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Challenges Facing Space Reactor Power Systems Development

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Resources, Community, and
Economic Development Division

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The Honorable Robert A. Roe
Chairman, Committee on Science,
Space and Technology
House of Representatives

The Honorable Manuel Lujan, Jr.
Ranking Minority Member
Committee on Science, Space
and Technology
House of Representatives

As requested by the former Chairman and current Ranking Minority Member in a May 20, 1986, letter and as agreed in subsequent discussions with your office, we are providing information on DOE's space nuclear reactor research and development programs. Specifically, this report provides information on the space reactor development programs, management strategies among the various sponsoring organizations, and safety-related tasks associated with DOE's program activities.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time, we will send copies to appropriate congressional committees; the Secretary of Energy; the Secretary of Defense; the Administrator of NASA; and the Director, Office of Management and Budget. We will also make copies available to others upon request.

This work was performed under the direction of Keith O. Fultz, Associate Director. Other major contributors are listed in appendix IV.

J. Dexter Peach
Assistant Comptroller General

Executive Summary

Purpose

Within the last few years, proposed civil and military space missions, including the Strategic Defense Initiative (SDI), which require power at high levels, continuously, and for long durations, have renewed interest in space nuclear reactor power technology.

The Department of Energy (DOE) is participating in two programs with other federal organizations to research and develop technology for space nuclear reactor power systems capable of delivering electrical power in the multihundred kilowatt and multimegawatt range. The former Chairman of the House Committee on Science, Space and Technology and its current Ranking Minority Member requested that GAO provide information on

- DOE's space nuclear reactor development programs,
- management and coordination among the sponsoring organizations, and
- safety-related tasks associated with DOE's program activities.

Background

Power requirements for space missions have grown steadily over time; for many emerging applications, such as space-based radar systems and manned and unmanned space exploration, nuclear reactor power systems are considered the only realistic option. Besides the ability to generate high power levels reliably with a relatively small, light-weight system, space reactors could provide continuous power for very long periods. They are believed to be more survivable than alternative power sources against natural and hostile threats.

The two space reactor research and development programs, in which DOE is participating, are the SP-100 Space Reactor program and the Multimegawatt Space Nuclear Power program. The SP-100 program was initiated in February 1983 to develop technology for space nuclear reactor power systems capable of providing up to 1 megawatt (1,000 kilowatts) of electricity for future civil and defense space missions. It is jointly funded by DOE, the Department of Defense's (DOD) Strategic Defense Initiative Organization (SDIO), and the National Aeronautics and Space Administration (NASA). The Multimegawatt program, which is funded by SDIO and DOE, was established in 1985 specifically to address SDI power requirements in the tens to hundreds of megawatts. SDI is a research program to explore key technologies needed for a defense system against nuclear ballistic missiles.

Results in Brief

Although the SP-100 program is much further along than the Multimegawatt program, both are in early stages of development. The programs are also under joint sponsorship of several federal organizations. DOE, however, is primarily responsible for developing space-based nuclear reactor power systems technology for both programs.

While DOE is making progress toward developing space nuclear power technology to meet DOD and NASA's space needs, the programs face a number of challenges—the most important of which involves putting a safe reactor in space.

GAO's Analysis

SP-100 Program Status and Challenges

The SP-100 program is in an early stage of development. The first of three phases of the SP-100 program was completed in fiscal year 1985 and resulted in the selection of a power system concept which includes a compact nuclear reactor for producing power in the 10 kilowatt to 1,000 kilowatt range. In the ongoing second phase of the SP-100 program, targeted for completion in fiscal year 1992, DOE expects to demonstrate the readiness of the space reactor power system technology for subsequent launch and spaceflight use. The planned third phase involves the manufacture, launch, and first spaceflight use of a SP-100 power system by 1995.

Challenges facing the SP-100 program include

- coordinating and controlling the activities of a complex structure consisting of numerous organizations that must work together effectively for the program to succeed;
- demonstrating the technology that will meet specified size, weight, performance, and safety requirements for space reactor power systems; and
- obtaining a commitment from DOD or NASA to use the SP-100 power system technology in a space project.

In addition, before a reactor can be used in space, the President's Office of Science and Technology Policy must determine if the risks are commensurate with the mission benefits. With respect to possible consequences of developing and operating space nuclear reactors, DOE is addressing the risk of radiation exposure to the public and the environment. DOE believes that space reactors can be operated safely through design or operational features, such as equipping a reactor with control mechanisms to prevent it from starting up until a stable orbit is reached and designing the reactor to remain intact should it reenter the earth's atmosphere. A safety review process, including independent oversight, has been established with the objective of ensuring that risks associated with space reactor use are as low as can reasonably be achieved.

Multimegawatt Program Status and Challenges

The Multimegawatt program, which is still in its infancy, faces perhaps even greater challenges than the SP-100 program. The current phase of the Multimegawatt program, planned through 1992, focuses on defining and designing a multimegawatt nuclear power system concept that, alone or in combination with a nonnuclear power system, meets the SI requirements. The defense system for SDI will need much greater power (ten to hundreds of megawatts) than that which is expected from technology to be demonstrated in the SP-100 program. Higher reactor operating temperatures and major technological advances in space power systems are needed. However, the program's projected funding levels have been reduced. As a result, DOE has adjusted the time frames and scope of work originally planned. Program managers state that it will still be possible for DOE to meet its goal of determining the technical feasibility of providing multimegawatt nuclear power for SDI by the early 1990s. However, program officials stated that high risk, but promising, space reactor concepts may not be practical to pursue at currently forecast budget levels and time constraints.

Recommendations

This report provides information on space reactor research and development programs; it contains no recommendations.

Agency Comments

We requested comments on a draft of this report from DOE, DOD, and NASA. The three organizations concurred with the report's content.

Contents

Figures

Abbreviations

DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
GAO	General Accounting Office
GES	Ground Engineering System
JPL	Jet Propulsion Laboratory
MMW	Multimegawatt
NASA	National Aeronautics and Space Administration
OSTP	Office of Science and Technology Policy
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization

Introduction

Within recent years, proposed U.S. space missions have shown the need for electric power levels well beyond those available through existing sources. The electric power used in space missions, such as the Voyager spacecraft launched by the National Aeronautics and Space Administration (NASA) and navigation satellites launched by the Department of Defense (DOD), has been generated by solar cells, chemical fuel cells, or low-power nuclear sources. Each of these sources offers unique advantages; however, they have practical limits to the amount of electrical power they can supply continuously and for long periods of time.

During the 1950s to the early 1970s, the United States engaged in extensive space reactor development programs and even demonstrated a reactor power system in 1965 that produced 500 watts in space. Because firm missions that would use the nuclear reactor technology did not materialize and, because existing power sources were able to meet proposed space mission needs, the space nuclear power programs were terminated. Interest, however, has been renewed in developing space nuclear reactors because of the need for higher power levels and other requirements for future space missions.

On May 20, 1986, the former Chairman of the House Committee on Science, Space and Technology and its current Ranking Minority Member requested that we provide information on the Department of Energy's (DOE) space nuclear reactor research and development activities. DOE is participating with DOD and NASA in a program to develop technology for a space nuclear reactor power system to provide electrical power in the multihundred kilowatt[1] range. DOE is also working with DOD in another program to advance space nuclear reactor concepts that would provide power in the multimegawatt range.

This chapter provides background information on space nuclear reactor systems, their advantages over other power systems, and future space missions for which their need has been identified. It also briefly describes DOE's two space reactor research and development programs. Finally, the chapter contains information on the objectives, scope, and methodology used to conduct our review on space reactor research and development.

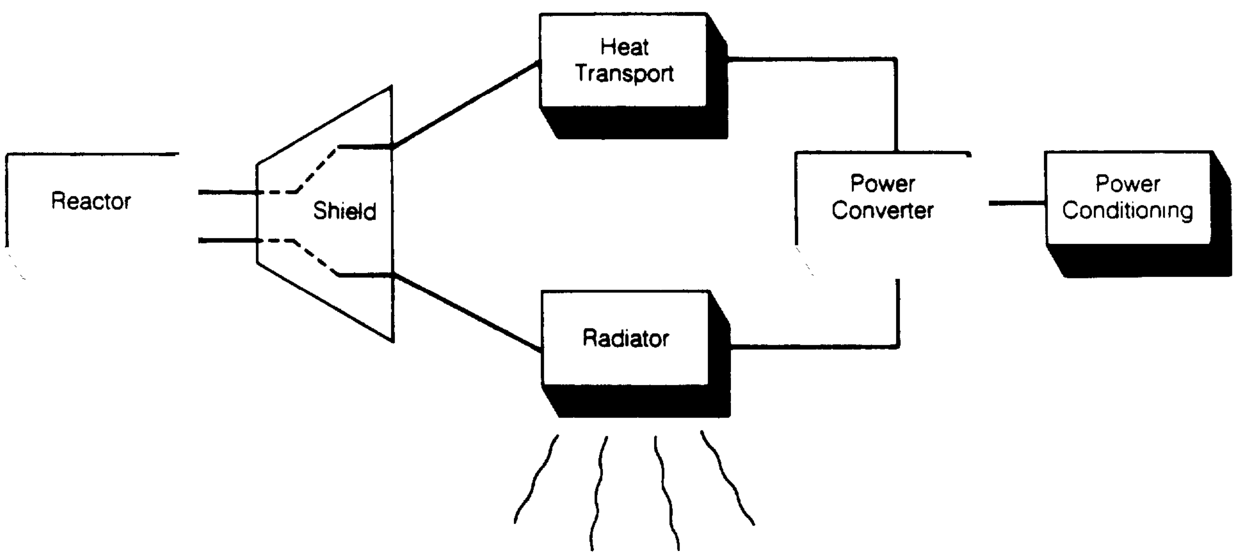
[1] A watt is the electrical unit of power. A kilowatt is 1 thousand watts; a megawatt is 1 million watts

Space Nuclear Reactor Power Systems and Their Advantages

Space nuclear reactor power systems are made up of several subsystems in addition to the reactor. The design of these power systems can vary and depends on factors such as mission type and duration, operating environment, electrical load demands, and other performance requirements. Nuclear reactors, however, because of their unique characteristics are considered the only power source option for many emerging civil and military space missions.

A nuclear reactor power system consists of several subsystems: (1) a compact nuclear reactor, (2) shielding, (3) a heat transport system, (4) a power conversion system, (5) a radiator, and (6) a power conditioning and control system. Figure 1.1 illustrates a basic space nuclear reactor power system.

Figure 1.1: Space Nuclear Reactor Power System



Source: NASA.

The reactor power system operates as follows. When a reactor is operating, a chain reaction fissioning process of the uranium material in the reactor core is sustained. The process generates tremendous quantities of heat and also produces hazardous levels of radioactivity. The shielding provides protection for other flight system components from the radioactivity. To convert heat to electricity, coolant passes through the reactor core, absorbs the heat and is pumped to an energy converter that converts the heat to electricity. A power conditioning and control system regulates and delivers power to other flight system components. Residual waste heat from the converter is transported to and through radiator panels and dissipated into space.

Alternative power system sources, such as solar cells, chemical fuel cells, and low-power nuclear radioisotopes, are available for space applications, but they cannot match the performance and characteristics of a nuclear power system for particular missions. Solar arrays, for example, made up of photovoltaic cells that convert the sun's light to electricity, are limited in the power they can deliver because the greater the power requirements, the larger will be the system's size, which will cause it to become very massive. In addition, the intensity of the power supplied by a solar cell system depends on its distance from the sun. A compact nuclear reactor, in comparison, has size advantages and can operate independently of the sun.

A compact nuclear reactor also offers other advantages compared with either chemical fuel or radioisotope power sources. A chemical fuel power system, which has fuel cells that convert chemical energy directly into power, can supply high levels of power but only for short periods of time. Nuclear reactors, in comparison, can operate at high power levels for long durations. While a nuclear radioisotope system that converts heat from the spontaneous decay of radioactive material[2] into electricity can also operate for long durations, it is generally limited to low power needs (less than 10 kilowatts) because of the quantity of fuel and weight that would be needed to supply higher levels of power.

Nuclear reactors also have other advantages over existing power sources, depending on mission type. For example, where reducing space system vulnerability to military attack is a major objective, nuclear-powered space systems have advantages over other alternatives because of rugged construction utilizing high-temperature, high-strength materials that provide intrinsic hardness against hostile attack. Also, the compact size of nuclear power systems makes them more maneuverable for defense missions.

[2]The material is plutonium-238, a radioactive, man-made element.

Space Nuclear Reactor Power Proposed for Future Space Missions

DOD and NASA are currently considering future space missions whose power needs are in the tens, hundreds, or even thousands of kilowatts of electricity. Space nuclear reactor power technology has been identified for the power systems that will meet these missions' power needs.

Among near-term military missions is the proposed Strategic Defense Initiative (SDI), popularly called "Star Wars." The SDI is a DOD research program to explore key technologies needed to assess the feasibility of building a defense system against the threat of nuclear ballistic missiles. The program includes research on sophisticated surveillance, sensing, orbital transfer vehicles, and intercept systems and weapons platforms that will need electrical power in the hundreds of kilowatts and tens to hundreds of megawatts. Other potential military applications that require high power levels, not necessarily SDI-related, include space-based radar and a space-based submarine communications system.

NASA has identified a number of potential civil missions, including unmanned science and exploration, manned space operations, and private commercial operations in space. According to a March 1987 report prepared by NASA's Jet Propulsion Laboratory,[3] electrical power at greater levels than have been available seems essential to accomplishing civil mission objectives, and the availability of space nuclear power is an integral assumption in current U.S. planning for the next 60 years of space exploration, utilization, and settlement.

The study states that various science and exploration missions—for example, spacecraft travel to Mars for on-site studies and sample analyses from its surface—will further the investigation of our solar system. While most of the principal science and exploration missions of the coming decades will require significant power levels for spacecraft, large space observatories are also being planned, some of which will require the same high power levels, many in the multihundred kilowatt range.

The study also reports that space operations considered during the 1995 to 2050 time frame include space vehicles and outposts where humans would live and work. A wide variety of activities will be conducted from a proposed space station, such as (1) spacecraft servicing, (2) space technology and engineering research, and (3) life science research.

[3] Preliminary Survey of 21st Century Civil Mission Applications of Space Nuclear Power prepared by the Jet Propulsion Laboratory, California Institute of Technology, March 1987.

Commercial uses of space will probably continue to expand beyond present enterprises such as communication satellites. The report states that commercial enterprises will exploit the space environment for the benefit of private industry. One such enterprise being proposed is a materials-processing platform that would place a research and manufacturing facility in orbit. By eliminating gravitational effects, the facility would allow processing of glasses and fibers and biological materials under conditions different from those on earth.

Space Nuclear Reactor Power Programs

Two research and development programs are underway to develop technology for providing nuclear reactor-generated electricity for space missions: the SP-100 Space Reactor Program and the Multimegawatt (MMW) Space Nuclear Power Program. Although the SP-100 program is much further along than the MMW program, both are in early stages of development. The programs also are under the joint sponsorship of various federal departments and/or agencies. DOE, however, is primarily responsible for developing space-based nuclear reactor power systems technology in both programs. While DOE is making progress toward developing space nuclear power technology, the programs face a number of challenges—the most important of which will be that of putting a safe reactor in space. Chapters 2 and 4 of this report provide information, respectively, on the background and current status of the SP-100 program and the MMW program. Included in those chapters is information on management strategies and coordination among the funding agencies and challenges facing each program. Chapter 3 provides information on SP-100's safety program which was developed to address safety concerns of putting a nuclear reactor in space. It also contains information on resources to carry out safety-related tasks.

Objectives, Scope, and Methodology

This report provides information in response to a request from the former Chairman of the House Committee on Science, Space and Technology and its current Ranking Minority Member to study the area of space nuclear reactor development. As requested in the May 20, 1986, letter and as amended by agreements reached in subsequent meetings with the Committee office, our objectives were to provide information on

- DOE's space nuclear reactor development programs;
- management strategies applied in the space nuclear reactor programs to ensure coordination among the funding agencies: DOE, Strategic Defense Initiative Organization (SDIO), and NASA; and
- resources projected to perform safety-related tasks.

We reviewed SP-100 and MMW program activities at DOE, DOD, and NASA headquarters and DOE field operation offices and facilities. We visited the DOE San Francisco Operations Office in Oakland, California; the DOE Richland Operations Office in Richland, Washington; the Ground Engineering System Project Office in Pasadena, California; the Multimegawatt Project Integration Office at DOE's Idaho Operations Office in Idaho Falls, Idaho; Argonne National Laboratory-West in Idaho Falls, Idaho; and the Hanford Engineering Development Laboratory in Richland, Washington. We also visited the Air Force Space Technology Center at Kirtland Air Force Base, New Mexico, which conducts studies of power requirements and capability of power subsystems to meet overall SDI mission requirement studies.

While visiting these sites, we obtained and reviewed the programs' and projects' policies, procedures, plans, status reports, and other documents. We interviewed officials in various program segments and others knowledgeable about space reactor development and potential uses of space reactors. Our review was also based on discussions during meetings and documentation obtained from government agencies, consulting firms, universities, and industrial firms that describe and illustrate technical aspects of space power systems. We did not independently evaluate the reactor designs or development. Our work was performed in accordance with generally accepted government auditing standards and was performed between August 1986 and July 1987.

We requested comments from DOE, DOD, and NASA on a draft of this report. All three organizations concurred with the report's contents. DOE, in particular, stated that "Overall, the report is well done and the major issues are discussed from a well balanced perspective." The written comments from DOE and DOD are presented in appendixes II and III, respectively. NASA's comments were provided orally. Minor technical corrections and suggested editorials changes have been incorporated where appropriate.

SP-100 Program Faces Many Challenges to Demonstrating Technological Readiness

The SP-100 program was formed in 1983 as a joint endeavor supported by three federal organizations: DOE, NASA, and DOD's Defense Advanced Research Projects Agency (DARPA). The program was established to develop technology for space reactor power systems aimed at satisfying electrical power requirements ranging from about 10 kilowatts to about 1 megawatt. The program's primary goal, which is to provide the technical basis for mission planners to select nuclear reactor power systems for their space missions, however, poses many challenges. These challenges include

- coordinating the activities of numerous organizations that must work together effectively for the program to succeed,
- demonstrating space reactor technology, and
- obtaining a commitment from DOD or NASA to use the SP-100 power system technology in a space project.

The following sections of this chapter provide background and current status information on the SP-100 program and details on the challenges facing the program.

Status of the SP-100 Program

The SP-100 program is proceeding through three phases:

- Phase I included technology assessment and the selection of a nuclear power system concept for further development in succeeding phases.
- Phase II is aimed at further development of the selected concept with the objective of demonstrating that nuclear reactor power system technology is ready for flight systems development.
- Phase III is expected to include a flight demonstration and use of a reactor power system integrated with a space application.

Phase I of the SP-100 program, which took place from 1983 to 1985, was funded by DOE, NASA, and DARPA and cost approximately $51 million. (When the SDI research program was established in 1984, SDIO, which was created within DOD, replaced DARPA in the program and the program was brought under SDIO's direction.) The selection of an SP-100 reactor power system concept in phase I culminated 3 years of data gathering and technical investigation and advancement. The power system concept approved for development is a compact, high-temperature, fast reactor cooled by liquid metal, together with an energy conversion process with no moving parts that will produce power in the 10 kilowatt to 1,000 kilowatt range.[1]

Phase II of the SP-100 program is a projected 7-year phase (1986-92) to include engineering development and ground testing of major subsystems and is funded by DOE, NASA, and SDIO. According to DOE officials, phase II is estimated to cost about $721.7 million. Lead responsibilities for segments of the program are divided among the following agencies:

- SDIO is responsible for overall program direction.
- DOE is to develop, build, and demonstrate the selected nuclear reactor power system concept and technology.
- NASA is to develop advanced materials and power system technologies directed toward improved nonnuclear power systems.
- NASA and the Air Force (under SDIO's direction) will define and update future civil and military requirements for space power.

Of the $721.7 million estimated cost for phase II, the Project Manager told us that $691.7 million is being spent on DOE's Ground Engineering System (GES) project to design, develop, and demonstrate a power system concept. The remaining $30 million will support NASA's research efforts on advanced materials and power system technologies for future upgrades of SP-100 beyond its first demonstration and updates of civil requirements for space power. For example, NASA is planning to research advanced materials and improved techniques that may be more suitable for its missions. According to NASA officials, although the SP-100 program strategy was adjusted to accommodate the emphasis on potential near-term military applications, the technology developed for the SP-100 power system can still be applied to power systems for NASA's missions planned for the year 2000 and beyond. SDIO will separately fund updates of military requirements as needed.

Planning for phase III of the SP-100 program, the flight demonstration phase, is in an early stage. Phase III is expected to begin in fiscal year 1989, overlapping phase II. According to SP-100 program officials, funding for this flight demonstration phase would be shared. Early cost estimates have ranged from approximately $500 million for a 5-year effort

[1] In a fast reactor, the chain reaction that creates energy is sustained by highly energetic neutrons impacting a specific type of uranium atom. These neutrons do not need to be slowed down by moderating materials in order to cause fissions. This characteristic allows the system to become compact. The power system employs thermoelectric energy conversion, a means of generating electricity by creating a temperature difference between "hot" and "cold" sides of a special material.

to deliver an SP-100 space reactor power system for flight use to more than $1 billion for integrating, testing, and launching a power system with a propulsion system.

In September 1985, SDIO established an electric propulsion system as a reference mission for flight demonstration and assigned the Air Force the responsibility for identifying the activities, cost, and schedule needed to carry out a flight demonstration. The propulsion system uses electricity to heat gas, which is the propellant. The system will demonstrate orbital maneuvering capabilities needed to deploy and operate space platforms and will also illustrate and test the interaction between the propulsion system and the SP-100 power system. However, the electric propulsion system may not be flown. If DOD decides to use the SP-100 power system technology for a specific application, such as one of its target discrimination or surveillance applications, plans could get underway to demonstrate the SP-100 technology with one of these other applications. Program officials said the timing of SDIO's requirements is still not known, but the target launch date for planning purposes is fiscal year 1995.

Management Coordination and Control

Because the SP-100 program involves three federal organizations at the program level and numerous organizations at the project level, the program needs to be effectively coordinated at both the program and project levels to achieve program goals. A steering committee—made up of the SDIO Director, NASA's Associate Administrator for Aeronautics and Space Technology and DOE's Assistant Secretary for Nuclear Energy—heads up the SP-100 program structure. SDIO's Space Power Manager, in the role of SP-100 Program Director, will provide overall direction for the SP-100 program. At the project level, the GES Program Director at DOE headquarters is responsible for the overall direction and results of the GES project, which is the primary activity in the current phase of the program. To carry out the program and project objectives, written agreements have been prepared to establish roles and responsibilities among the organizations and managers involved.

At the program level, coordination between the sponsors of the program—DOD (represented by SDIO), NASA, and DOE—is essential since each organization's basic purpose is different and each has an independent need with respect to U.S. space missions. For example, DOD is responsible for protecting the security of our country. With respect to U.S. space missions, DOD is interested in establishing a space defense system to eliminate the threat of nuclear ballistic missiles. The technology for a nuclear reactor power system is one that is being explored by DOD as a power source for concepts being developed for the SDI. NASA, which is responsible for various space science and exploration missions is planning several civil space missions in the late 1990s and beyond with varying levels of power requirements that can be powered by nuclear reactor power systems. DOE, which has the responsibility for developing nuclear power system technology, to include space power systems, is attempting to develop technology that will be useful to both DOD and NASA. Therefore, to achieve the SP-100 program goals, the three organizations must work together to ensure that DOE's design and development of the SP-100 power system technology are responsive to proposed DOD's and NASA's space applications.

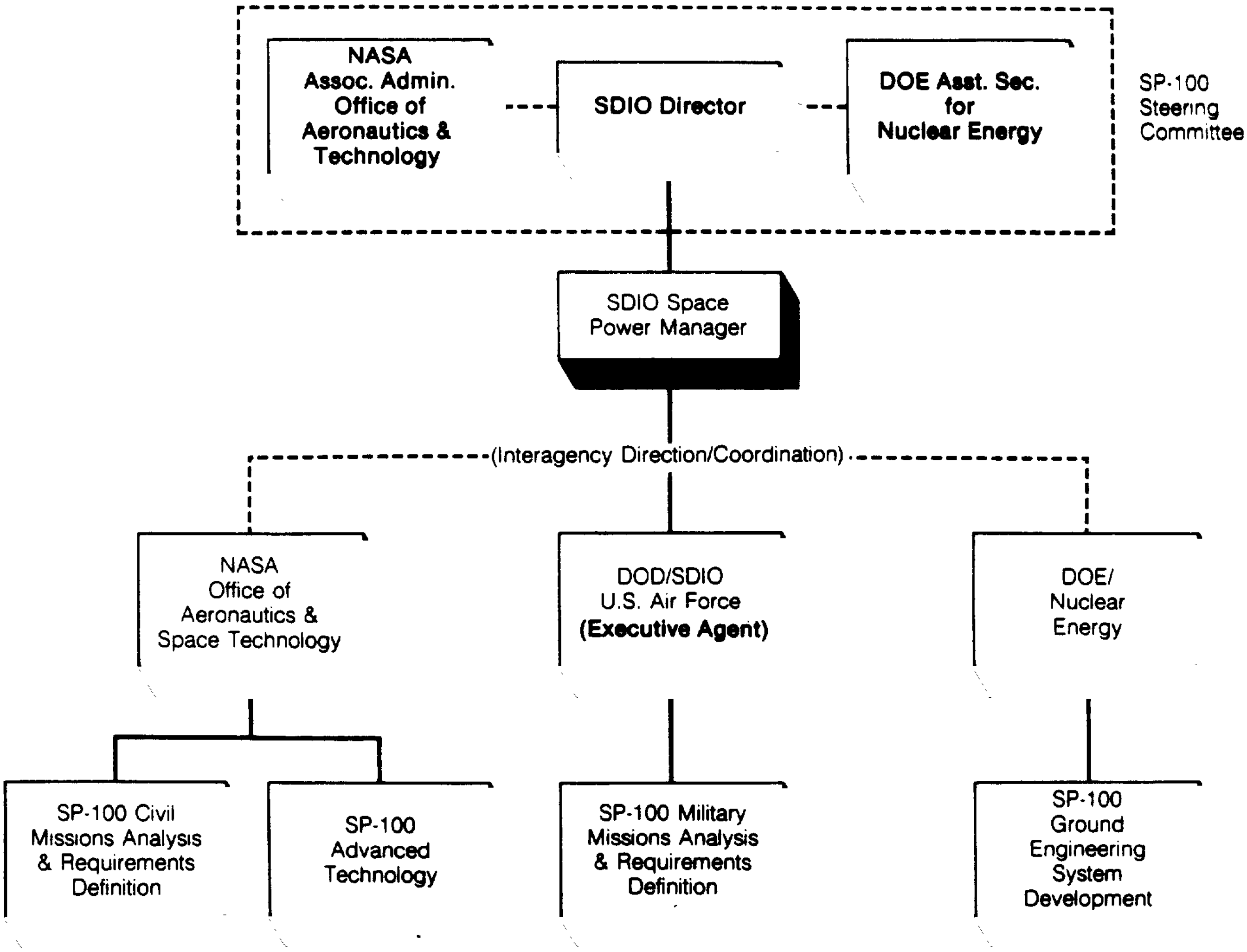
To ensure successful completion of program goals, activities are being coordinated at the program level and officials from the three organizations have prepared agreements specifying their respective roles and responsibilities. For example, officials from DOD, NASA, and DOE signed a Memorandum of Agreement in October 1985 which contains objectives, organizational structure, and responsibilities to carry out the program goals for phase II. (See fig. 2.1.)

The steering committee approves the program goals, ensures their respective organizations provide program resources, and monitors the program's progress. It also approved the management structure that divides lead responsibilities for segments of the program among the three organizations.

At the project level, numerous organizations conduct technical activities that need to be coordinated and managed to achieve program goals. Figure 2.2 depicts the structure for carrying out the GES project. The SP-100 GES Program Director at DOE headquarters is responsible for the overall direction and results of the GES project. The GES Project Office is located at NASA's Jet Propulsion Laboratory (JPL). The GES Project Manager at JPL is assisted by the Project Deputy for Space Operations at JPL and the Project Deputy for Nuclear Operations at Los Alamos National Laboratory. The GES Project Manager is responsible for the technical direction of activities performed throughout DOE and NASA laboratories and by contractors, as shown in figure 2.2.

Although DOE projects are usually managed by DOE operations offices, JPL has the overall technical direction role for the GES project rather than a DOE field office. The SP-100 GES Program Director said that the three

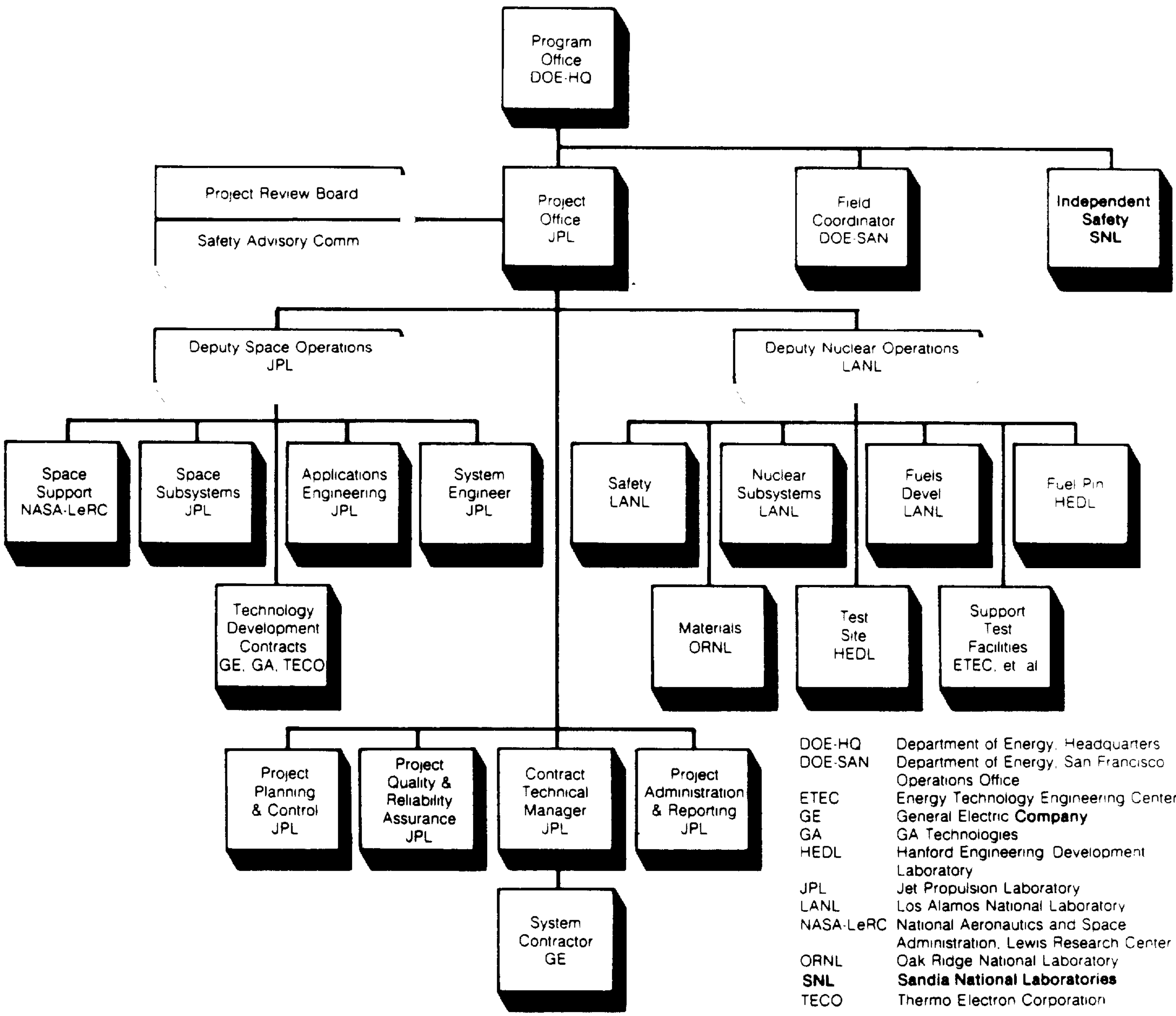
Figure 2.1: SP-100 Phase II Management Structure



Source: NASA.

funding agencies agreed to have an organization with spacecraft expertise in the project management role. JPL officials told us that over the years JPL has established its experience in systems integration and managing space flight projects for NASA, such as the Voyager and the planned Galileo interplanetary exploration missions.

Figure 2.2: SP-100 GES Program/Project Organization



DOE-HQ	Department of Energy, Headquarters
DOE-SAN	Department of Energy, San Francisco Operations Office
ETEC	Energy Technology Engineering Center
GE	General Electric Company
GA	GA Technologies
HEDL	Hanford Engineering Development Laboratory
JPL	Jet Propulsion Laboratory
LANL	Los Alamos National Laboratory
NASA-LeRC	National Aeronautics and Space Administration, Lewis Research Center
ORNL	Oak Ridge National Laboratory
SNL	Sandia National Laboratories
TECO	Thermo Electron Corporation

Source: SP-100 GES Project Office.

DOE's field office in San Francisco, however, has some project responsibilities. As the office in charge of SP-100 field direction, the San Francisco Operations Office is responsible for contract administration and funding control for the system development contract with General Electric Company. Although the DOE field office negotiates the terms of the system development contract, DOE will depend on JPL to handle the technical direction of the project.

In order to meet the challenge of managing GES project activities, written agreements have been prepared to establish working relationships and responsibilities among individual managers, offices, and organizational levels. For example, DOE headquarters, DOE's San Francisco Operations Office, JPL, and Los Alamos National Laboratory signed a Memorandum of Understanding for the SP-100 GES project in October 1985 which establishes project objectives, organizational structure, and responsibilities among the parties involved.

Other documents, including those being prepared to implement the system development contract, that form the basis for project coordination are the

- SP-100 GES development contract between DOE and General Electric;
- Memorandum of Understanding between DOE headquarters, DOE San Francisco Operations Office, and DOE Richland Operations Office for performance of nuclear assembly testing and validation;
- Interface Management Plan for managing all interfaces between General Electric and participating government laboratories; and
- Interface Control Documents, which cover in more detail the relationship between and responsibilities of General Electric and the laboratories.

Demonstrating Space Reactor Technology

Although the power system concept selected for development is considered technically feasible, the GES project faces the difficult challenge of demonstrating that the space reactor technology works. New designs, fuels, and materials for the power system's components and subsystems are needed to meet the physical demands of higher operating temperatures and other requirements for the system, such as size, weight, and performance requirements. The SP-100 reactor is expected to operate at temperatures of about 2100° Fahrenheit—more than twice the temperatures of liquid metal cooled reactors on earth (620° - 900° F) and hotter than liquid metal cooled space reactors developed in the 1960s (1300°

F). The GES test program is intended to verify that the design and technologies advanced for the nuclear power system are ready for flight systems.

New Design

According to program officials, the SP-100 power system design and technology must demonstrate a 100-kilowatt reference system that will be both safe and reliable and meet specified size, weight, and performance requirements. The technology developed for the system must be scalable in different sizes to generate power levels of 10 to 1,000 kilowatts by varying both size and number of parts. However, the size to be demonstrated in the GES project must be limited to one-third of the NASA Space Transportation System Shuttle cargo bay to leave room for the rest of the flight system. The power system also must not weigh more than about 6,600 pounds. In addition, the system must meet a number of performance requirements, including some of the following. The system must

- be capable of providing continuous full power for 7 years and have a life span of up to 10 years;
- have reliability greater than 95 percent;
- be capable of surviving both the natural space environment and hostile threats; and
- not be dangerous to the public when tested on earth, nor later when it is part of a flight system.

Advances in Fuels and Materials

Because of the high operating temperatures for a liquid metal cooled space reactor and length of operating time, technological advances need to be achieved in fuels and materials used to build the SP-100 reactor and other power subsystems to deliver power while remaining reliable. The reactor fuel being developed consists of pellets made of fissionable uranium material stacked in thin tubes called fuel pins. SP-100 needs fuel that can provide full power for 7 years at the specified operating temperature and without deforming the fuel container enough to crack it. Fissioning causes fuel pellets to swell and release gases. If the swelling and pressure are too great, they can cause cracks in the material (called cladding) that holds them. When fuel cladding cracks, fission gases can flow out and coolant fluid can flow in. Such changes could lead to system degradation and premature shutdown.

Researchers are working to ensure the compatibility of various materials to be used in the space power system. Incompatible materials can react destructively with one another. Materials must also perform at different operating temperatures and must have adequate strength not to crack under cold conditions before the reactor starts up, during hot operating conditions, or when changes occur between the two states. They must also be able to withstand heavy vibrations that may occur at launch and also resist damage from radiation and particles that occur naturally in space.

Verifying Design and Engineering Accomplishments

Two test programs conducted by the system development contractor are intended to verify that the design and technologies advanced for the nuclear power system are ready for flight use. General Electric, the system development contractor, is responsible for designing the power system and building and testing the components and subsystems. General Electric is assisted by other industrial contractors and government national laboratories. Designs for the entire power system as well as the subsystems are to be reviewed by program officials and independent review groups at intervals, and final reviews of the ground engineering system design is expected to take place before subsystems are built for testing.

The two test programs, which will determine whether the design and technologies advanced are ready for flight use, cover (1) component lifetimes and (2) power system subsystem test assemblies operating performance. Each set of tests involves developing a model that predicts performance, comparing analytical predictions of how components or power system subassemblies will behave with experimental data from hardware tests, and revising models as needed to improve the accuracy of their predictions.

Fuels, materials, and components are being subjected to high temperatures and nuclear radiation in research reactors at several facilities. The power subsystem assemblies are to be tested in temperature-controlled vacuum vessels to simulate the space environment. The nuclear assembly test will include test of the reactor, control drives, control drums, coolant pumps, and shield. The test is scheduled to take place in a containment facility at DOE's Hanford Engineering Development Laboratory. An integrated system-level assembly test consisting of an electric heat source and the nonnuclear subsystems of the power system is planned to demonstrate thaw of the reactor coolant, thermoelectric energy conversion, and waste heat radiation. The integrated assembly test will take place at a location to be determined by General Electric.

Obtaining a Firm User Commitment

The success of the SP-100 program will also depend on whether NASA or DOD mission planners ultimately select the SP-100 technology for use in operational flight. Although NASA and DOD have indicated that the SP-100 power system technology is needed for some future civil and military missions, neither have yet committed themselves to using the SP-100 technology for any specific space application. A dedicated user is needed for the program to continue flight system development, qualification, and demonstration. In this connection, previous space reactor programs undertaken in the 1950s to the early 1970s were terminated because firm missions that would use nuclear reactor technology did not materialize.

Finding a user has been an SP-100 program objective since phase I. To ensure an orderly and effective transition from engineering development to production of a flight system, DOD or NASA must commit to a firm requirement. The GES Project Office is responsible for contacting potential users to provide them with information about SP-100 technology and encourage its use, as well as for keeping abreast of how users' requirements are evolving. However, DOE nuclear energy officials stated that finding a committed user for an unproven technology is no easy task. The difficulties lie with the familiar "chicken and egg syndrome." That is, which comes first: the requirements of a mission or a technology to enable that mission. Users typically will not commit to a technology that has not been adequately developed and, conversely, new technology cannot be adequately developed without a specific user commitment.

According to the GES project's Applications Engineering Manager at JPL, an important first step toward obtaining a user commitment has been achieved. Several industrial firms bidding on SDI program space systems are discussing possible use of SP-100 technology for their concepts. However, decisions still to be made in DOD concerning engineering feasibility of SP-100 technology and time frames for the SDI program will determine whether and when one of these potential users could make a firm commitment to launch with SP-100.

SP-100 Program's Top Priority: Developing a Safe Reactor

While the SP-100 program has a number of initiatives aimed at addressing the challenges discussed in chapter 2, officials involved in the program state that their highest priority is developing a safe reactor for space flight use. Although SP-100 program managers are confident that space nuclear reactors can be operated safely, many questions will have to be addressed about the dangers from launching and operating a nuclear reactor in space. What, for example, would have happened had the space shuttle Challenger's payload included a nuclear reactor containing significant amounts of nuclear fuel? What are the possibilities and consequences of U.S. space reactors leaving orbit and returning to earth, as did the Russian satellite Cosmos 954 that spread radioactive debris over an isolated area of Canada in 1978? Answers to these and many other safety questions are being pursued during design of the SP-100 reactor in the GES project.

This chapter discusses DOE's approach to reducing the dangers of possible exposure of the public and the environment to harmful levels of radiation. It also discusses the formal safety review and approval process required prior to using nuclear reactors in space. Further, the chapter presents information on the safety organization and specific safety roles and responsibilities of program offices and officials. And it concludes with information on funds allotted to safety and related reliability and quality assurance tasks.

DOE's Approach to Developing Safe Space Reactors

DOE has identified safety issues in all phases of operating a space nuclear reactor and plans to either preclude the occurrence of safety-related accidents or reduce the risk of accidents to acceptable levels. The primary safety issue is the possible exposure of the earth's population and environment to harmful radiation levels generated by the reactor. Exposure can occur if the reactor becomes operational before reaching a safe orbit or if it returns to earth before the radioactive material has decayed. Program officials stated that 300 years is considered adequate for a decay period for the radioactive material. If missions require reactor operation in stable orbits below a 300-year stable orbit, boosting from this low orbit will be required at the end of mission. Other issues include the potential failure to control or protect the system or its nuclear materials adequately, potential release of hazardous nonnuclear as well as radioactive materials, and potential failure of the system to operate as designed or intended.

DOE plans to address safety issues through design and/or operational features. Inherent design features for safety include hardware devices such as reactor control mechanisms that are physically locked in shutdown position to prevent unplanned startup. Operational features involve procedures, such as not starting the reactor until a stable orbit is achieved. This is a key feature for space reactors. The reactors will be launched in what is known as a radioactively cold condition. This means that no radioactive fission products are available for release.

Mission Phases

DOE has analyzed ways in which safety issues could arise during flight mission phases. According to program officials, a projected space flight mission can be separated into the following phases: (1) transportation and ground handling, (2) launch, (3) ascent and orbit insertion, (4) operations, and (5) end-of-life disposition. The space reactor will be constructed at a contractor site and be transported to the launch site. The ground handling phase includes loading and removing the space reactor from the transportation vehicle, storage, preflight testing, loading into the launch vehicle, and transport to the launch area. The launch phase starts with the fueling of the rocket and ends with launch vehicle lift-off. The ascent phase covers the time from lift-off through deployment in a stable orbit. The operational phase begins when the reactor is turned on and ends with reactor shutdown. End-of-life disposition phase starts with shutdown and ends with the reactor's ultimate disposition.

The primary safety objective in the first three phases of a space mission is to ensure that the reactor is unable to sustain a chain reaction (subcritical mode) under all possible conditions, including accidents. General Electric, the system development contractor, is responsible for designing a reactor that will not startup under the most severe accident conditions. These include the effects of explosions or impacts with the earth's surface, flooding by water, and core melting by propellant fires. According to program officials, the reactor will be designed to startup when control drums are rotated to their startup positions and safety rods are removed. To prevent reactor startup before it is placed in orbit, both the control drums and safety rods are to be locked into position. Removal of the locking mechanisms is planned by an astronaut or a specially coded signal from earth. According to program officials, these locking mechanisms are to be designed to withstand the explosive forces comparable to that experienced in the Challenger accident.

During the transportation and ground handling phase, an additional objective is to safeguard the system and its nuclear materials. According to the GES Project Manager, the reactor is not a hazard while on the launch pad because the fuel emits only Alpha radiation, which is easily blocked by a person's skin. This type of radiation is harmful only if the source material has entered a person's body. The fuel, although not a radiation hazard, is a safeguard concern because the amount in an SP-100 reactor is expected to exceed both national and international standards for a significant quantity of highly enriched uranium. The International Atomic Energy Agency, an agency of the United Nations, considers 25 kilograms of this type of material to be a "significant quantity" having the potential for diversion and clandestine use. Thus, the fuel will be safeguarded under established DOE and Nuclear Regulatory Commission procedures and regulations, which encompass physical security, materials control and accountability, and inspections to verify materials inventory and to ensure that materials remain in a subcritical state.

Also during the ground handling phase, some preflight zero-power testing is to be done on the launch site, although it is not expected to produce hazardous levels of radiation. In zero-power operation, the reactor coolant is not needed and little radioactivity is produced. According to a NASA report,[1] radiation levels at the launch site will be so low that no special exclusion zones will be established. (Exclusion zones are areas where because of radiological hazards, access would be limited to personnel with special protective equipment and clothing.)

The SP-100 reactor is to be designed to remain intact during accidents that could also occur in space. According to the GES Project Manager, the reactor will be safe during operation in orbit. The reactor would retain all radioactive material produced during operation and, therefore, have no impact on public health, safety, or the space environment. The reactor is also being designed to operate reliably and safely in space without continual control transmissions from a ground base. According to program officials, component failure or damage to the reactor while in operation would result in a loss of power through a reactor shutdown with no danger to the space environment. SP-100 is being designed with multiple independent shutdown paths to ensure that shutdown will be achieved. A program official stated that, in the unlikely event that systems failed and a shutdown did not occur, space could be contaminated. He added that, although this would present no immediate safety hazard, the long-range implications of increasing amounts of space contamination are less certain.

[1] Civil Applications of Nuclear Power—Final Report of the Civil Missions Advisory Group, prepared by NASA Headquarters, September 1984.

According to program officials, following the end of operation, the reactor is to remain in space indefinitely. As a backup precaution against potentially hazardous exposure resulting from inadvertent reentry, the reactor is being designed to survive reentry intact, including impact with the earth's surface.

Flight Approval Process

Before space nuclear reactors can be used in a space mission, they have to undergo a safety review process to establish that the associated risks are worth the benefits to be derived. The safety review process is prescribed by a 1977 presidential directive. The directive establishes the basic procedures to be followed for launching space nuclear systems and basically requires an assessment of the mission risk versus benefits. The directive requires that an ad hoc Interagency Nuclear Safety Review Panel be set up to determine risk posed by use of a nuclear reactor power system in space. The determination that mission benefits using these power systems are worth the risk is to be made by the Office of Science and Technology Policy[2] (OSTP) or by the President under certain circumstances.

The Interagency Nuclear Safety Review Panel review begins shortly after a mission is identified and a power system concept is selected and consists primarily of review and analysis of data contained in preliminary, updated, and final safety analysis reports. Sometime after mission selection, General Electric is expected to issue a Preliminary Safety Analysis Report. This report is to describe the mission and the nuclear power source and identify and characterize the potential accident environments and how the power source would respond to these environments. The preliminary report is expected to contain information that quantifies the resulting risks. The second report, the Updated Safety Analysis Report, is issued as soon as possible after the power system design is firm. At this point General Electric plans to begin hardware fabrication, which leads to actual manufacture of the power system for the mission use. The second report is expected to update information on the mission and associated risks. The Final Safety Analysis Report is issued about 1 year before the scheduled launch. This report provides a detailed description of the final system design, the mission, and a Nuclear Risk Analysis Document which contains a probabilistic description of the risk resulting from potential accidents that could involve the nuclear power source of the spacecraft.

[2]The OSTP is part of the Executive Office of the President responsible for providing scientific advice to the President and for coordinating scientific activities in the Executive Branch.

After review of the Final Safety Analysis Report, the Interagency Nuclear Safety Review Panel is expected to prepare a Safety Evaluation Report which summarizes the panel's risk evaluation. The report is submitted to DOE, DOD, and NASA for review after which the agency requesting use of the nuclear power source will propose a launch approval to the OSTP. For example, NASA would request approval for a mission to explore a planet. The Director of OSTP is authorized to approve a launch unless the spacecraft contains a significant amount of radioactive material or if in the opinion of the Director, OSTP, the decision should be made by the President.

SP-100 GES Program Officials Have Specific Safety Responsibilities

The SP-100 program has implemented a safety plan to incorporate safety measures into the SP-100 reactor design. The plan, issued in November 1986, defined an organization and the overall framework and strategy for safety, as well as specific roles and responsibilities for program participants. The program provides for independent oversight and assessment by advisory groups and consultants.

Safety Roles and Responsibilities

The SP-100 program places safety responsibility on line management beginning with the Program Manager and Program Office down the management chain through the Project Office to General Electric. The SP-100 GES Program Director, who is responsible for the overall direction and results of the GES project, approved the safety policy and criteria, the Safety Program Plan, the contract safety technical specifications imposed on General Electric, and all safety documents involving the reactor test site at the Hanford Engineering Development Laboratory. The Program Director also approves Safety Analysis Reports and the Project Office Safety Implementation Plan. Safety Implementation Plans, which translate the Safety Program Plan into specific actions, are detailed plans prepared by the Project Office, the reactor test site operator, and the system contractor. The Program Director also is expected to ensure adequate and appropriate interaction between the SP-100 GES project and outside advisory groups on safety matters.

DOE's San Francisco Operations Office performs general safety oversight and review of program safety efforts. As a DOE contracting agent, this office is responsible for ensuring that safety activities of the system contractor are within contract scope. For example, it must approve the contractor's Safety Implementation Plan.

The GES Project Manager at JPL is responsible for implementing the Safety Program Plan and for ensuring compliance with the safety criteria. He is also responsible for preparing the Project Office Safety Implementation Plan and for preparing the contract safety technical specifications through his Deputy for Nuclear Operations. The technical specifications establish requirements for systems, subsystems, and components to meet safety criteria. For example, one specification states that

> "the reactor shall be designed to remain subcritical for all credible transportation, handling, launch, and ascent abort accidents. It shall also remain subcritical during reentry, ground impact, and subsequent immersion in water or soil."

General Electric is responsible for demonstrating that its reference flight system design meets the safety technical specifications required by the contract. General Electric is expected to demonstrate this through test and analysis and to develop detailed safety design specifications that will be used in manufacturing the system. General Electric is also expected to perform a safety analysis that identifies the spectrum of potential accidents and to calculate their probabilities and consequences.

The test site operator at the Hanford Engineering Development Laboratory is responsible for testing the SP-100 GES nuclear subsystem including the reactor. The test is to be conducted in a specially modified reactor containment facility, and the laboratory is responsible for developing a report—with help from General Electric—that identifies and addresses all the safety concerns of ground testing the reactor. The laboratory is also expected to prepare all required National Environmental Policy Act documentation and provide DOE safeguards while the reactor fuel is on site.

The SP-100 organization provides for three separate sources of safety advice and counsel to the SP-100 Program and Project Offices. These are (1) a Safety Advisory Committee that advises the GES Project Office, (2) an independent Safety Assessment Group at Sandia National Laboratories that advises the SP-100 GES Program Director, and (3) a consultant available to the SP-100 GES Program Director. An independent Safety Advisory Committee made up of experts inside and outside of government provides review and oversight of project and contractor activities. The committee advises the Project Office on issues that may affect safety, safeguards, and environmental requirements and considerations, including related reliability and quality assurance matters (i.e., surety). Members include professors of engineering; expert consultants in the field of space surety; program-independent experts from DOD, NASA, and DOE; and a policy analyst from OSTP. The GES Project Manager is responsible for providing this committee with resources to do its job. The committee, which was formed in phase I of the program, has met 15 times and plans to meet at least 4 times a year starting in fiscal year 1987.

An Independent Safety Assessment Group—the second source of advice and counsel on safety matters—follows safety activities within the GES project and advises the SP-100 GES Program Director. Also, at the Director's request, the group will perform independent assessments of design, development, testing, and disassembly of the reactor. The third source is an independent safety consultant who is available to the SP-100 GES Program Director for safety advice and counsel.

Cost of Safety Is Difficult to Segregate

Although specific funds have been allocated for safety-related tasks, program officials pointed out that the dollar amount for safety does not reflect the total program investment in safety. It represents less than what is actually spent to build a safe reactor. They stated that many tasks are undertaken and dollars spent that are not specifically identified for safety purposes but contribute to the development of a safe reactor.

Program officials characterized the specific tasks for which staff hours and costs can be estimated primarily as management, planning, and oversight. What is not separately accounted for and what program officials stated would be very difficult to do is to segregate the cost of designing a safe reactor from the cost of the whole system. The GES Project Manager identified $20.3 million budgeted for specific safety tasks, of which $13.8 million would go to General Electric. These tasks, for example, include providing technical management over environmental, safety, health, and safeguards activities; planning activities to prepare a Safety Implementation Plan; and reviewing safety information provided to the test site operator and assisting in GES safety reviews.

DOE also has an SP-100 quality and reliability program that is closely related to the SP-100 safety program. The program encompasses all the activities required to ensure that the SP-100 space nuclear power system meets design requirements and specifications, that hardware is fabricated and assembled in accordance with that design, that effective testing is performed to confirm the adequacy of and conformance to the design, and that the hardware and systems will operate safely, reliably, and effectively so that mission success is achieved. An example of the relationship between safety, quality, and reliability is the development and use of a Critical Items List. This list identifies the level of importance of each component or function of the SP-100 system based on safety and reliability considerations. The list is used to establish the degree of quality assurance required for each specific component or function based on the potential impacts should it fail to perform as designed. The list is also used as a management tool to track and document that all critical design issues are addressed throughout the design, fabrication, testing, and integrated assembly of the system. The SP-100 program has allotted $31.7 million for quality and reliability tasks with $21.3 million going to the contractor and the remaining $10.4 million allocated among the participating laboratories. Specific contractor tasks include, for example, writing a Quality Assurance Plan and planning and verifying quality-related activities by audit, surveillance, and inspections.

The Multimegawatt Program Faces Greater Challenges Than the SP-100 Program

In fiscal year 1985, SDIO initiated research on multimegawatt space power technology with DOE to specifically address SDI power requirements. The goal of the Multimegawatt Space Nuclear Power Program is to establish and advance the technology base for space power systems by the early 1990s to determine the feasibility of satisfying SDI mission requirements. DOE is responsible for developing the concepts and technology for a nuclear power system. The MMW program, though, faces technical and planning challenges of greater magnitude than those facing the SP-100 program. The program is in the initial stages of development; efforts are underway to define and assess power system concepts and to develop technologies. The program eventually is expected to achieve major advances beyond existing space power systems to meet the power levels required by SDI. Funding reductions and changes in SDIO's approach to meeting its long-term goal, however, have required program managers to modify the original program plans.

This chapter provides (1) background and current status information on the MMW program, (2) reasons why technological advances are needed to meet SDI requirements, and (3) planning challenges facing the MMW nuclear program.

Status of the MMW Program

The near-term objective of the MMW program is to identify and develop at least one space nuclear power system concept that, alone or in combination with a nonnuclear power system, can meet the SDI power needs of ten to hundreds of megawatts and for which critical technical feasibility issues related to the concepts in areas such as the reactor heat source, shielding, and power conversion, have been resolved. To meet the near-term objective of the MMW nuclear program, DOE plans to focus its efforts on (1) defining and designing nuclear power system concepts; (2) identifying and advancing technologies, including resolving feasibility issues that reflect the range of power system concepts under consideration; and (3) fabricating and testing a thermionic fuel element[1] to be used in high temperature reactors that could produce two to five megawatts of power with a 7-year operational lifetime. MMW program officials told us that in fiscal years 1985, 1986, and 1987, funds received for the program totaled $31.9 million. According to SDIO officials, funds projected

[1]In the thermionic concept, electricity is produced in the reactor core itself. A thermionic fuel element consists of cells surrounding each fuel element in the reactor. Each cell produces electricity by using the heat from a nuclear reaction in the fuel. Activities on the thermionic fuel element are intended to demonstrate the performance and verify the operating lifetime of technology that is ready for additional development based on research that was conducted in the SP-100 program. According to program officials, the technology developed on thermionics is considered promising and suitable for multimegawatt power levels.

through fiscal year 1992 total about $304 million. Definition and development of concepts and technologies may lead to a later engineering phase of the MMW program.

In fiscal year 1986, DOE contracted with six private firms to define multimegawatt power system concepts and with two firms to develop technologies. (See app. I.) In addition, DOE selected eight DOE national laboratories to participate in the program to define multimegawatt power system concepts, develop technologies, and provide project technical integration and other support to DOE. According to the MMW Program Director, the laboratories were selected based on their proposals to do multimegawatt research and on their recognized capabilities. Some national laboratories have built up capabilities enabling them to be recognized as centers of excellence in one or more technology areas.

Technological Advances Needed to Meet SDI Requirements

Although the SDI framework and power requirements are still being defined, the defense system envisioned for the SDI will need very large amounts of electrical power, significantly more than can be provided by current space power systems. Power levels needed are estimated to be in the range of ten to hundreds of megawatts for SDI missions. The higher power levels and anticipated performance requirements of the SDI concepts require major technological advancements in space power systems.

The SDI missions are expected to operate under various power modes. Both continuous high-level power and burst power lasting seconds or minutes will be required to operate space-based warhead detection devices and to fire defensive weapons. Rapid transitions from continuous to burst modes of operation will also be required. According to program officials, power systems to supply the needed power levels will require operating temperatures in the range of 2000° to 3500° Fahrenheit as compared with SP-100's temperature range of 1900° to 2100° Fahrenheit.

Higher operating temperatures require advances in all areas of technology for power systems. For example, advanced reactor fuels and materials and subsystems, such as shielding and heat transport systems, need to be developed because of the more stringent requirements imposed by the higher operating temperatures. Improvements are also needed in other areas of a power system—for example, radiators and power conversion systems—because of requirements to reduce weights and sizes. According to program officials, the use of existing solar, chemical, or nuclear technology, including SP-100, for multimegawatt power system development would result in systems with weights and sizes that could lead to excessive deployment costs. In addition, deployment could require multiple launches and in-space assembly.

Planning Under Funding Uncertainties and Evolving Deployment Strategies

DOE established two phases to meet its near-term objective. The current phase of the MMW nuclear program, planned for completion in fiscal year 1989, focuses on defining and designing nuclear power system concepts and on identifying and advancing technologies. The second phase, planned for completion in fiscal year 1992, is intended to result in the selection of one concept that will meet SDI multimegawatt power requirements.

The Program Director told us that, starting in 1984, a detailed strategy was worked out to advance and refine power system concepts and technologies. The MMW program strategy, based on early estimates of expected funding, was to solicit and evaluate a broad spectrum of candidate power system concepts from industry and government laboratories. This effort would be followed by a narrowing of the number of potential concepts during fiscal year 1986, and then the beginning of a technology development effort. A further narrowing of the number of power system concepts was expected to occur in fiscal year 1988, and technology development was to be focused on the selected candidate concepts. Ultimately, this approach would have enabled program managers to determine the overall feasibility of an MMW power system concept by the early 1990s.

However, because of cuts in projected levels of funding and the possibility that SDI may begin to be deployed earlier than originally anticipated, DOE has made adjustments to the scope of work involved and in time frames to carry out certain program activities for the MMW nuclear program.

Funding Reductions

In fiscal years 1986 and 1987, the MMW nuclear program received less funds than planned. Program officials stated that, similar to the SP-100 program, a number of DOE and SDIO programs received less funds than planned when both agencies were appropriated less funds for their space power budgets than they had requested. In fiscal year 1986, the program received from DOE and SDIO a total of $15.8 million, or about 92 percent of the $17.2 million requested. In fiscal year 1987, the $14.6 million received was about 37 percent of the total $39.7 million requested. (Both funding levels requested and received exclude amounts for a classified MMW nuclear project.) Funding requested through 1992 is projected to total $326.9 million.

As a result of lower funding levels experienced and anticipated for future years, DOE changed its strategy for both concept definition and technology development. Funding for power system concept definition work, originally planned to proceed until August 1987, was cut off in March 1987 and is expected to resume in April 1988. When DOE halted concept work, the laboratories and private firms doing concept work submitted final reports on the work they had completed as of that date. The data in these reports were used to prepare and issue a request for proposal to industry for concept design studies in July 1987. Industrial firms have been invited to propose concepts after reviewing those that were reported on by laboratories and firms. DOE plans to select up to eight concepts for 9 months of additional development, to be followed by a further narrowing to two or three concepts in early 1989. By 1992, at least one power system concept is to be selected that will meet SDI multimegawatt power requirements.

Funding for technology development work continued in fiscal year 1987 but only in areas where program managers believed that it would help concept proposers and DOE decide which concepts are more likely to be feasible. Under the old program strategy, generic technology development, not linked to any particular concept, would have been funded in addition to technology linked to applications. MMW program staff told us they established priorities among technology areas and selected for funding in fiscal year 1987, five considered most relevant to evaluating feasibility. The five are reactor fuels, materials, energy storage, thermal management, and instrumentation and control.

SDIO's New Approach to Deployment

The MMW program strategy has also been affected by SDIO's proposal to develop and deploy an antiballistic missile system by placing portions of it in operation at three different times. Each phase of successive deployment would facilitate achieving the ultimate system, while providing increments of protection from ballistic missile attack.

Although program officials told us that multimegawatt nuclear power will not be needed for the first phase, they added that SDIO's emphasis on phased deployment creates uncertainties in the original time frames planned to address MMW power requirements. When the MMW program was established, multimegawatt power would have been needed in the post-2000 time frame, but now it may be required sooner, depending on the timing and content of the phases of deployment. In response to SDIO's phased strategy, the July 1987 request for proposals for concept design studies was geared toward possible SDI phased deployment. The request solicited design studies for power systems categorized by power levels and system concepts of tens and hundreds of megawatts. DOE has established categories to meet possible SDI requirements for mid-term deployment and to meet anticipated power requirements in the ultimate defense system.

Concerns Raised About Adjustments Made

Program managers state that they can meet their near-term objective of identifying at least one space nuclear reactor power system concept despite concerns raised about the impact of adjustments made to their program strategy. Program officials stated that along with reduced funding, new time frame pressures from SDIO's possible phased deployment will force the MMW program to set aside some concepts while attempting to accelerate development of those selected. A near-term focus may not allow enough time for researchers to advance technology far enough to succeed. Concepts that seem high risk are likely to be set aside. Program managers said they were concerned about the possibility of eliminating concepts that might be better than those selected, if more were known about technical feasibility.

Firms and Laboratories That Worked on Defining Multimegawatt Power System Concepts and Technologies Fiscal Year 1986

Firms

AVCO Research Labs, Inc.
Babcock and Wilcox
GA Technologies
General Electric Company
Grumman Corporation
Rockwell International Corporation
Science Applications International Corporation
Westinghouse Electric Corporation

DOE Laboratories

Argonne National Laboratory
Brookhaven National Laboratory
Idaho National Engineering Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Oak Ridge National Laboratory
Pacific Northwest Laboratories
Sandia National Laboratory, Albuquerque

Comments From the Department of Energy

Department of Energy
Washington, DC 20585

NOV - 9 1987

Mr. Keith O. Fultz
Associate Director
Resources, Community, and
Economic Development Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Fultz:

The Department of Energy (DOE) appreciates the opportunity to review and comment on the General Accounting Office (GAO) draft report entitled, "Nuclear Science: Challenges Facing Space Reactor Power Systems Development." Overall, the report is well done and the major issues are discussed from a well balanced perspective. Minor corrections and suggested editorial changes are being provided separately to Mr. Thomas E. Melloy.

DOE hopes that these comments will be helpful to GAO in their preparation of the final report.

Sincerely,

Lawrence F. Davenport
Assistant Secretary
Management and Administration

Comments From the Department of Defense

DEPARTMENT OF DEFENSE
STRATEGIC DEFENSE INITIATIVE ORGANIZATION
WASHINGTON, DC 20301-7100

CP

5 November 1987

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and International
Affairs Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) Draft Report, "NUCLEAR SCIENCE: Challenges Facing Space Reactor Power Systems Development," dated October 1, 1987 (GAO Code 301739) OSD Case 7419. The DoD concurs with the GAO findings, and has no further comment on the draft report.

The DoD appreciates the interest the GAO has in space reactors. They are a significant part of planning to have survivable, compact power systems for space platforms.

The DoD also appreciates the opportunity to comment on the report in draft form.

Sincerely,

Gordon A. Smith

GORDON A. SMITH
Deputy Director

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