Vegas, Nevada, October 24, 1961.

U.S. Air Force. *Fact Sheet: Lincoln Experimental Satellites LES-8 and -9*. Office of Information, Air Force Systems Command. (No date.)

U.S. Atomic Energy Commission. *SNAP Fact Sheet*. Washington: Atomic Energy Commission, September 1, 1963.

U.S. Department of Energy. *Organization and Functions Fact Sheet*. Washington: Department of Energy, Office of Public Affairs, October 1, 1977.

U.S. Department of Energy. *Program Plan: Office of Special Nuclear Projects (Space and Special Radioisotopic Systems Applications — Revised 6/12/84)*. Washington: Department of Energy, 1984.

U.S. Department of Energy. *Space Nuclear Systems Briefing Book*. Washington: Department of Energy, February 1982.

U.S. Energy Research and Development Administration. *ERDA Public Information Plan LES 8/9*. Washington: Energy Research and Development Administration, July 1975.

U.S. Energy Research and Development Administration. *Information from ERDA: Multi-Hundred Watt Nuclear Generator—Power for LES Satellites 8 and 9*. Washington: Energy Research and Development Administration, July 1975.

Interviews

<i>Person</i>	<i>Place</i>	<i>Date</i>
Brouns, Robert	U.S. Department of Energy Germantown, MD	7/20/84
Carpenter, Robert	Fairchild Industries, Inc. Germantown, MD	11/3/83
Dassoulas, John	Applied Physics Laboratory Howard Co., MD	11/14/83
Dick, Paul	Teledyne, Inc. Timonium, MD	12/8/83
Dix, George ("Mike")	Home Damascus, MD	12/7/83
Finger, Harold	U.S. Center for Energy Awareness Washington, DC	12/6/83
Hall, Charles	Home Los Altos, CA	1/25/84
Kerr, Thomas	National Aeronautics and Space Administration Washington, D.C.	11/10/83
Klein, Milton	Electric Power Research Institute Palo Alto, CA	1/25/84
Linkous, Guy	Teledyne, Inc. Timonium, MD	5/9/84
Mills, Rod	National Aeronautics and Space Administration Washington, D.C.	7/9/84
Pitrolo, Augustine	U.S. Department of Energy Morgantown, W.VA	5/23/84

Press, Harry	Jet Propulsion Laboratory Pasadena, CA	1/23/84
Rock, Bernard	U.S. Department of Energy Germantown, MD	4/13/84
Seaborg, Glenn	Lawrence-Berkeley Laboratory Berkeley, CA	1/26/84
Soffen, Gerald	National Aeronautics and Space Administration-Goddard Greenbelt, MD	7/15/84
Stapfer, Gerald	JPL Pasadena, CA	1/23/84
Truscillo, Vincent	Jet Propulsion Laboratory Pasadena, CA	1/23/84
Waldron, Philip	Lincoln Laboratory (by phone) Lexington, MA	7/16/84
Webb, James E.	Home Washington, D.C.	12/12/83

FOOTNOTES

Frequently government press releases, Fact Sheets and other documents provide information without naming a person or a title as the source; when such documents are referenced in the text, names of persons and/or titles as sources must, of course, be omitted.

CHAPTER I

1. Quoted from Alice L. Buck, *A History of the Atomic Energy Commission* (Washington: U.S. Department of Energy, July 1983), p. 6.
2. "Special Report on Nuclear Energy in Space," *Nucleonics*, April 1961. (Quotations taken from cover page.)

CHAPTER II

1. Headline, "President Shows Atom Generator," *The Evening Star*, (Washington, D.C.), January 16, 1959, p. 1. (From DOE archives.)
2. Statement of Col. Jack Armstrong in *Hearings Before Subcommittee of the Joint Committee on Atomic Energy Congress of the United States, Eighty-Fifth Congress Second Session on Outer Space Propulsion By Nuclear Energy*, January 22, 23, and February 6, 1958 (quotation, p. 125.)
3. "First Atom Battery Developed by U.S.," *The Washington Post*, January 17, 1959, p. 1. (From DOE archives.)
4. "5-Lb. Device Hailed as Big Breakthrough," *The Evening Star* (Washington, D.C.), January 16, 1959, p. 1.
5. Glenn T. Seaborg and William R. Corliss, *Man and Atom* (New York: E. P. Dutton and Company, Inc., 1971), p. 86.
6. *Ibid.*
7. Becquerel's experiments taken from "Radioactivity," *Collier's Encyclopedia* (1982), Vol. 19, p. 604.

8. Curies' discoveries and the nuclear battery of Moseley taken from *ibid.*, pp. 604-605, and from Seaborg, *op. cit.*, p. 87.
9. See William R. Corliss and Douglas G. Harvey, *Radioisotopic Power Generation* (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964), p. 10.
10. Descriptions taken from *ibid.*, p. 8 and from Seaborg, *op. cit.*, p. 87.
11. "Isotope," *Collier's Encyclopedia* (1982), Vol. 13, p. 320.
12. "Radioactivity," (*Collier's . . .*), *op. cit.*, pp. 604-607.
13. From Corliss and Harvey, *op. cit.*, p. 3.
14. *Ibid.*, p. 10.
15. Chronology of world events and information on AEC expansion is from Buck, *op. cit.*, pp. 1-2.
16. Study cited in Corliss and Harvey, *op. cit.*, p. 10.
17. Study (*RAND Report*, February 1949) cited in *ibid.*
18. Corliss and Harvey, *op. cit.*, pp. 10-11.
19. *SNAP Nuclear Generator Press Kit* (Washington: Atomic Energy Commission, June 26, 1961), "Attachment 2: SNAP Fact Sheet," note, p. 2. (From DOE archives.)
20. *RTG A Source of Power: A History of the Radioisotopic Thermoelectric Generators Fueled at Mound* (by Carol Craig, Mound Public Relations, Miamisburg, Ohio, 1983).
21. Letter from Assistant Secretary of Defense to Chairman Atomic Energy Commission, August 15, 1955. (From DOE archives.)
22. From *SNAP . . . Press Kit*, *op. cit.*, "Attachment 4: History of . . . SNAP Program. . .," pp. 1-2. (From DOE archives.)
23. Cited in *The Pied Piper—A Historical Overview of the U.S. Space Power Reactor Program* (by George P. Dix and Susan S. Voss), paper presented at the First Symposium on Space Nuclear Power Systems, Albuquerque, New Mexico, January 11, 1984, p. 1.

24. "Sputnik in the Sky" (by Robert Hotz), *Aviation Week & Space Technology*, October 14, 1957, p. 21.
25. "USAF Pushes Pied Piper Space Vehicle," *Aviation Week & Space Technology*, October 14, 1957, p. 26.
26. "Memorandum For the Chairman, Subject: Chairman's Request For Information on Pied Piper Change of Name," from Director Division of Reactor Development AEC, February 24, 1958. (From DOE archives.)
27. James R. Killian, *Sputnik, Scientists and Eisenhower* (Cambridge & London: The MIT Press, 1977), p. 119. (Emphasis in original.)
28. *Ibid.*, pp. 144-145.
29. Quoted in *ibid.*, p. 140 (from a private memoir written by Dr. Keith Glennan).
30. Description of SNAP-1 and SNAP-3 concepts and developments taken from *SNAP . . . Press Kit*, op. cit., ("Attachment 4, History. . .," pp. 2-3). (From DOE archives.)
31. Information on radioisotope sales from *Twenty-third Semi-annual Report of the U.S. Atomic Energy Commission* (Washington: U.S. Government Printing Office, January 1958), p. 158.

CHAPTER III

1. John M. Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge, Mass., and London, England: The MIT Press 1970) p. 13.
2. *Ibid.*
3. Homer E. Newell, *Beyond The Atmosphere* (Washington: National Aeronautics and Space Administration, 1980), p. 89.
4. *Ibid.*, pp. 95-96.
5. *Ibid.*

6. "AEC Establishes Aerospace Nuclear Safety Board," AEC public release, November 23, 1959. (From DOE archives.)
7. Letter from Keith Glennan to John McCone, May 12, 1960. (From DOE archives.)
8. *Ibid*
9. Letter of transmittal (McCone to Glennan) for "Memorandum of Understanding," August 30, 1960. (From DOE archives.)
10. From *Hearings Before the Joint Committee on Atomic Energy, Congress of the United States, Eighty-seventh Congress, First Session, on Development, Growth, & State of the Atomic Energy Industry*, February 21, 23, 24, 27, 28, March 1, 2, and 3, 1961 (quotations pp. 19-20.)
11. "Remarks by Leland J. Haworth, Commissioner U.S. Atomic Energy Commission At Luncheon of Space Nuclear Conference The American Rocket Society . . . May 5, 1961." (From DOE archives.)
12. *Summary of Attitudes Encountered in Brazil Toward Operational SNAP Devices* (by J. G. Morse, Manager Auxiliary Power Systems Department, Nuclear Division, The Martin Company, June 5, 1961). (From DOE archives.)
13. Information about Dr. Lapp's call and the hurried preparation of a safety document obtained in a personal interview with George "Mike" Dix. Mr. Dix also indicated that a comprehensive safety report had already been prepared earlier for the SNAP-1.
14. Personal interview with Mike Dix.
15. See, for example, "Nuclear Power in Outer Space," *Nucleonics*, August 1960, pp. 58-63.
16. "Isotopic Power Ready for Space But Caution Delays Use," *Nucleonics*, July 1960, pp. 26-27.
17. *Ibid*.
18. "Announcement No. E-69: Aerospace Nuclear Safety Conference," May 27, 1960 (AEC). (From DOE archives.)

19. "Aerospace Nuclear Safety," memorandum for Chairman McCone, September 30, 1960, prepared by Director Division of Reactor Development. (From DOE archives.)
20. *Ibid.*
21. *Safety Aspects of the Nuclear Space Program* (Remarks by Lt. Col. Joseph A. Connor, Jr., . . . Before the Annual Conference of the Atomic Industrial Forum, Fairmont Hotel, San Francisco, California, December 15, 1960). AEC press release, December 15, 1960. (From DOE archives.)
22. Glenn T. Seaborg, *Kennedy, Krushchev and the Test Ban* (Berkeley, Los Angeles, London: University of California Press), first page of "Preface."
23. Personal Interview with Glenn Seaborg.
24. Information on Seaborg's previous scientific work with radioactivity and isotopes taken from "Glenn T. Seaborg," *Who's Who in America*, 42nd Edition, 1982-1983, p. 2997.
25. Harold Finger (in a personal interview) stated that in Webb's mind NASA was not only a technical R&D center but a management R&D organization. Webb's own writings clearly bear out this approach and philosophy.
26. Arnold S. Levine, *Managing NASA in the Apollo Era* (Washington: National Aeronautics and Space Administration, 1982), "Preface" (by James E. Webb), p. XII.
27. *Ibid*, p. XIII.
28. Personal interview with Dr. Seaborg.
29. Personal interview with James E. Webb.
30. Recollections and expressions of philosophy by James E. Webb obtained in personal interview. Quotation at end is from Levine ("Preface"), op. cit., p. XIII.
31. Personal interview with Glenn Seaborg.
32. Kennedy quotation taken from *Public Papers of the Presidents of the United States: John F. Kennedy, 1961* (Washington: U.S. Government Printing Office, 1962), pp. 403-494.

33. Webb's recollections and point of view are from a personal interview.
34. Personal interview with John Dassoulas.
35. *Ibid.*
36. Information from personal interviews with John Dassoulas and Paul Dick.
37. Quoted material on specific initiation of the program for SNAPs at DOD request is taken from a letter to the Vice President of the U.S. (Chairman of the National Aeronautics and Space Council) from John Graham (Acting Chairman of AEC) on May 10, 1961, urging approval by the Council of the use of SNAP-3 on TRANSIT. (From DOE archives.)
38. *Safety Analysis of the Transit Generator* (by D.G. Harvey and T.J. Dobry, The Martin Company), MND-P-2479, March 1961, p. VII. (From DOE archives.)
39. "Impact Test Results for the Transit Generator," memorandum for Seaborg and the Commissioners from AEC General Manager, April 22, 1961. (From DOE archives.)
40. "Summary of Hazards Analysis of Transit Generator," April 26, 1961, by Facilities Licensing, Division of Licensing and Regulation, AEC. (From DOE archives.)
41. "Joint Meeting Concerning Nuclear Safety Responsibilities for Transit," memorandum to Director Division of Reactor Development from Chief SNAP Branch, May 4, 1961. (From DOE archives.)
42. Letter to Secretary McNamara from John Graham (Acting Chairman, AEC), May 8, 1961. (From DOE archives.)
43. Letter to the President from Glenn Seaborg, May 6, 1961. (From DOE archives.)
44. Letter to Chet Holifield (Chairman, JCAE) from Glenn Seaborg. (From DOE archives; date unclear.)
45. "Nuclear Power Is A Space Issue," *New York Times*, May 16, 1961. (From DOE archives; page number not discernible.)

46. "U.S. Hesitates to Use Atom Device In Satellite Flight Across Cuba," *New York Times*, May 19, 1961, p. 2. (From DOE archives.)
47. Memorandum, Seaborg to General Manager, June 8, 1961 (in DOE archives), accompanied by note: "This memo not sent. Commission instructed me to convey this message orally to General Manager."
48. Letter to Chairman Seaborg from his Special Assistant, Howard C. Brown, Jr., reporting conversation with Gilpatric of DOD, June 23, 1961. (From DOE archives.)
49. Personal interviews with Robert Carpenter and John Dassoulas.
50. Account taken from personal interviews with Carpenter and Dassoulas.
51. "3-in-1 Satellite Is World's First," *New York Journal American*, June 29, 1961, p. 1.
52. "World's First 'Atomic Battery' In Space Continues To Operate Successfully," AEC press release, September 8, 1961. (From DOE archives.)
53. *Nuclear Power And Space* (Remarks by Dr. Glenn T. Seaborg . . . Prepared for Delivery at International Symposium on Aerospace Nuclear Propulsion, Hotel Riviera, Las Vegas, Nevada, October 24, 1961. AEC press release. (From DOE archives.)
54. Letter from Seaborg to Vice President Lyndon Johnson, November 4, 1961. (From DOE archives.)
55. Letter from Lyndon Johnson to Glenn Seaborg, November 6, 1961. (From DOE archives.)

CHAPTER IV

1. Impressions of organizational atmosphere and relationships at AEC/ERDA from personal interview with Bob Carpenter.
2. *Ibid.*

3. Letter to John McCone (Chairman, AEC) from T. Keith Glennan (NASA Administrator), August 3, 1960. (From DOE archives.)
4. Information taken from "Opening Statement of Dr. Frank Pittman Before the JCAE Subcommittee on Research and Development and Radiation." (From DOE archives.)
5. Letter to AEC General Manager from Robert C. Seamans, Jr. (NASA Associate Administrator), August 8, 1962. (From DOE archives.)
6. *Hearings Before the Subcommittee on Research, Development, & Radiation of the Joint Committee on Atomic Energy Congress of the United States, Eighty-seventh Congress Second Session, on Space Nuclear Power Application*, September 13, 14, & 19, 1962 (quotations, pp. 10 and 12-13.)
7. Information on key international events in the period described taken from Seaborg (*Kennedy . . . and the Test Ban*), op. cit.
8. Quotations in this paragraph are taken from *Public Papers of the Presidents of the United States: John F. Kennedy, 1963* (Washington: Government Printing Office, 1964), pp. 460-461 and 463-464.
9. *Ibid.*, pp. 280-282.
10. Quoted materials in text of paragraph are from "Kennedy's Offer Stirs Confusion, Dismay" (by Alfred P. Alibrando), *Aviation Week & Space Technology*, September 30, 1963, p. 26. Offset quotation is from "Kennedy's Space Boomerang" (by Robert Hotz) in the same issue of *Aviation Week* (p. 21).
11. "New National Space Policy Needed" (by Robert Hotz), *Aviation Week & Space Technology*, November 4, 1963. p. 21.
12. "Krushchev Puts Russia Back Into Manned Lunar Landing Race" (by Alfred P. Alibrando), *Aviation Week & Space Technology*, November 11, 1963, p. 29.

13. "An Indelible Mark" (by Robert Hotz), *Aviation Week & Space Technology*, December 2, 1963, p. 21. President Kennedy is quoted from *Public Papers of the Presidents of the United States: John F. Kennedy, 1963* (Washington: U.S. Government Printing Office, 1964), p. 883.
14. See *Newsweek* issues for September 2 and September 9 (the march on Washington and the test ban treaty), October 21 (poll of whites regarding the Negro revolt), November 5 (Vietnam showdown.)
15. "Snap-9A Isotope Generator Powers Navy Transit Navigation Satellite," *Aviation Week & Space Technology*, October 7, 1963, p. 37.
16. "Anniversary Statement by Dr. Glenn T. Seaborg, Chairman, U.S. Atomic Energy Commission," June 29, 1962, AEC press release. (From DOE archives.)
17. See, for example, "The President's Policy Statements on Outer Space," draft from NASA circulated at AEC on June 19, 1962. (From DOE archives.)
18. Letter from NASA Associate Administrator to AEC General Manager, July 8, 1963 — referring to a previous forecast of November 1962. (From DOE archives.)
19. "Nuclear Space Projects — Briefing of the Senate Committee on Aeronautical and Space Sciences," April 30, 1963. (From DOE archives.)
20. All facts in the preceding summary taken from *SNAP Fact Sheet* (Atomic Energy Commission), September 1, 1963. (From DOE archives.)
21. Information on the strontium-90 device contracts is from "AEC To Negotiate Contracts For Development of Space Nuclear Power Generator," November 15, 1963, AEC press release. (From DOE archives.)
22. "Summary Notes of Briefing By Representatives of the Martin Company on the SNAP Program," Tuesday, March 5, 1963 at D.C. office of AEC; published at AEC on March 29, 1963. (From DOE archives.)

23. "Summary Notes of Briefing On SNAP Program," Wednesday, February 13, 1963 at D.C. office of AEC; published at AEC on May 27, 1963. (From DOE archives.)
24. "Use of SNAP-9A In Navigation Satellites: Report to the General Manager by the Director Division of Reactor Development," transmitted August 1, 1963 by Secretary AEC. (From DOE archives.)
25. "Supplement to AEC 1000/75—Approval To Use SNAP-9A On TRANSIT: Report to the General Manager by the Director of Reactor Development," August 26, 1963. (From DOE archives.)
26. "Satellite, First To Be Wholly Powered By Nuclear Energy, Now In Orbit," September 30, 1963, AEC press release. (From DOE archives.)
27. "Second Satellite Wholly Powered By Nuclear Energy, Launched Recently; Operating Successfully," December 6, 1963, AEC press release. (From DOE archives.)
28. "Status Report on SNAP-9A," memorandum from Director Division of Reactor Development to AEC General Manager, February 5, 1964. (From DOE archives.)
29. Personal interview with Mike Dix.
30. *Procedures for Securing Clearance* (by Thomas B. Kerr), no date, National Aeronautics and Space Administration, pp. 1-2. Document provided to interviewer at time of personal interview with Mr. Kerr.
31. *Ibid.*, p. 2.
32. "Safety Review of Aerospace Nuclear Projects," AEC memorandum to the Chairman and Commissioners from the General Manager, January 14, 1963. (From DOE archives.)
33. "Expert Review and Advice on Space Nuclear Safety Problems: Report to the Commission by the General Manager and the Director of Regulation," April 1, 1964. (From DOE archives.)
34. *SNAP Fact Sheet*, September 1, 1963. (From DOE archives.)

35. Personal interview with Mike Dix.
36. "AEC 1000/75—Approval To Use SNAP-9A On TRANSIT And AEC 1000/76—Supplement to AEC 1000/75," AEC memorandum to Director of Division of Reactor Development from Secretary AEC, September 3, 1963. (From DOE archives.)
37. "Memorandum for Chairman Seaborg, Subject: SNAP-9A," from General Manager, AEC, April 23, 1964. (From DOE archives.)
38. Press release (April 22, 1964) attached to letter from Seaborg to Dr. Welsh (Executive Secretary National Aeronautics and Space Council), April 23, 1964. (From DOE archives.)
39. "Foreign Reaction to SNAP-9A Failure to Orbit," AEC memorandum to Chairman and Commissioners from Director Division of Public Information, June 5, 1964. (From DOE archives.)
40. See, for example, letter to Senator Morse from Seaborg, October 29, 1964. (From DOE archives.)
41. Letter from Dr. Welsh to Glenn Seaborg, November 4, 1964, commending the requested presentation by Dr. Joseph Lieberman and Mr. Robert Carpenter (From DOE archives.)
42. Letter from Seaborg to Senator Pastore (Chairman JCAE) and accompanying press release, January 5, 1965. (From DOE archives.)
43. Personal interview with Bob Carpenter.
44. Personal interview with Mike Dix.
45. Personal interview with Tom Kerr.
46. *Ibid.*
47. See "Johnson Stress on Military Space Seen," "Johnson Familiar With Aerospace Facilities," and "Continued Space Effort," *Aviation Week & Space Technology*, December 2, 1963 (pp. 26ff and 28). President Johnson quoted from

- Public Papers of the Presidents of the United States: Lyndon B. Johnson, 1963-1964, Book I* (Washington: U.S. Government Printing Office, 1965), p. 8.
48. "Another Step Forward" (by Robert Hotz), *Aviation Week & Space Technology*, December 16, 1963, p. 25.
 49. "Nuclear Flight Program Cancelled As President Trims FY '65 Budget," *Aviation Week & Space Technology*, December 30, 1963, p. 22.
 50. "South Vietnamese Raiders Extending War" (by Larry Booda) and "Options in Vietnam," *Aviation Week & Space Technology*, April 6, 1964 (pp. 16-19).
 51. "Washington Roundup," *Aviation Week & Space Technology*, April 27, 1964, p. 25.
 52. "Preliminary Response by James Webb to President's Letter of January 30, 1964," sent to Glenn Seaborg on May 18, 1964. (From DOE archives.)
 53. "The SNAP Report: Suggested Outline," memorandum for the Commissioners, January 14, 1963. (From DOE archives.)
 54. "Tentative Schedule—SNAP Program Study Seminars," memorandum for the Commissioners, January 31, 1963. (From DOE archives.)
 55. "Memorandum For Commissioner Tape: SNAP Report," from James T. Ramey, January 24, 1964. (From DOE archives. Emphasis in original.)
 56. See "Conclusions" in *Systems for Nuclear Auxiliary Power: A Report by the Commission—1964*, TID-20103 (Washington: U.S. Atomic Energy Commission, February 1964). (Copy from DOE archives. Emphasis in original.)
 57. Letter to Seaborg from Welsh (NASC), February 7, 1964. (From DOE archives.)
 58. "Agreement Between The Atomic Energy Commission and the National Aeronautics and Space Administration on Space Nuclear Systems" (proposed agreement, attached to memorandum for Chairman and the Commissioners pre-

pared by AEC General Manager, January 22, 1965). (From DOE archives.)

59. "AEC Creates Division of Space Nuclear Systems: Harold B. Finger Named Director," AEC public announcement, June 17, 1965. (From DOE archives.)
60. *From Hearings Before The Joint Committee on Atomic Energy, Congress of the United States Eighty-ninth Congress First Session on Space Nuclear Generators*, August 6, 1965, Washington: U.S. Government Printing Office, 1966, p. 10.
61. Organization charts taken from "Appendix 4 . . . Address by Harold B. Finger . . . [to the] Atomic Industrial Forum 12th Annual Conference . . . Washington, D.C., November 17, 1965"; in published proceedings of *Hearings Before The Joint Committee on Atomic Energy (On Space Nuclear Power Generators)*, August 6, 1965 (Washington: U.S. Government Printing Office, 1966), p. 251.

CHAPTER V

1. A good account of this (and other) APOLLO missions appears in Edgar M. Cortright (editor), *Apollo Expeditions to the Moon* (Washington: National Aeronautics and Space Administration, 1975).
2. "The Long War" (by Robert Hotz), *Aviation Week & Space Technology*, January 3, 1966, p. 11.
3. Information on changed fuel amounts taken from *Nuclear Safety of Space Nuclear Power Systems* (by George P. Dix), no date, U.S. Atomic Energy Commission. (Document supplied by Mr. Dix at time of personal interview.)
4. See "Address By Harold B. Finger . . . [to the] Atomic Industrial Forum . . .," *op. cit.*, p. 250.
5. *Ibid.*, pp. 252-253 (offset quotation, p. 253).
6. *Ibid.*, p. 253.
7. Description of Sandia taken from memorandum from Har-

old Finger to Assistant General Manager for Reactors, AEC, "Assignment of Space Isotope Power To An AEC Laboratory," October 18, 1965. This memorandum actually describes discussions with, and strengths and weaknesses of, *three* candidate AEC labs (Brookhaven, Oak Ridge, and Sandia) prior to the selection of Sandia. Information on Sandia, pp. 6-7. (From DOE archives.)

8. Information in this paragraph taken from personal interview with Harold Finger.
9. Personal interview with Bernard Rock.
10. "AEC Doubles Space Radioisotope Efforts," *Aviation Week & Space Technology*, January 10, 1966, p. 78.
11. *Ibid.*
12. Memorandum, Finger to Director, Office of Congressional Relations, "Suggested Outline for Discussion of Space Nuclear Systems With the Vice President," March 9, 1966. (From DOE archives.)
13. Quoted from Robert Seamans' remarks to the National Space Club in November 1965 cited in "Washington Scene: AAP—Wednesday's Child" (by Henry Simmons), *Astronautics and Aeronautics*, February 1966, p. 5.
14. "Washington Scene; AAP—Wednesday's Child," (by Henry Simmons), *Astronautics and Aeronautics*, February 1966, p. 5.
15. Personal interview with Milton Klein.
16. Personal interview with Bernard Rock.
17. See memorandum for AEC General Manager from Harold B. Finger, March 1, 1966, "Subject: Memorandum of Understanding Between AEC and NASA Concerning The Use of Isotopic SNAP Devices For NASA Space Vehicles." (From DOE archives.)
18. "An Interagency Agreement Between the Atomic Energy Commission and the National Aeronautics and Space Administration Concerning SNAP Devices For NASA Space Vehicles," no date; however, effective date of agreement shown as September 1965. (From DOE archives.)

19. Personal interview with Mike Dix.
20. *Ibid.*
21. Information in paragraph obtained from personal interviews with Paul Dick and Guy Linkous of Teledyne.
22. Information from AEC "Discussion Paper: Use of SNAP-19 Generators on the NASA Nimbus-B Spacecraft," November 13, 1967. (From DOE archives.)
23. See memorandum for Chairman Seaborg (and the Commissioners), "Subject: Use of SNAP-19 Generators on NASA Nimbus-B Spacecraft," by Director of Regulation, November 29, 1967. (From DOE archives.)
24. Memorandum to Milton Klein and Peter A. Morris (Director, Reactor Licensing) from Secretary AEC, "Subject: AEC 1000/120 — Use of SNAP-19 Generators on NASA Nimbus-B Spacecraft," January 16, 1968. (From DOE archives.)
25. Letters from Seaborg to Director DDR&E and to Administrator NASA, May 15, 1968. (From DOE archives.)
26. Personal interview with Guy Linkous.
27. Personal interview with Harry Press.
28. Information taken from letter from General Manager AEC to Executive Director JCAE, May 20, 1968. (From DOE archives.)
29. Personal interview with Mike Dix.
30. "Nimbus SNAP-19 Generators Recovered" (picture caption), *Aviation Week & Space Technology*, October 14, 1968, p. 16.
31. "Second Nimbus-B," NASA news release, June 28, 1968. (From DOE archives.)
32. Letter from Acting Administrator NASA to the Vice President, March 13, 1969. (From DOE archives.)
33. Letter from the Vice President to Acting Administrator NASA, March 21, 1969. (From DOE archives.)

34. Personal interview with Harry Press.
35. Information obtained from Mike Dix.
36. These identified elements of ALSEPs are taken from Cortright (editor), *op. cit.*, pp. 240-241.
37. Memorandum for Chairman Seaborg and the Commissioners prepared by Director Division of Reactor Development and Technology, "Subject: Selection of Contractor For Isotopic Orbital Space Power Unit." January 14, 1965. (From DOE archives.)
38. "Report to the General Manager . . . : Approval of SNAP-27 Program And Authority To Execute Modification No. 2 To Contract . . . With The General Electric Company For The Conduct Of SNAP-27 Work," transmitted by Acting Secretary AEC, April 7, 1968. (From DOE archives.)
39. Personal interview with Augustine Pitrolo.
40. *Ibid.*
41. *Ibid.*
42. *Ibid.*
43. In a personal interview Webb stressed this point.
44. Interview with James Webb.
45. Notes of "Telephone Call from George Mueller" (NASA) from Cape Kennedy, 3:00 P.M., October 10, 1968. (From DOE archives.)
46. Letter from George E. Mueller to Glenn T. Seaborg, November 13, 1968. (From DOE archives.)
47. *Ibid.*
48. Information from personal interview with Augustine Pitrolo and from Cortright (editor), *op. cit.*, p. 225. Astronauts quoted from Cortright.
49. Taken from "Exuberance Sets Tone of First EVA," *Aviation Week & Space Technology*, November 24, 1969, pp. 19-21, quotation, p. 20.
50. Personal interview with Augustine Pitrolo.

51. "Scientists Concede Value of Man In Lunar Experiment Deployment," *Aviation Week & Space Technology*, December 1, 1969, pp. 20-21.
52. Personal interviews with Pitrolo and Dix.
53. Personal interviews with Carpenter, Dix, and Pitrolo.
54. "Response To Queries On SNAP-27 Reentry," by Director AEC Division of Public Information, April 28, 1970. (From DOE archives.)
55. "Washington Roundup," *Aviation Week & Space Technology*, April 6, 1969, p. 17.

CHAPTER VI

1. "Overlooked Space Program Benefits," *Aviation Week & Space Technology*, March 15, 1971, p. 11.
2. "Aerospace Business in the Seventies" (by Abraham Hyatt, North American Rockwell, Corp.), *Astronautics and Aeronautics*, July 1971, p. 49.
3. Budget figures from *ibid.*
4. "Report From The Director, Space Nuclear Systems Division To The General Manager (for information meeting item 'AEC/User Agency Funding For Space Nuclear Power Systems'," May 21, 1971, pp. 1-4. Offset quotation, p. 4. (From DOE archives.)
5. Personal interview with Milton Klein.
6. See Klein's testimony in *AEC Authorizing Legislation Fiscal Year 1972: Hearings Before the Joint Committee on Atomic Energy Congress of the United States Ninety-Second Congress First Session*, March 9, 16 & 17, 1971, Part 3 (Washington: U.S. Government Printing Office, 1971), pp. 1249 & 1251.
7. "Correspondence on Sandia Participation In Space Electric Power Program," October 23, 1970. (From DOE archives.)
8. Opinion expressed by Bernard Rock in a personal interview.

9. AEC press release, January 5, 1973, "Enclosure 1" to letter from AEC General Manager to Honorable John O. Pastore, Chairman JCAE on the same date. (From DOE archives.)
10. *Ibid.*
11. Personal interview with John Dassoulas.
12. Description of this RTG taken from "Nuclear Safety Review Procedures For Navy Satellite Mission," June 1, 1970. (From DOE archives.)
13. Personal interview with John Dassoulas.
14. Personal interviews with Augustine Pitrolo and Tom Kerr.
15. "Apollo 17/SNAP-27 Status Report," December 13, 1972. (From DOE archives.)
16. "Electric Power Systems For Space: A Progress Report," *Astronautics and Aeronautics*, December 1975, p. 26.
17. See *Remarks [By Congressman Chet Holifield, Chairman JCAE] On The Occasion Of Presenting A SNAP-27 Generator To The Smithsonian Institute* (sic), December 9, 1970. (From DOE archives.)
18. See "The Last Liftoff" (by Robert Hotz), *Aviation Week & Space Technology*, December 11, 1972, p. 17.
19. Personal interview with Charles Hall.
20. *Ibid.*
21. *Ibid.* (Hall was not sure, at first, of the AEC representative's identity, but finally decided during the interview it was Bob Carpenter.)
22. *Ibid.*
23. Personal interviews with Charles Hall and Guy Linkous.
24. Definition from *U.S. Radioisotopic Thermoelectric Generator Space Operating Experience (June 1961-December 1982)*, (by Gary L. Bennett, James J. Lombardo, & Bernard J. Rock), paper presented before the 18th Intersociety Energy Conversion Engineering Conference, Orlando, Florida, August 21-26, 1983, note p. 6.

25. Personal interview with Charles Hall and Guy Linkous.
26. Information from "Use of Isotopic Nuclear Systems on the NASA PIONEER Spacecraft" (staff paper), December 30, 1971. (From DOE archives.)
27. Personal interviews with Charles Hall and Mike Dix. Hall told of the Bay Area newspaper coverage.
28. "Pioneer 10 Blazes Path to Jupiter, Beyond," *Aviation Week & Space Technology*, December 10, 1973, p. 21.
29. "Pioneer 11 Retargeted for Saturn Encounter," *Aviation Week & Space Technology*, March 25, 1974, p. 18.
30. "Pioneer's Success Buys Saturn Hopes," *Aviation Week & Space Technology*, December 9, 1974, p. 16.
31. Personal interview with Charles Hall.
32. Alice L. Buck, *A History Of The Atomic Energy Commission*, op. cit., p. 8.
33. See references to these missions in letter from James Fletcher (NASA Administrator) to William Anders (Commissioner AEC), June 7, 1974, (From DOE archives.)
34. Personal interview with Paul Dick.
35. Letter, Fletcher to Anders, June 7, 1974, op. cit. (From DOE archives.)
36. Letter from Anders to Fletcher, June 28, 1974. (From DOE archives.)
37. See *Nomination of Dr. Robert C. Seamans, Jr. To Be Administrator, Energy Research & Development Administration: Joint Hearing Before the Joint Committee on Atomic Energy Congress of the United States & the Committee on Interior & Insular Affairs of the U.S. Senate, Ninety-Third Congress Second Session*, December 11, 1974 (Washington: U.S. Government Printing Office, 1974), p. 7.

CHAPTER VII

1. See Daniel Ford, *The Cult of the Atom* (New York: A Touchstone Book Published by Simon & Schuster, Inc., 1982), p. 134.
2. See Elizabeth S. Rolph, *Nuclear Power and the Public Safety* (Lexington, Mass.: Lexington Books, 1979), pp. 152-153.
3. View expressed by Mike Dix in a personal interview.
4. Jack M. Holl, *The United States Department of Energy: A History* (Washington: U.S. Department of Energy, November 1982), p. 5.
5. *Organization and Functions Fact Sheet*, Department of Energy, Office of Public Affairs, October 1, 1977. (From DOE archives.)
6. Alice L. Buck, *A History of the Energy Research and Development Administration* (Washington: U.S. Department of Energy, March 1982), p. 63.
7. See Prentice C. Dean, *Energy History Chronology from World War II To the Present* (Washington: U.S. Department of Energy, August 1982), p. 63.
8. *Ibid.*, p. 66.
9. Personal interview with Robert Carpenter.
10. Personal interview with Mike Dix.
11. *Statement [of Dr. Richard W. Roberts, Assistant Administrator for Nuclear Energy] For The FY 1977 Authorization Hearings Before the Committee on Aeronautical and Space Sciences U.S. Senate*, February 3, 1976, p. 2. (From DOE archives.)
12. Personal interview with Bernard Rock.
13. See, for example, *Statement [of Dr. Richard W. Roberts, Assistant Administrator for Nuclear Energy] For The FY 1976 Appropriations Hearings, U.S. Congress*, no date. (From DOE archives.)

14. Mark Washburn, *Distant Encounters* (San Diego: Harcourt Brace Jovanovich, 1983), p. 6.
15. "Layoffs at Cape Total 2,000," *Aviation Week & Space Technology*, July 21, 1975, p. 18.
16. Account of President Carter's remarks taken from "Carter Discourages Major New Space Efforts," *Aviation Week & Space Technology*, May 30, 1977, p. 13.
17. "NASA's Loss of Thrust" (by George C. Wilson), *Astronautics and Aeronautics*, January 1978, pp. 6-7, 10; Webb quotation, p. 7.
18. Information from *Aeronautics and Space Report of the President: 1980 Activities*, (Washington: National Aeronautics and Space Administration, 1980), pp. 95-97; Appendixes B-1, B-2, and B-3.
19. Mark Washburn especially has made the point that in spite of terrestrial events that seemed to dull public interest in the Nation's space program, the Space Age had a dynamic of its own in sensitizing people and piercing their consciousness. See Washburn, *op. cit.*, pp. 7-9.
20. Personal interview with Gerald Soffen.
21. *Ibid.*
22. Information from personal interview with Robert Brouns, RTG program representative at Langley for the Viking missions.
23. *Ibid.*
24. Interview with Jerry Soffen.
25. Mark Washburn, *Mars At Last!* (New York: G.P. Putnam's Sons, 1977), p. 217.
26. Interview with Jerry Soffen.
27. *Ibid.*
28. "Information Memorandum: Status of SNAP-19 Radioisotopic Thermoelectric Generators Aboard the NASA VIKING II Lander," to ERDA Administrator from Director

- Division of Nuclear Research and Applications, January 27, 1977. (From DOE archives.)
29. From *Fact Sheet: Lincoln Experimental Satellites LES-8 and 9*, Office of Information, Air Force Systems Command, no date, p. 1. (From DOE archives.)
 30. *Ibid.*, p. 2.
 31. Telephone interview with Philip Waldron.
 32. *Information from ERDA: Multi-Hundred Watt Nuclear Generator — Power for LES Satellites 8 & 9*, July 1975, p. 1. (From DOE archives.)
 33. *Ibid.*, p. 2.
 34. "Questions and Answers on LES 8 and 9," p. 4, in *ERDA Public Information Plan LES 8/9*, September 1975. (From DOE archives.)
 35. *Information from ERDA: . . .*, op. cit., pp. 1-2.
 36. Personal interview with Augustine Pitrolo.
 37. Telephone interview with Phil Waldron.
 38. "DOD, ERDA Seek Space Power Focus," *Aviation Week & Space Technology*, September 13, 1976, pp. 79 and 83.
 39. Information in the first two paragraphs taken from Washburn, *Distant Encounters*, op. cit., pp. 48-49.
 40. Personal interview with Vincent Truscello.
 41. *Ibid.*
 42. *Space Nuclear Systems Briefing Book*, Department of Energy, February 1982 (section on "Use of Nuclear Power in Space By The United States of America," p. 9). (From DOE archives.)
 43. "ERDA News Feature: Nuclear Power To Make Possible Longest Space Mission," July 29, 1977, p. 1. (From DOE archives.)
 44. Personal interview with Rod Mills.

45. "VOYAGER: Running A Planetary Post Pattern" (by Mark D. Zimmerman), *Machine Design*, August 25, 1977, pp. 26, 29.
46. *Ibid.*, p. 29.
47. Washburn, *Distant Encounters*, op. cit., p. 83.
48. *Ibid.*
49. "Technology: Plutonium Power for Space Exploration," *New York Times*, August 31, 1977. (From DOE archives; page number not discernible.)
50. "Space Nuclear Power Gains Foreseen," *Aviation Week & Space Technology*, October 17, 1977, p. 129.
51. *Program Plan: Office of Special Nuclear Projects (Space and Special Radioisotopic Systems Applications, Department of Energy)*, Revised 6/12/84, p. 13. (From DOE archives.)
52. "Solar-Polar Plans Advance Despite Pullout by NASA," *Aviation Week & Space Technology*, December 28, 1981, p. 12.
53. "Space . . . Power Gains . . .," *Aviation Week . . .*, op. cit., p. 129.
54. *Nuclear Electric Power For Space Systems: Technology Background And Flight Systems Program* by Gary L. Bennett, James J. Lombardo, and Bernard J. Rock, Space and Terrestrial Systems Division, U.S. Department of Energy) paper delivered at 16th Intersociety Energy Conversion Engineering Conference, Atlanta, Georgia, August 9-14, 1981, p. 3.
55. See Holl, op. cit., p. 8.
56. *Ibid.*
57. "Technology's Brighter Image," *Machine Design*, July 24, 1980, p. 67.
58. "NASA Moves to Salvage Planetary Program," *Aviation Week & Space Technology*, November 2, 1981, p. 16.

59. "Science Academy Asks Caution In Research, Development Cuts," *Aviation Week & Space Technology*, November 2, 1981, p. 16.
60. "Better Than Nothing" (by William H. Gregory), *Aviation Week & Space Technology*, July 12, 1982, p. 13. President Reagan quoted from *Public Papers of the Presidents of the United States: Ronald Reagan, 1982, Book II* (Washington: U.S. Government Printing Office, 1983), p. 892.

CHAPTER VIII

1. Personal interview with Jerry Soffen.
2. Personal interview with Rod Mills.
3. Personal interviews with Vincent Truscello and Gerald Stapfer.
4. Personal interview with Guy Linkous.
5. Personal interview with Bob Carpenter.
6. Holl, op. cit., pp. 9-10.
7. *Ibid.*, p. 10.
8. Personal interview with Bernard Rock.
9. *Program Plan: . . . 6/12/84*, op. cit., p. 3.
10. *Ibid.*, p. 6.
11. Personal interview with Bernard Rock.
12. See, for example, "Bean-Counting the Solar System" (by William H. Gregory), *Aviation Week & Space Technology*, December 14, 1981, p. 11.
13. Washburn, *Distant Encounters*, op. cit., p. 262; citation of project scientist, *ibid.*

APPENDIX A. CHRONOLOGY

143

Time Period	Milieu-Defining Events	Institutional Events	Technical Events & Developments
1896			H Becquerel discovers radioactivity
1913			H G J. Moseley reports construction of first nuclear battery
1945			Nuclear battery (of Lehanov & Bellakov) generates 10 ⁶ amps. device built by P H Miller using PO-210
July-August 1945	First A-bomb detonated at Alamogordo. Hiroshima and Nagasaki bombs dropped. "Atomic Age" begins		
June-July 1946	Operation Crossroads conducted at Bikini		
August 1946		AEC established by Atomic Energy Act	
Jan. 1947		AEC begins operations under David E. Lilienthal	
Oct 1947		AEC appoints Industrial Advisory Group to investigate peaceful uses of atomic energy	
1948-1952	U.S. conducts numerous atomic tests in Pacific & Nevada; Soviets detonate their first A-bomb in 1949, first U.S. test of experimental thermonuclear device at Eniwetok in 1952		
July 1950		Gordon Dean becomes chairman of AEC	
1951			AEC lets series of contracts to study 1-kw electrical space power plant using reactors or isotopes
1952			RAND issues Project Feedback report discussing radioisotopic power for space. Several companies recommend using isotopes for space power as result of AEC contracts
Nov. 1952	Eisenhower elected President		
July 1953	Eisenhower delivers "Atoms for Peace" speech before U.N.		
Dec 1953	Atomic Energy Act of 1954 gives added impetus to development of peacetime atomic uses & private development of reactors		
Aug. 1954			
1954			K C. Jordan & J H. Birden build nuclear thermoelectric generator at Mound Laboratory

July 1955	Eisenhower proposes "Open Skies" policy for mutual aerial inspection during Geneva Summit		
Aug 1955		Space nuclear auxiliary power program begins in Joint AEC/DOD Aircraft Nuclear Propulsion Office	Upon DOD request. AEC begins work on nuclear auxiliary power system (reactor and RTG) for USAF uses
Feb 1956	AEC makes available 20,000 kilograms of U-235 for use in power and research reactors abroad and 20,000 kilograms for power reactors in U.S		
Mar 1956			AEC low-level effort undertaken by Martin-Baltimore for isotope-fuel space power unit for military satellite
July 1956		AF advanced reconnaissance system designated WS-117L	AEC proceeds with development of heat source for WS-117L
Nov. 1956	Eisenhower re-elected		
Oct 1957	Soviets launch Sputnik Name "Pied Piper" (AF code name for 117L) compromised by <i>Aviation Week</i> article		New unclassified title of "SNAP" authorized to refer to AEC's work on Space Nuclear Auxiliary Power
Nov 1957		President's Science Advisory Committee created	
July 1958		John McCone becomes chairman of AEC; NASA established	
Aug 1958	Eisenhower announces moratorium on weapons testing (to begin Oct. 31)	T Keith Glennan appointed first administrator of NASA	
Nov. 1958-Sept. 1961	U.S., Great Britain, & U.S.S.R agree to moratorium on atmospheric nuclear testing		
Jan. 1959	Eisenhower reveals existence of plutonium fuel (by-product of weapons development) for spacecraft		Martin Company and AEC demonstrate SNAP-3B to president
May 1960	Summit conference broken up by U-2 Incident		
Oct. 1960		Joint AEC/NASA Nuclear Propulsion Office created with Harold Finger as head	
Nov. 1960	Kennedy elected President.		
Feb. 1961		James E. Webb becomes head of NASA	
Mar. 1961		Glenn Seaborg named AEC chairman; atomic regulatory function placed under AEC Director of Regulations	
May 1961	Kennedy gives special message to Congress committing U.S. to reach the Moon "before decade is out"		

June 1961		SNAP 3-A orbits successfully on Navy TRANSIT 4A navigational satellite
Sept. 1961	Soviets break nuclear test moratorium; Kennedy orders resumption of underground testing	
Nov. 1961		Second SNAP 3-A orbits successfully on Navy TRANSIT 4B navigational satellite
Feb. 1962	John Glenn becomes first U.S. astronaut to orbit the earth	
April 1962	Kennedy authorizes resumption of atmospheric testing	
June 1962		Office of Science & Technology created in Executive Office of President
July 1962-June 1963	Underground tests conducted in Nevada	
Oct. 1962	Cuban Missile Crisis	
Aug 1963	Limited Nuclear Test Ban Treaty signing by U.S., Great Britain, & U.S.S.R.	
Sept 1963		SNAP 9-A orbits successfully on Navy TRANSIT-5BN-1 navigational satellite
Nov. 1963	Kennedy assassinated; Lyndon Johnson becomes President	
Dec. 1963		Second SNAP 9-A orbits successfully on Navy TRANSIT-5BN-2 navigational satellite
April 1964		Third SNAP 9-A launched on Navy TRANSIT-5BN-3, mission aborted (SNAP burned up on re-entry)
Aug. 1964	"Gulf of Tonkin" resolution begins heavy U.S. involvement in Vietnam; Johnson signs Private Ownership of Special Nuclear Materials Act	
Nov 1964	Johnson elected President	
Dec. 1964		AEC issues permit to construct Oyster Creek power plant—first civilian reactor built on competitive basis without government assistance
1965-1970	U.S. involvement in Vietnam increases criticism of government and protests about nuclear safety, begins to place stress on space budgets	

April 1965			SNAP 10 (reactor) successfully achieves orbit
June 1965		Harold Finger heads new Space Nuclear Systems Division of AEC	
Nov 1965		Finger decentralizes many space-nuclear functions to laboratories	
Jan 1967	Fire on APOLLO at Cape Kennedy delays lunar program		
Mar. 1967		Harold Finger receives new permanent assignment at NASA, replaced in AEC and RTG program roles by Milton Klein	
Feb 1968	Tet offensive in Vietnam		
April 1968	M L King, Jr assassinated		
May 1968			SNAP 19B2 launched on NIMBUS-B-1 weather satellite, mission aborted, heat source retrieved
June 1968	Robert F Kennedy assassinated		
July 1968	Treaty for Non-Proliferation of Nuclear Weapons signed		
Oct 1968		James Webb retires as administrator of NASA	
Nov 1968	Nixon elected President		Official decision made not to use SNAP device on first APOLLO lunar landing
Dec. 1968	APOLLO 8 orbits Moon		
Jan 1969		Council on Environmental Quality established	
Mar 1969		Thomas O Paine becomes NASA administrator	
April 1969			SNAP 19B3 launched on NIMBUS III, successfully achieves orbit
July 1969	APOLLO 11 lands on Moon		
Nov 1969			SNAP 27 device successfully placed on lunar surface on APOLLO 12 mission
Jan 1970		Russell Train appointed chairman of Council on Environmental Quality, first report of Council submitted to Congress in August 1970	

Mar. 1970	Treaty for Non-Proliferation of Nuclear Weapons ratified by U.S., Great Britain, U.S.S.R. & 45 other nations	
April 1970	Millions participate in first "Earth Day" anti-pollution demonstrations; APOLLO 13 mission aborted on way to Moon	SNAP 27 heat source returned to Tonga Trench in deep Pacific
May 1970	Campus unrest and Kent State killings follow president's announcement of Cambodian incursion	
July 1970		Environmental Protection Agency and National Oceanic & Atmospheric Administration created
Jan. 1971		SNAP 27 device successfully placed on lunar surface on APOLLO 14
June 1971		President proposes new Department of Natural Resources
July 1971		SNAP 27 device successfully placed on lunar surface on APOLLO 15
Aug 1971		James R. Schlesinger becomes chairman of AEC, replacing Seaborg
Nov 1971		David Gabriel replaces Milton Klein as director of Space Nuclear Systems Division
Feb 1972	President Nixon visits China, pledges "normalization of relations"	
Mar 1972		SNAP 19 device successfully launched on PIONEER 10 to Jupiter and beyond
April 1972		SNAP 27 device successfully placed on lunar surface on APOLLO 16
May 1972	President Nixon visits U.S.S.R., holds summit talks and signs SALT I	
Sept 1972		TRANSIT-RTG device successfully orbits on Navy TRIAD-01-1X navigational satellite
Nov. 1972	Nixon re-elected President	
Dec 1972		SNAP 27 device successfully placed on lunar surface on APOLLO 17

Jan 1973	North and South Vietnam and U.S. sign peace treaty "officially" ending Vietnam conflict and U.S. involvement	Joint AEC-NASA Space Nuclear Systems Office dissolved	Major cutbacks made in nuclear rocket propulsion & space reactor programs
Feb 1973		Dixy Lee Ray designated AEC chairman	
Mar 1973	Last GIs leave Vietnam		
April 1973		National Energy Office established in Executive Office of the President	SNAP 19 device successfully launched on PIONEER 11 to Jupiter, Saturn, and beyond
June 1973		President proposes to Congress a Department of Energy & Natural Resources & an independent Energy Research & Development Administration (ERDA)	
Summer 1973	Watergate hearings held in Washington		
Oct. 1973	Yom Kippur War. Arab OPEC countries embargo oil sales to U.S.	President establishes Energy Research and Development Advisory Council	
Nov 1973	President Nixon calls for Project Independence (re energy)		
Dec 1973	Gerald Ford sworn in as vice president following resignation of Spiro Agnew	Federal Energy Office established	SNAP 19 powers PIONEER 10 in its fly-by of Jupiter
May 1974		Federal Energy Administration Act establishes Federal Energy Administration incorporating Federal Energy Office	
Aug 1974	President Nixon resigns. Vice President Ford becomes President		
Oct. 1974		Ford signs Energy Reorganization Act of 1974 abolishing AEC and establishing ERDA and Nuclear Regulatory Commission	
Dec. 1974			SNAP 19 powers PIONEER 11 in its fly-by of Jupiter
Jan 1975		ERDA activated; Robert Seamans, Jr. named administrator. RTG programs become part of new Division of Nuclear Research and Applications	
April 1975	South Vietnam falls to North Vietnamese		
Aug 1975			SNAP 19 device successfully launched on VIKING 1 mission to Mars
Sept 1975			SNAP 19 device successfully launched on VIKING 2 mission to Mars

Mar. 1976			MHW devices successfully orbit on LES 8/9 DOD communication satellites
May 1976		ERDA assumes responsibility for managing Clinch River Breeder Reactor	
July-Aug. 1976			SNAP 19 devices successfully power VIKINGS 1 and 2 in Mars landings
Nov. 1976	Carter elected President		
April 1977	President announces U S will defer reprocessing of spent reactor fuel indefinitely, delays Clinch River development	President proposes a Cabinet-level Department of Energy (DOE)	
Aug. 1977		Energy Reorganization Act creates DOE, abolishing ERDA, Federal Energy Administration, and Joint Committee on Atomic Energy	MHW device successfully launched on VOYAGER 2 mission to Jupiter, Saturn, and beyond
Sept. 1977			MHW device successfully launched on VOYAGER 1 mission to Jupiter, Saturn, and beyond
Oct. 1977		DOE activated; James Schlesinger nominated as first Secretary of Energy	
Jan 1978	Soviet spy satellite containing nuclear reactor breaks up over northwest Canada		
Mar. 1978	Nuclear Non-Proliferation Act authorizes president to pursue international studies on proliferation of nuclear materials		
Jan. 1979	Revolution forces Shah of Iran to flee		
Mar 1979	Three Mile Island accident		
July 1979			MHW successfully powers VOYAGER 1 fly-through of Jovian system
Aug. 1979		Charles Duncan, Jr., named Secretary of Department of Energy	MHW successfully powers VOYAGER 2 fly-through of Jovian system
Sept. 1979			SNAP 19 successfully powers PIONEER 10 in Saturn fly-by
Nov. 1979	U.S. embassy hostages seized in Iran		
Nov. 1980	Ronald Reagan elected President		MHW successfully powers VOYAGER 1 in rendez vous with Saturnian system

Jan 1981

James B. Edwards named Secretary of Department of Energy

Feb 1981

Reagan presents "America's New Beginning: A Program for Economic Recovery" to Congress

Edwards announces major reorganization of DOE, creates Energy Policy Task Force

Aug 1981

MHW successfully powers VOYAGER 2 in rendez vous with Saturnian system

Oct 1981

Reagan announces nuclear energy policy, proposes accelerated deployment of methods for storing high-level radioactive waste, lifts ban on commercial reprocessing of nuclear fuel

TABLE B. TABLE OF ISOTOPE SYSTEMS IN SPACE

<i>Power Source</i>	<i>Sponsoring Agency and Spacecraft</i>	<i>Mission Type</i>	<i>Launch Date</i>	<i>Outcome</i>
SNAP-3A	Navy-Transit 4A	Navigational	June 29, 1961	Successfully achieved orbit
SNAP-3A	Navy-Transit 4B	Navigational	Nov. 15, 1961	Successfully achieved orbit
SNAP-9A	Navy-Transit-5BN-1	Navigational	Sept. 28, 1963	Successfully achieved orbit
SNAP-9A	Navy-Transit-5BN-2	Navigational	Dec. 5, 1963	Successfully achieved orbit
SNAP-9A	Navy-Transit-5BN-3	Navigational	April 21, 1964	Mission aborted; burned up on re-entry
SNAP-19B2	NASA-Nimbus-B-1	Meteorological	May 18, 1968	Mission aborted; heat source retrieved
SNAP-19B3	NASA-Nimbus-III	Meteorological	April 14, 1969	Successfully achieved orbit
SNAP-27	NASA-Apollo 12	Lunar	Nov. 14, 1969	Successfully placed on lunar surface
SNAP-27	NASA-Apollo 13	Lunar	April 11, 1970	Mission aborted on way to Moon; heat source returned to South Pacific Ocean
SNAP-27	NASA-Apollo 14	Lunar	Jan. 31, 1971	Successfully placed on lunar surface
SNAP-27	NASA-Apollo 15	Lunar	July 26, 1971	Successfully placed on lunar surface
SNAP-19	NASA-Pioneer 10	Planetary	Mar. 2, 1972	Successfully operated to Jupiter and beyond
SNAP-27	NASA-Apollo 16	Lunar	April 16, 1972	Successfully placed on lunar surface
Transit-RTG	Navy-"Transit" (TRIAD-01-1X)	Navigational	Sept. 2, 1972	Successfully achieved orbit
SNAP-27	NASA-Apollo 17	Lunar	Dec. 7, 1972	Successfully placed on lunar surface
SNAP-19	NASA-Pioneer 11	Planetary	April 5, 1973	Successfully operated to Jupiter, Saturn, and beyond
SNAP-19	NASA-Viking 1	Mars	Aug. 20, 1975	Successfully landed on Mars
SNAP-19	NASA-Viking 2	Mars	Sept. 9, 1975	Successfully landed on Mars
MHW	AF-LES 8	Communications	Mar. 14, 1976	Successfully achieved orbit

MHW	AF-LES 9	Communi- cations	Mar. 14, 1976	Successfully achieved orbit
MHW	NASA-Voyager 2	Planetary	Aug. 20, 1977	Successfully operated to Jupiter, Saturn, and beyond
MHW	NASA-Voyager 1	Planetary	Sept. 5, 1977	Successfully operated to Jupiter, Saturn, and beyond

APPENDIX C. BUDGETS FOR THE RTG PROGRAM

TABLE C: BUDGETS FOR THE RTG PROGRAM*
(Figures in thousands of dollars)

1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
46	485	1,890	3,526	2,386	1,170	4,189	11,279	27,260	28,643
1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
37,158	48,154	35,516	29,703	20,645	18,294	16,372	29,030	27,900	27,272
1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
25,085	29,137	24,100	34,000	33,700	36,000	34,246	37,962	27,735	27,950

Explanation of Budget Figure Aggregations

The space RTG program existed under many organizational names and within many organizational configurations. Therefore, it is not readily identifiable as a single, separate entity through the years since 1956. In preparing the budget figures and plottings for APPENDIX C, the following procedures were followed to identify dollar amounts that could be said to represent allocations to the "Space RTG Program":

- for the years 1956-1972, subtotals were obtained from budgets for "Space Electric Power Development" at the AEC. The specific line items included to arrive at the program totals were: "Radioisotopes," "Power Conversion Technology," "Space Nuclear Safety," and "Isotope Fuel Development." "Isotope Fuel Development" did not appear as a budget item until 1962.
- for the years 1973-1974, two items were taken from the "Space electric Power Program" budgets: "Total Isotope Systems *Operating*" funds and "Total Radioisotope Systems Equipment" funds.
- for 1975, two items were taken from the "Space Nuclear Systems Program" budget: "Total Space Electric Power *Operating*" funds and "Total Space Electric Power Equipment" funds.
- for 1976 and 1977, three items were taken from the "Nuclear Research and Applications Program" budgets: "Total Space Applications *Operating*," "Space Applications *Capital Equipment*," and "Advanced Isotope Separation Technology *Capital Equipment*" funds.

- for 1978 and 1979, totals for “Space and Terrestrial Applications *Operating Expenses*” “Space and Terrestrial Applications *Capital Equipment*” were used, but from each of these totals, sub-items for “*Terrestrial Isotope Applications*” were subtracted. In 1978, the latter amount was substantial for “Operating,” \$4,400 thousand; but in 1979, the figure on this item was \$4,300 thousand.
- for 1980-1982, subtotals under “Advanced Nuclear Systems” were taken for “Space and Terrestrial Applications *Operating Expenses*” and “. . . *Capital Equipment*,” and the sub-item “*Terrestrial Isotope Applications*” was subtracted, amounting to \$2,000 to \$2,700 thousand in each of those years.
- for 1983-1985, subtotals under “Advanced Nuclear Systems” were taken for “Space and Special Applications *Operating Expenses*” and “. . . *Capital Equipment*,” and the sub-item “*Special Applications*” (described as heavily terrestrially-oriented) was subtracted. This item amounted to -0- in 1983 and \$1,000 thousand in 1984 and 1985.

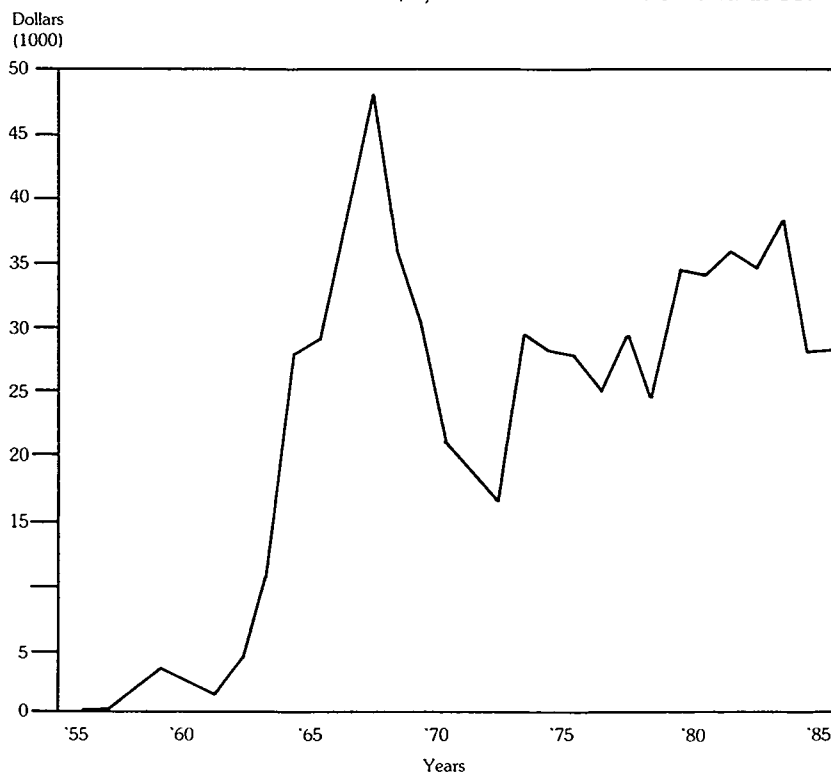


Figure C-1 RTG budget fluctuations

APPENDIX D. CHANGES IN ORGANIZATIONAL LOCATIONS OF THE RTG PROGRAM

During the years 1955-1982, the location of the RTG program within government agencies changed from time to time. (See organization charts in Figs. D-1 to D-7.)

1955-1960

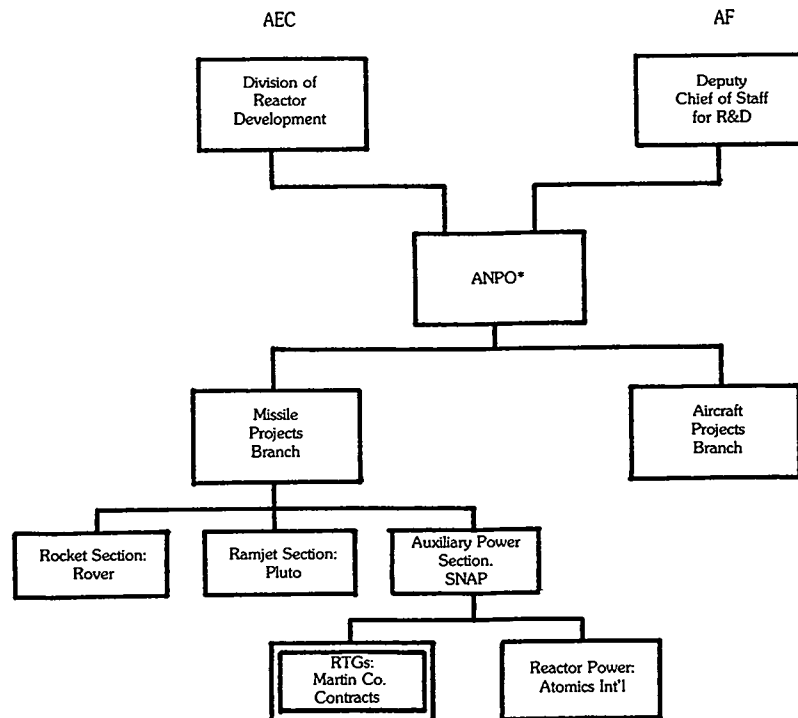


Figure D-1

*Aircraft Nuclear Propulsion Office (Joint AEC/AF).

1961-1965
(As of August 1960)

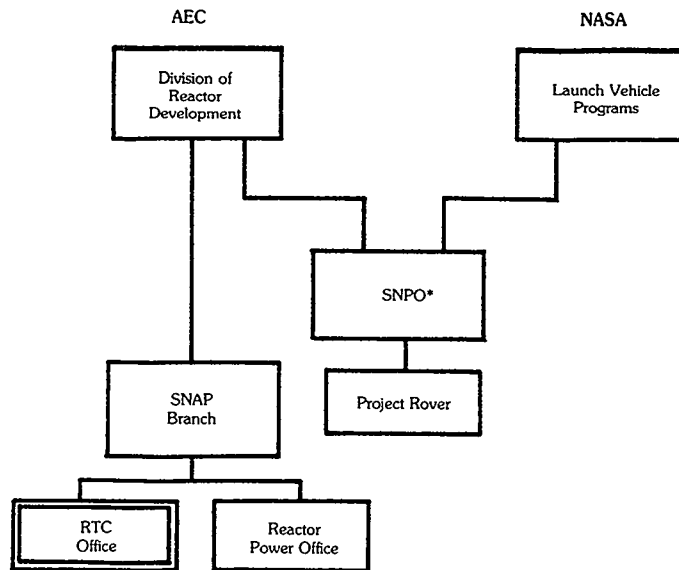


Figure D-2

*Space Nuclear Propulsion Office (Joint AEC/NASA).

1965-1972*

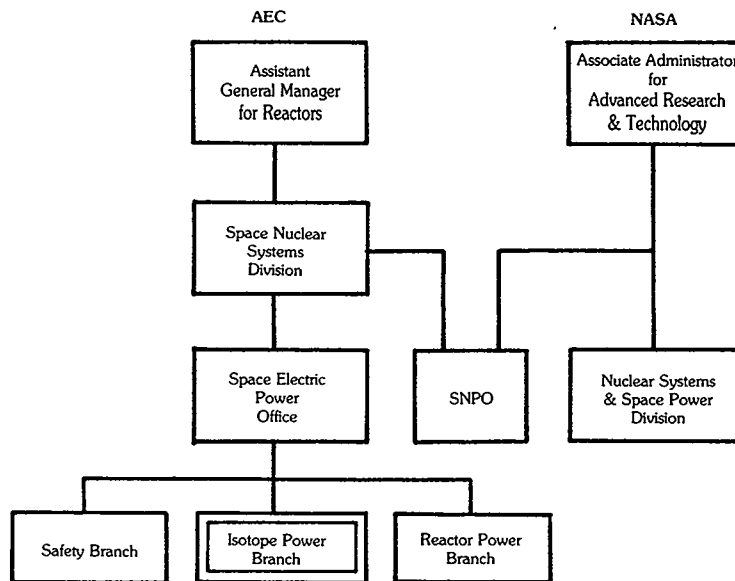


Figure D-3

*After creation of Space Nuclear Systems Division at AEC. There were 23 divisions at the Commission at this time.

1973-1974*
AEC

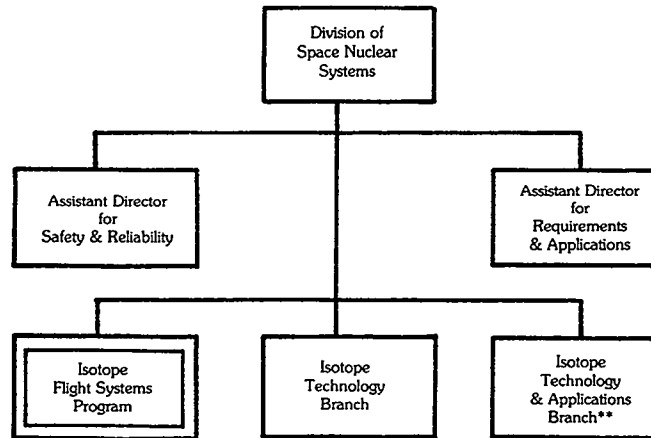


Figure D-4

*After dissolution of Joint AEC/NASA Space Nuclear Propulsion Office.

**Earlier divided into *Reactor Power Systems Branch* & *Power Conversion Branch*.

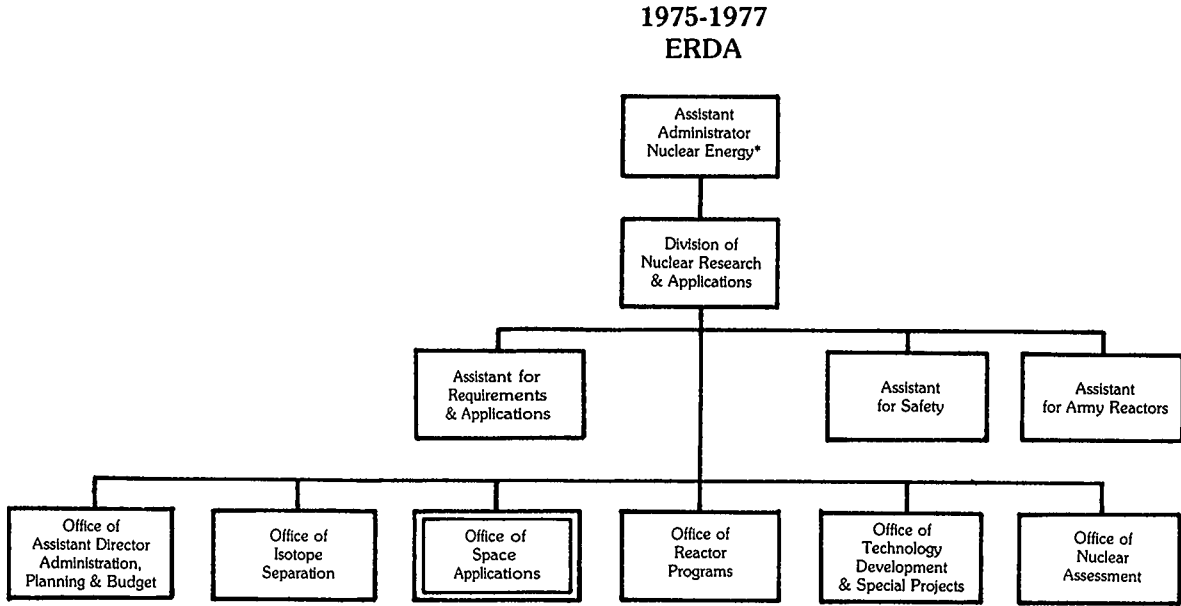


Figure D-5

*Other "Assistant Administrators" at ERDA were for: Administration; Conservation; Environment and Safety; Field Operations; Fossil Energy; International Affairs; National Security; Planning & Analysis; Geothermal & Advanced Energy Systems.

1978-1981
DOE

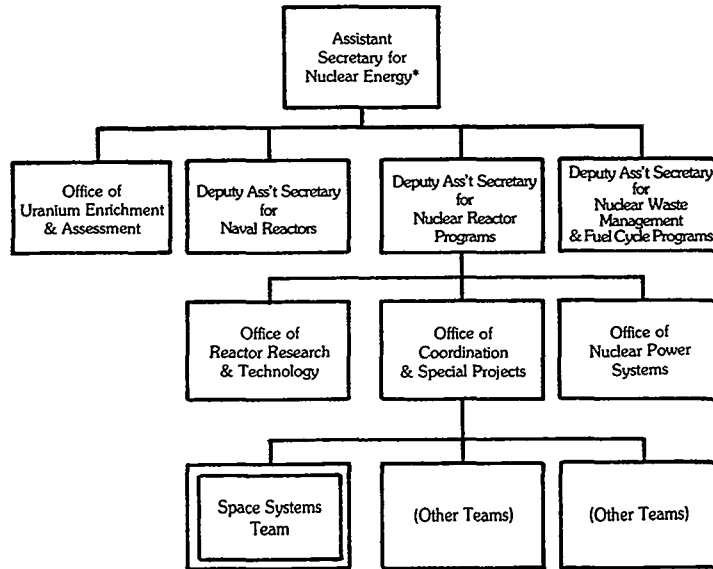


Figure D-6

*At first the term at this level was *Energy Technology*, later it became *Nuclear Energy*. Other Assistant Secretaries at DOE were for: Conservation & Solar Applications; Defense; Environment; Intergovernmental & Institutional Affairs; International Affairs; Policy & Evaluation; Resource Application.

1982*
DOE

160

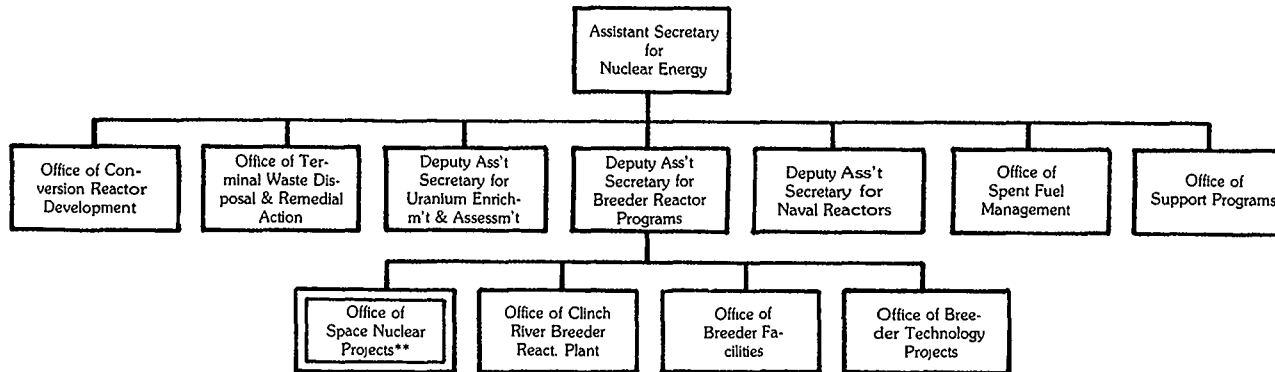


Figure D-7

*Although configurations varied somewhat under DOE/*Nuclear Energy*, just two are shown: Before and after a reorganization which "flattened" the organization.

**Later this was designated *Space & Terrestrial Applications Programs*, and then *Space & Special Applications Programs*.

TABLE E. DEVELOPMENTS IN RTG TECHNOLOGY

PARAMETERS	SNAP-3B	SNAP-9A	SNAP-19	SNAP-27	TRANSIT-RTG	MHW-RTG	GPHS-RTG
MISSION	TRANSIT 4	TRANSIT 5BN	PIONEER	APOLLO	TRIAD	VOYAGER	GALILEO
BOM POWER ^a PER RTG, W(E)	2.7	26.8	40.3	73.4	35.6	158.0	292.0
THERMOELECTRIC MATERIAL	PBTE 2N/2P	PBTE 2N/2P	PBTE 2N/ TAGS-8	PBTE 3N/3P	PBTE 2N/3P	SIGE	SIGE
PU-238 FUEL FORM	METAL	METAL	PMC ^b	OXIDE MICRO- SPHERES	PMC ^b	PRESSED OXIDE	PRESSED OXIDE
CONVERSION EFFICIENCY, %	5.1	5.1	6.2	5.0	4.2	6.6	6.6
SPECIFIC POWER W(E)/KG	1.29	2.2	3.0	2.3 ^c	2.6	4.2	5.2

Source Gary Bennett, James J. Lombardo, and Bernard J. Rock, *U.S. Radioisotope Thermoelectric Generator Space Operating Experience (June 1961-December 1982)*, Paper presented before the 18th Intersociety Energy Conversion Engineering Conference, Orlando, Florida, August 21-26, 1983.

^aBeginning-of-Mission.

^bPlutonia Molybdenum Cermet. (Cermet: a heat-resistant alloy formed by compacting and sintering a metal and a ceramic substance.)

^cThe SNAP-27 Specific Power is calculated with the mass of the fuel cask included.

The table above indicates changes and improvements in the RTG technology from early SNAP-3 devices to the GPHS = RTG to be used on the GALILEO mission.

*Significance of Developments in RTG Technology**

Essentials of the Technology. An RTG basically consists of a radioisotopic heat source and a thermoelectric converter that transforms thermal energy into electrical energy through two conductors, made of different metals, which are at different temperatures at their point of juncture. The heat results from the radioactive decay of plutonium-238, a radioisotope which has a half-life of 87.8 years. Plutonium-238 fueled all RTGs that flew on U.S. space missions. The principal decay process of this radioisotope is by emission of alpha particles, which are easily absorbed in the heat source to produce heat and require no special shielding.

Design Type and Trends. The RTG's flown since 1961 can be grouped into six basic design concepts—SNAP-3, SNAP-9A, SNAP-19, SNAP-27, TRANSIT-RTG, MHW-RTG. The general trend was to improve generator performance, efficiency, and specific power (electric power per kg of weight).

Basic Improvements. Power requirements for missions rose from a few watts electric to the 292 W(e) required in the forthcoming Galileo mission. Conversion efficiency rose slightly but specific power improved greatly as lighter weight converter materials (Beryllium or aluminum) reduced mass, even as fuel loadings increased and high-temperature thermoelectric power-conversion materials were introduced.

Snap-3(B). Each generator in the SNAP-3(B) RTG, which was the first to fly, was designed to provide an initial power output of 2.7 W(e). Heat source was approximately 52.5 W(t) of encapsulated plutonium-238 metal. Design life was five years. The power-conversion subsystem consisted of 27 spring-loaded, series-connected pairs of PbTe 2N/2P thermoelectric elements operating at a hot-juncture temperature of about 783 K and a cold-juncture temperature of about 366 K. This subsystem had a power-conversion efficiency of 5 to 6 percent and specific power of 1.29.

SNAP 9A. RTGs were adopted for the DOD Transit 5BN-1 and 5BN-2 satellites because RTGs are inherently radiation-resistant, while solar cells on earlier Transits were adversely affected by the 1962 high-altitude nuclear explosion. Each SNAP-9A was designed to provide 25 W(e) at a nominal 6V for five years in space after one year of storage on Earth. Thermal inventory of approximately 525 W(t) was supplied by Pu-238 metal encapsulated in a heat

*Abstracted from Bennett et al, 1983 paper (op. cit.) and *Enhancing Technology Leadership: Space . . .* (op. cit.), by the same authors.

W(e) = Watts electric

W(t) = Watts thermal

K = Kelvin

source of six fuel capsules maintained in a segmented graphite heat-accumulator block. The main body of the sealed generator was a cylindrical magnesium-thorium shell containing six heat-dissipating magnesium fins and 36 threaded holes; 70 pairs of series-connected PbTe 2N/2P thermoelectric couples were assembled in 35 modules of two couples each. Hot-junction temperature was calculated at about 790 K at beginning of life. Some waste heat from the RTG was used to maintain electronic instruments in the satellite at a temperature near 293 K.

SNAP-19. This technology-improvement program built on the SNAP-9A developments. The SNAP-19B power system was designed specifically for NASA's Nimbus weather satellites—a first demonstration of RTG technology aboard NASA spacecraft. Modifications to SNAP-19B were required to power the Pioneer and Viking missions.

Nimbus/SNAP-19. Specifications required 50 W(e) deliverable after one year in orbit. Two SNAP-19B's, with higher fuel loadings than those of SNAP-9A, were used on Nimbus III. To meet safety requirements, the Pu-238 fuel was changed from a metal form to oxide microspheres. Thermoelectric elements were made of cold-pressed and sintered PbTe. Each RTG thermopile consisted of 90 PbTe 3P/2N couples distributed in six modules of three parallel rows of five couples each. Modules were connected in series and enclosed in a magnesium-thorium housing. Hot-junction temperature was 800K. The two RTG's produced 56 W(e) — 49.4 W(e) usable — at launch and 47 W(e) one year later. Unlike the sealed capsules used in SNAP-3B and SNAP-9As, the SNAP-19B fuel capsule was vented into the generator. Possible sources of power degradation were identified as: rate of argon leakage; replacement of argon with helium in fuel decay; oxygen released from the PuO fuel attacking the thermoelectric elements and bonds. Design of subsequent RTGs was changed to reduce these sources of degradation.

Pioneer/Snap-19. Improvements for powering the Jupiter fly-by were made in the 19B converter, heat source, and structural configuration. A TAGS-SnTe/2N* thermocouple was designed with modified electrical circuitry to limit the magnetic field from the RTG to very low levels. Fill gas was a 75:25 helium-argon mixture, with a zirconium getter added to eliminate oxygen in the RTG. End covers were bolted and seam-welded to the cylindrical housing to further reduce gas leakage. Mission requirement called for four RTGs to produce 120 W(e) total at the Jupiter fly-by. Power output at Jupiter encounter was 144 W(e) for Pioneer 10 and 142.6 W(e) for Pioneer 11. Estimated minimum power requirements for a Saturn fly-by were 90 W(e) and the RTG's on Pioneer 11 actually provided 119.3 W(e) at Saturn.

*TAGS: a solid solution of silver antimony telluride in germanium telluride.

Viking SNAP-19. Distinctive mission requirements for Viking included high-temperature (400 K) sterilization, storage during the long cruise to Mars, and ability to withstand the rapid, extreme temperature changes of the Martian day-night thermal cycle. Each Viking Lander used two Snap-19 RTG's modified to meet those requirements. Each RTG was to produce a minimum of 35 W(e) during a 90-day Mars surface mission following an 11 to 12-month cruise after launch. The two series-connected RTGs were the primary power sources on each Viking Lander, supplying the energy for scientific instruments and for recharging four nickel-cadmium batteries. The RTGs also supplied the Landers with thermal energy. All four RTGs more than met the 90-day requirement.

A modification from Pioneer SNAP-19 was the addition of a dome reservoir. Initial fill gas for the converter was a 90:10 helium-argon mixture; the reservoir was filled with a 95:5 argon-helium mixture. This configuration permitted a controlled interchange of gases in the two volumes to minimize heat-source operating temperatures up to launch while maximizing electrical output at the end of the mission. Although data-relay capability ended, the RTGs on the Viking Landers were still operating when last transmissions were received and those on Viking Lander-1 were capable of providing power through 1994.

In the development of the SNAP-19s, the principal contribution to power degradation was judged to come from gas effects. Changes made in SNAP-9A and Nimbus SNAP-19 designs significantly minimized the degradation effects in the SNAP-19s.

SNAP-27. The SNAP-27 RTG was developed to power the experiments of NASA's Apollo Lunar Surface Experiments Package (ALSEP). The RTG design requirement was to provide at least 63.5 W(e) at 16 V DC one year after lunar emplacement. The use of RTGs was a natural choice because of their light weight, reliability, and ability to produce full electrical power during the long lunar night-day cycle. Since the ALSEPs were to be positioned manually by the astronauts, the designers took advantage of this assembly capability: the converter and sealed-fuel-capsule were kept separate in the Lunar Module and assembled on the Moon.

SNAP-27 used 442 thermoelectric couples made of PbTe 3N/3P elements arranged in two series strings of 221 couples connected in parallel. Heat from the fuel capsule, which was loaded with Pu-238 oxide microspheres and had a nominal rating of 1,480 W(t), was transmitted to the hot frame of the RTG by radiation coupling. Design analysis and ground tests indicated that the hot-junction temperature was about 866 K and the cold-side thermoelectric temperature was maintained at about 547 K in the lunar environment. Both the cold frame and the outer case were made of beryllium. Eight cross-rolled beryllium fins were attached integrally to the outer case by brazing. The converter had a mass of 12.7 kg. The mass of the fuel-capsule assembly,

without the graphite Lunar Module cask, was about 7 kg.

Five SNAP-27 powered ALSEPs were placed on the lunar surface. In each case, all of the RTGs exceeded their mission requirements in both power and life-cycle. All five ALSEPs, powered by RTGs, were operating when NASA shut down the stations on 30 September 1977.

Transit-RTG. The Transit-RTG was developed specifically as the primary power source for the DOD TRIAD navigational satellite. Auxiliary power was provided by four solar-cell panels and one 6 Ah nickel-cadmium battery. The objective of the Transit-RTG program was to produce an RTG capable of providing a minimum end-of-mission power of 30 W(e) after five years, at a minimum of 3 V. To do this, the 12-sided converter used light-weight PbTe thermoelectric panels (Isotec) that operated at a low hot-side temperature of 673 K in a vacuum, eliminating the need for hermetic sealing and a cover gas to inhibit the sublimation of thermoelectric material. The Transit-RTG was designed to be modular; each of the 12 Isotec panels contained 36 PbTe 2N/3P couples arranged in a series-parallel matrix with four couples in a row in parallel and nine rows in series. The panels were supported structurally by 12 webbed, magnesium-thorium corner posts with teflon insulators. The masses of the converter and heat source were 5.98 and 4.2 kg respectively. Including a titanium heat-source cage and support structure, the Transit-RTG had a mass of about 13.6 kg. The short-term objectives of the TRIAD satellite were demonstrated, including a checkout of RTG performance; however, a telemetry-converter failure caused a loss of further telemetry data. The TRIAD satellite continues to operate normally and to provide magnetometer data using power from the RTG.

MHW-RTG. The MHW-RTG was designed to provide a major increase in the power output of a space RTG. The DOD Lincoln Experimental Satellites 8 and 9, required 125 W(e) per RTG, with an output voltage of 30 (± 0.5) V at the end of mission — an operational life of at least five years after launch. The NASA VOYAGER mission required 128 W(e) per RTG, with an end-of-mission output of 30 (± 0.5) V or an operational life of at least four years after launch. To achieve these requirements, the MHW-RTG was equipped with a new heat source of 24 pressed plutonium oxide fuel spheres, each producing about 100 W(t). Electrical conversion was achieved through 312 silicon-germanium (SiGe) thermoelectric couples—high temperature alloys. The converter consisted of a beryllium outer case; end-closure structures that physically held the heat source; thermoelectric elements; a multifoil (molybdenum-Astroquartz) insulation packet and a molybdenum internal frame; and a gas-management system. The gas-management system maintained an argon or xenon gas environment to allow partial power operation on the launch pad; full-power operation in space was effected by venting the gas

through a pressure-relief device. The average RTG flight masses were 39.69 kg for LES 8/9 and 37.69 kg for Voyager 1/2. The 312 thermoelectric couples were arranged in 24 circumferential rows, each row containing 13 couples individually bolted to the outer case. The design hot-junction temperature was 1,273 K with a cold-junction temperature of 573 K. Design voltage was 30 V. The peak initial power was 159.6 W(e) for RTG Number 3 on Voyager 2. The MHW-RTGs allowed the LES 8/9 satellites to operate beyond the five-year operational life; enabled NASA to complete flights to Jupiter and Saturn; and will enable Voyager 2 to conduct an extended mission to Uranus in 1986.

GPHS-RTG. The successful performance of the MHW-RTG led to the use of SiGe technology for the high-power — 285 W(e) — General Purpose Heat Source RTG, which is to be launched in 1986 on the NASA Galileo Mission to Jupiter and the International Solar-Polar Mission around the sun.

Transition to High-Temperature Materials. The use of high-temperature SiGe alloys as thermoelectric power-conversion materials was a direct outgrowth of spacecraft requirements for higher RTG power levels and lower RTG masses. In general, higher hot-side operating temperature means a high efficiency, although the optimum temperature is dictated by the mission life, i.e., minimizing sublimation. The cold-side temperature is optimized to obtain the desired power-to-mass ratio. To a first approximation, PbTe can be used from room temperature to about 900 K before materials properties and the figure of merit become concerns. The SiGe alloy can be used from room temperature to about 1,300 K and offers the potential of higher power with improved efficiency.

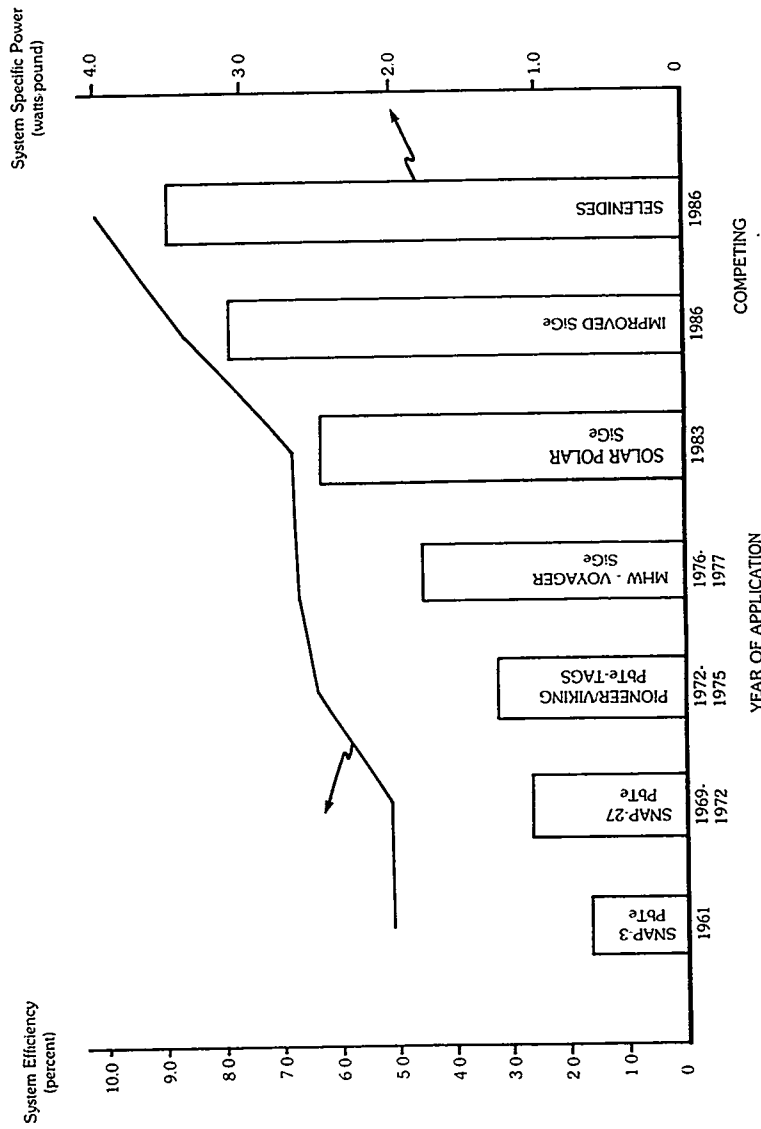


Figure E. RTG performance demonstrated/predicted.

Source: Gary L. Bennett, James J. Lombardo, and Bernard J. Rock, *Enhancing Technological Leadership: Space Nuclear Electric Power Systems*. Paper delivered at Annual Meeting of the American Astronautical Society, October 20-23, 1980, Boston, MA.

INDEX

- Aberdeen Proving Ground, 24
- aborts, 18, 36, 38-39, 57, 63, 68, 70, 72, 100
- AEC (Atomic Energy Commission), 1-2, 4-5, 7-10, 12-13, 15-21, 23-26, 28-30, 33-38, 40-43, 45-46, 56-65, 67-68, 70-71, 73-78, 80-81, 83
 - appointment of Seaborg, 19-21
 - arrival of Seaborg, 28
 - assuming RTG costs, 77
 - budgets, 39-40, 56, 59, 72, 81
 - cutbacks, 76
 - demise of agency, 80-83
 - policies, 58, 73-76, 81
 - retirement of Seaborg, 75, 83
- Aerojet (Corporation), 40
- Aerospace Nuclear Safety Board, 15, 19
- Agna (stage rocket), 63
- Air Force (U.S.), 8-10, 21, 24, 90-92, 96, 103
- Alamogordo, New Mexico, 1
- "alpha" particles, 37
- ALSEP (Apollo Lunar Surface Experiments Package), 60, 65-66, 68-69, 76
- American University, 30
- Ames, (NASA, Sunnyvale, Calif.), 51, 62, 77, 79
- Anders, William, 81
- Anderson, Clinton (U.S. Senator), 9
- Anderson, Lt. Col. (USAF), 16, 23, 45
- Andrews AFB, 26
- antinuclear (movement/sentiments), 28, 72-73, 80
- APL (Applied Physics Laboratory), 22-23, 26, 29, 76
- Apollo (total program), 20, 29, 31, 41, 59, 64-71, 76-77, 85, 87, 98
 - Extension Systems Program (AAP), 60
 - fire at Cape Kennedy, 56, 67
 - flagging public interest, 70
 - post-plans, 71, 80
- Apollo 8, 56, 67
- Apollo 9, 67
- Apollo 10, 67
- Apollo 11, 68-70
- Apollo 12, 12, 50, 65, 68, 70, 76
- Apollo 13, 56, 69-72
- Apollo 14, 72-74, 76
- Apollo 15, 73, 76
- Apollo 16, 73, 76
- Apollo 17, 73, 76

Apollo 18, 76
Apollo 19, 76
Apollo 20, 76
Apollo-Soyuz Test Project, 85
argon, 78
arms control, 31
Armstrong, Col. Jack (USAF), 4-5, 9, 16, 28, 45
Armstrong, Neil, 1, 68
Asteroid Belt, 79
Astronautics & Aeronautics (journal), 85
Atlas (vehicle), 19
Atmosphere
 controlled, 78
 low humidity, 78
atomic
 age, 3, 5, 33
 battery, 2, 4, 26
 bomb, 7
 energy, 20
 fission, 7
 nucleus, 7
 radiation, 6-7
 revolution, 6
Atomic Energy Act, 13
Atomic Industrial Forum, 19, 42
Atomics International (Div. of N. American Aviation), 12, 75
"Atoms for Peace," 2, 12-13, 17
Aviation Week (journal), 9-10, 31, 39, 56, 92

Bay of Pigs, 23
Bean, Alan, 50, 68-69
Becquerel, Henri, 6
Bendix Corporation, 65
Bennet, R.D., 35
Bennett, Gary, 101
Berkeley (campus, Univ. of Calif.), 19
beryllium, 66
Bicentennial (U.S.), 89
"big" nuclear technologies, 5, 99, 102
BIPS (Brayton Isotope Power System), 96
Birden, John, 9
Bowles, Chester, 26
"breakthrough" (in RTG technology), 5, 12, 100
Brouns, Robert, 88

budget

- battles/crunch, 31-32, 39-41, 56, 71, 92, 96-99
- for AEC, 39-41, 56, 59
- for military, 40, 92
- for NASA, 40, 56, 59-60, 65, 72, 85, 87, 96, 102
(and shuttle, 85, 103)
- for Pioneer, 77
- for SNAP-27, 65-66
- for RTG program, 59, 81, 99, 105
- for Viking, 87

Bureau of the Budget, 20

burn-up, 19, 37-39, 61-62

Cape Canaveral (or Cape Kennedy), 19, 23, 68-69, 91-92

Carpenter, Robert, 25-26, 28, 39, 44, 46, 62, 69-70, 77, 85, 87, 92, 103-104

Carter, Jimmy, 84-85

cell-mercury vapor system, 8

cerium, 12

cesium-vapor, 34

Christmas Island, 30

Clark, Duncan, 38

Clinch River Breeder Reactor, 84, 97

Coast Guard (U.S.), 29, 33

Congress (U.S.), 15, 20, 22, 28, 31, 39, 59, 66, 80, 83-84, 102, 104

Connor, Lt. Col. Joseph A., Jr. (USAF), 19

Conrad, Pete, 68

conservation, 83

convertors/conversion, 7, 35, 97, 100, 104

Cuba, 23-25

Cuban Missile Crisis, 30

Curie, (Marie & Pierre), 6

curies (fuel units), 5, 13, 57, 61, 65, 76, 91

curium, 34

Dallas, Texas, 32

Dassoulas, John, 23, 25-26, 76

decentralization (of organizations), 57-58, 75

Defense Department (U.S.), 2, 5, 9, 11, 18, 23-25, 34-37, 52, 73, 86, 90-92, 103-104

Dick, Paul, 47, 62, 80

dispersion, 39, 62

Division of Licensing & Regulation, 24, 38

Division of Nuclear Research & Applications, 85, 95

Division of Reactor Development, 16-17, 28, 33, 38

Division of Reactor Safety Research, 83
Dix, George ("Mike"), 17-18, 36-37, 39, 44, 61, 63, 70, 79, 85, 102
Dobry, Ted, 101-102
DOE (Department of Energy, U.S.), 83
 (creation of, 84), 85, 97, 102, 104
Dryden, Hugh, 20, 59
dynamic systems (for RTGs), 81, 96, 100, 104

Edwards AFB, 98
Edwards, James, 104
efficiency, 5, 97 (improvement, 104)
Eisenhower, Dwight D., 2, 4, 10-14, 17-18, 26, 45
Eniwetok, 8
ERDA (Energy Research & Development Administration), (creation, 83)
 (disbanding 84), 85, 92-93, 95
European Space Agency, 96
Evening Star (Washington, D.C. newspaper), 4
executive secretariat (NASA), 20

Federal Energy Administration, 84
Federal Radiation Council (standards), 19
Finger, Harold, 16-17, 36, 42-44, 57-58, 60, 66-67, 75
Fletcher, James, 81, 85
Foster, John, 63
fuel
 capsule (for SNAP-27), 66, 68-70
 costs/funds, 66, 103
 form, 23, 37-38, 61-62, 66, 70, 91
 loads (curies), 57, 61, 64-65, 76, 91, 100
 propellant, 65
 re-use, 64
 sales of isotopes for, 13

Gabriel, David, 75
Galileo (mission), 96-98, 101, 103
General Atomic Corporation, 75
General Electric Corporation (GE), 34, 65-68, 73, 77, 91, 103
Glenn, John, 30
Glennan, T. Keith, 11, 15-16
"glove box assembly," 78
GPHS (General Purpose Heat Source RTG), 97
 (conversion efficiency, 97)
Graham, John, 24
Grand Tours, 73, 80, 92-94
graphite, 62, 68, 70, 91

Great Powers

- confrontations, 8, 30
- joint lunar program, 31-32
- race, 14, 16
- “guns and butter,” 40
- gyroscopic action, 12, 96

- half-life, 7, 33, 37
- Hall, Charles, 77-80
- Harris Survey, 97
- hazards, 15-19, 23-25, 35-39, 62, 100
 - (radiation near Jupiter, 79-80)
- heat sources, 58, 62, 100, 104
- Hiroshima, 5
- Hodel, Donald, 104
- Holifield, Chet (Congressman), 17
- Humphrey, Hubert H., 59
- hydrogen bomb, 8
- IMP (Interplanetary Monitoring Probe), 29, 33-34
- INSRP (Interagency Nuclear Safety Review Panel), 37, 61, 85
- international
 - affairs/arena, 19
 - confrontations, 7, 13, 30
 - incident, 25
- iridium, 91
- isotopes, 7-8, 13, 18-20, 23, 28-30, 59
 - containment, 24
 - power, 18, 28-29, 59
 - sales of fuel, 13

- Jaffe, Harold, 78
- James, William (quotation), 84
- “job shop,” 74, 101
- Johns Hopkins University, 22, 29
- Johnson, Lyndon B., 27, 39-40
- Joint AEC-DOD (AF) Aircraft Nuclear Propulsion Office (ANSPO), 16, 23
- Joint AEC-NASA Space Nuclear Propulsion Office (SNPO), 16, 36, 41, 43, 60
 - (dissolution, 75, 85)
- Joint Committee on Atomic Energy (JCAE), 4, 9, 17, 25, 29, 42, 74
 - (dissolution, 84)
- Jordan, Kenneth, 9
- JPL (Jet Propulsion Laboratory), 87, 89, 92-94, 103
- Jupiter, 1, 77-79, 92-95, 103
 - communication time to, 94

- encounter by Pioneer, 79-80
 - encounter by Voyager, 94-95
 - organics on, 94
 - pictures from, 94, 105
 - use of gravity by spacecraft, 94, 103
- Keirn, Donald J., 45
- Kennedy, John F., 2, 19, 21-22, 25, 30-32
(assassination, 32)
- Kerr, Tom, 36-37, 39
- Killian, James R., 10-11
- KIPS (Organic Rankine Isotope Power System), 96
- Kistiakowsky, George, 12
- Klein, Milton, 16, 43, 60, 67, 73-75
- Korean War, 8
- Krushchev, Nikita, 31-32
- Laird, Melvin (Congressman), 40
- Landers (Mars), 87-88
- Landsat, 85
- Lapp, Ralph, 17-18
- Latin America, 25
- lead telluride, 66, 91
- LES 8/9, 86, 90-92, 96, 103
- Limited Test Ban Treaty, 31
- Lincoln Laboratory (of MIT), 73, 90-91
- Linkous, Guy, 62-63, 103
- Lockheed Corporation, 10, 40
- Lombardo, James, 101
- Los Alamos Scientific Laboratory, 75, 91
- LM (Lunar Landing Module), 66, 68-70
(lifeboat use, 69-70)
- Luedecke, A.R., 38
- McAlees, Sam, 63
- McCone, John, 15, 18, 45
- Macmillan, Harold, 31
- McNamara, Robert, 21, 24, 40
- MACS (Medium Altitude Communications Satellite), 34
- Manhattan Project, 7
- manned (missions),
(lunar, 2, 46, 56-57, 65-71, 76
planetary, 71, 80, 102
"March on Washington," 32

- Mars, 73, 75, 87-90, 92-93, 102
 - communication time to, 88
 - dust on, 88
 - future missions, 102
 - geo-chemical observer, 102
 - landing, 89
 - nights on, 88
 - organics (lack of), 89
 - oxidizing processes, 89
 - winds on, 88
- Martin Company, 5, 12, 17-18, 23-26, 28-29, 34-35, 62, 65, 92, 100
- Martin, James, 87
- MHW (Multi-Hundred-Watt RTG), 73, 77, 86, 91, 93, 96-97
 - contract, 77
 - conversion efficiency, 97
- microspheres, 61-62, 91
- Millard, William, 66
- Mills, Rodney, 93, 102
- Minnesota Mining & Manufacturing Co. (3M), 5, 12, 28
- MITG (Modular Isotope Thermoelectric Generator), 105
- MJS (Mariner-Jupiter-Saturn mission), 75-76, 93
- molybdenum, 91
- Moon, 2, 4, 21-22, 32, 34, 42, 56, 60, 64-65, 67-72, 76-77, 87
 - aborted mission, 69-70
 - first landing, 68-69
 - orbiting by Apollo, 8, 56
 - race to, 22, 60, 67 (climax, 72), 74, 87
- moratorium, 11, 30
- Moseley, H.G.J., 6-7
- Mound Laboratory, 8-9, 12, 29, 64, 66
- Mozambique Channel, 38-39
- Mueller, George E., 67-68

- Nagasaki, 5
- NASA (National Aeronautics & Space Administration), 2, 5, 11, 13-16, 20-22, 28-30, 33-37, 40-43, 48-61, 63-65, 67, 70-73, 75, 77-78, 80-81, 85-88, 92-93, 96-98, 102-103, 105
 - Act, 15
 - budgets, 40, 56, 60, 65, 72, 85, 87, 96, 102-103
 - changed climate, 102
 - Goddard, 63
 - Langley, 87-88
 - Mission Centers, (role), 57
 - policies, 20-21, 58, 64, 75, 80-81

Webb appointment, 20-21
 Webb retirement, 67
 National Academy of Sciences, 98
 National Aeronautics & Space Council ("Space Council"), 24-25, 27, 39, 41, 61, 63
 Navy (U.S.), 22, 29, 33, 35, 38, 63, 72-73, 76, 90
 Neptune, 92-93
 NERVA (nuclear engine for rocket vehicle application), 40
 Newell, Homer, 14-15
 New York City (parade for astronauts), 72
New York Journal American, 26
New York Times, 25-95
 NIMBUS, 33, 59-64, 72, 77-78
 Nixon, Richard M., 67
 North American Aviation Corporation, 8
 nuclear
 auxiliary power, 2, 10, 16, 18, 24, 41
 battery, 6
 confrontations, 13
 fears, 1, 80, 84
 private development of power, 13
 reactors, 3-4, 7, 9, 13, 19, 33, 41, 62, 75, 80-81, 84
 space power, 2, 33 (possibly forbidden, 76)
 space propulsion, 16, 28, 33, 56, 59, 75, 99
 weapons testing, 8, 11, 30-31
 Nuclear Regulatory Commission (NRC), 83
 Nuclear Rocket Development Station (Nevada), 75
Nucleonics (journal), 18

 Oak Ridge National Laboratory, 13
 Ogburn, George, 63, 101
 Orbiting Astronomical Observatory, 33
 organizational change, 16, 20, 28-30 (for space-nuclear program, 41-44, 57-59), 73, 80-86, 99, 101-102, 104-105
 outgassing, 78
 Oval Office, 4, 17

 Pacific Missile Range, 35
 Pacific Ocean, 70
 Paine, Thomas O., 67
 Pasadena, Calif., 23, 87
 Pentagon, 15, 21
 phosphorescence, 6
 "Pied Piper," 9-10, 102
 Pioneer, 73, 77-80, 91

- budget, 77
 - Jupiter flyby, 79
 - Pioneer 10, 73, 77-80
 - Pioneer 11, 51, 73, 78-79
 - Pitrolo, Augustine, 65-70, 91
 - Pittman, Frank, 28, 33
 - Pluto, 92
 - plutonium, 2, 8, 20, 23, 33-35, 37-38, 57, 61-62, 65, 70, 76, 91, 95-96
 - dioxide sphere, 91
 - metal, 61
 - oxide, 61
 - PMC (plutonia molybdenum cermet), 91
 - political environment, 3, 10-15, 17-22, 25, 37, 60, 72, 102, 105
 - polonium, 5-6, 23
 - President's Science Advisor, 10
 - President's Science Advisory Committee, 10-11
 - Press, Harry, 63-64
 - Price, Harold, 62
 - "Project Feedback," 8
- quiet technology, 2, 6-8, 12-13, 16, 22, 26, 33, 35, 69, 97, 99, 102
- radioactivity, 6-7, 15, 18-19, 24, 36-39, 57, 61, 70, 79-80
 - decay, 7, 18
 - materials producing, 8, 25, 38, 57, 61
 - near Jupiter, 51, 79
 - radioisotopes/radioisotopic power, 2-3, 6-9, 12-13, 17-18, 20, 23
 - radium, 6
 - Ramey, James T., 41
 - RAND Corporation, 8
 - Ray, Dixy Lee, 83
 - Reagan, Ronald, 97-98, 104
 - recovery (of lost nuclear sources), 63-64
 - re-entry, 18-19, 24, 37-39, 61-63, 66-67, 69-70
 - abnormal, 69
 - Apollo 13, 69-70
 - container/cask for RTG, 66
 - intact, 39, 62, 64
 - vehicle, 66
 - velocities, 67, 69
 - regulation, 24, 37-38, 62, 83-84
 - research and development, 20, 35, 40-42, 66-67, 73-74, 83, 90, 95-98, 100, 105
 - energy, 97

- lack of funds for, 35
- military, 90-92
- mission requirements and, 41
- organizational, 20
- safety, 83, 100
- technical, 99-100
- Rock, Bernard, 59, 61, 78, 85, 95, 101, 104-105
- rotating machinery (for RTGs), 5, 12, 96, 100
- Rover, 16-17
- RTG (Radioisotopic Thermoelectric Generator)
 - budget, 59, 81, 99-100, 105
 - group/team, 28-30, 42-44, 46, 68, 70, 99-102
 - program, (plan, 95-96), (summary, 99-102), (future, 102-105)
- Rusk, Dean, 24
- safety, 3, 15-19, 24, 36-39, 41, 57, 58, 61-64, 66-67, 70, 80, 83, 91-92, 100-102
 - concepts, 39, 57, 60-62, 64, 100
 - procedures for clearance, 36
 - program, 36-39, 58, 64, 100
 - reviews, 18, 36-37, 64
 - shuttle and, 80
 - testing, 19, 24, 39, 58-59, 62, 64, 66-67
- Sagan, Carl, 94
- Scandia Corporation, 58, 63, 66-67, 75
- San Miguel Island, 63
- Santa Barbara Channel, 49, 63
- Saturn (planet), 1, 54, 79-80, 85, 92-95
 - communication time to, 94
 - encounter by Voyagers, 95
 - pictures from, 95
 - rings, 94-95
 - use of gravity by spacecraft, 94
- SBSS (Space Based Surveillance Spacecraft), 96
- Schlesinger, James, 83-84
- School of Aerospace Medicine (USAF), 32
- scientific community, 19, 102
- Seaborg, Glenn C., 6, 19-21, 24-27, 33, 38, 41, 46, 63, 67, 75, 83
 - appointment to AEC, 19-21
 - arrival at AEC, 28
 - retirement, 75
- Seamans, Robert, Jr., 20, 59
- Seebeck principle, 9
- selenide, 81, 95

- Senate (U.S.) Senators, 31, 33, 38
- shielding, 23, 36
- shuttle (NASA program/vehicle), 80, 96-98, (and NASA budget, 85, 103)
- silicon germanium, 91, 97
- Simpson, John A., 51
- Smithsonian
 - Institution, 76
 - Air & Space Museum, 89
- SNAP (Systems for Nuclear Auxiliary Power)
 - Fact Sheet, 33
 - program (general), 4, 9-10, 12, 16, 20, 23, 28-30, 41-44, 46, 57-60
(Report, 41), (plan for future, 104-105)
- SNAP-1, 12
- SNAP-3/3A, 4-5, 12, 17-18, 25-28, 33-34, 36, 45, 61, 72
- SNAP-7, 29, 33
- SNAP-9A, 33-39, 46-47, 57, 61, 76
- SNAP-11, 29, 34
- SNAP-13, 34
- SNAP-15, 34
- SNAP-19, 48-49, 51, 53, 60-62, 64-65, 73, 77-79, 81, 86, 88, 97
 - conversion efficiency, 97
 - discontinuance, 81
 - feasibility for Apollo, 65
 - for Pioneer, 77, (redesign, 78)
 - for Viking use, 88
- SNAP-27, 50, 57, 60, 65-70, 72-74, 76-77, 97
 - activation on Moon, 50, 65, 68-69
 - budget/costs, 65-67
 - conversion efficiency, 97
- Soffen, Gerald, 87-89, 102
- software on Voyager, 94
- SOLAR-POLAR, 97, 103-105
- solar power, 18, 41, 61, 64, 76-77, 80, 86, 88, 93
 - competition with RTGs, 86
 - study for Pioneer, 77
 - unsuitability for Viking, 88
 - vulnerability, 76
- Solar System Exploration Committee, 98
- South America, 23
- Southeast Asia, 40
- Soviets (Russians), 1, 11, 14, 18, 30-31, 102 (space reactor falling, 84)
- Soviet Union (Russia, U.S.S.R.), 8-11, 26, 32, 38
- space,
 - age, 1, 3, 87, 102

and the atom, 26
 applications, 85-86, 95, 102
 missions, 28-29, 41, 56-57, 72
 (distant, 74), (decline, 85)
 program, 7, 11, 14-15, 21-22, 31-33, 39-40, 56-57, 72-73 (momentum,
 73), 80, 83, 85, 87, 96-98, 102
 race, 1-2, 8, 13, 21-23, 26, 31, 56, 60, 64, 67, 72, 105
 vehicles (craft), 11, 15, 39, 50, 53, 56, 58, 63-64, 68, 78-80, (in foreign
 policy, 85), 87, 88, 90, 93-94, 98
 Space Electric Power Office, 42-44
 Space Nuclear Systems Applications Steering Group, 86, 92
 Space Nuclear Systems Division, 42-44, 57, 60, 73, 75, 77, (budget, 81)
 Special Message to Congress, 22
 Sputnik, 9-11, 14, 98
 Stapfer, Gerhard, 92, 103
 State Department (U.S.), 24-25, 37
 sterilization (of VIKING), 88
 strontium 90, 23, 33-34
 Surveyor (soft lunar landing vehicle/mission), 29, 34, 65

TAGS (thermoelectric material), 78
 technology,
 criticism of, 72, 97-99
 development (in program), 73-74, 98-100, 104-105
 Moon landing/return as demonstration (Webb), 22
 perceived advantages, 97-98
 readiness (in program), 73-74
 Teledyne Corporation, 47, 62, 77-78, 103
 terrestrial applications, 34, 85-86, 102-103
 test ban, 31
 thermal integration (on Viking), 88
 thermionic,
 conversion, 12
 generation, 34
 space reactor, 75
 thermocouple(s), 5, 8-9, 66, 91, 97, 100
 thermoelectric
 conversion, 9, 64
 material, 64 (TAGS, 78)
 thermopile, 9
 Three Mile Island, 84
 Tonga Trench, 70
 total environment ("larger" environment), 20, 22, 40, 98-102
 Tower, John, (U.S. Senator), 104

- Transit, 22-27, 29, 32, 34, 38, 47, 57, 72-73, 76, 90
- TRIAD-01-1X, 73, 76
- Truman, Harry S., 8, 20
- Truscello, Vincent, 92-93, 103
- TRW, 77-78
- turbine (action), 9, 12, 96

- United Nations, 13, 31
- universities, 21-22
- unstable elements, 7
- uranium, 6-7, 13, 20
- Uranus, 92-94

- Van Allen, James A., 51
- Vandenberg Air Force Base (Pacific Missile Range), 32, 35, 63
- Vanguard, 11, 18
- Venus, 80
- VIKING
 - budget, 87
 - program, 73, 75, 86-91, 94, 98, 102
 - wind screens on, 53, 88
- Viking 1, 53, 86, 89
- Viking 2, 86, 89
- Viking '75, 80-81
- Viking '79, 81, 90
- Von Karman Auditorium, 89, 94
- Voyager, 55, 86, 91-96, 98, 105
- Voyager 1, 86, 93-94
- Voyager 2, 86, 93-94

- Waldron, Philip, 90, 92
- War in Vietnam, 40, 56, 60
- War on Poverty, 40
- Washburn, Mark, 89, 94, 105
- Watergate, 85
- Water vapor (in SNAP 19), 78
- Webb, James E., 20-22, 40, 63-64, 67, 85-86, 98
 - appointment to NASA, 20-21
 - philosophy/approach, 20-22
 - retirement, 67
 - significance of race to Moon, 22, 64
- Welsh, Edward C., 41
- Westinghouse Electric Corporation, 12, 40
- White House, 84-85
- World War II, 1

- Young, Tom, 87