DOE/NE-0083

SP-100 SPACE REACTOR SAFETY

May 1987

DISCLAIMER

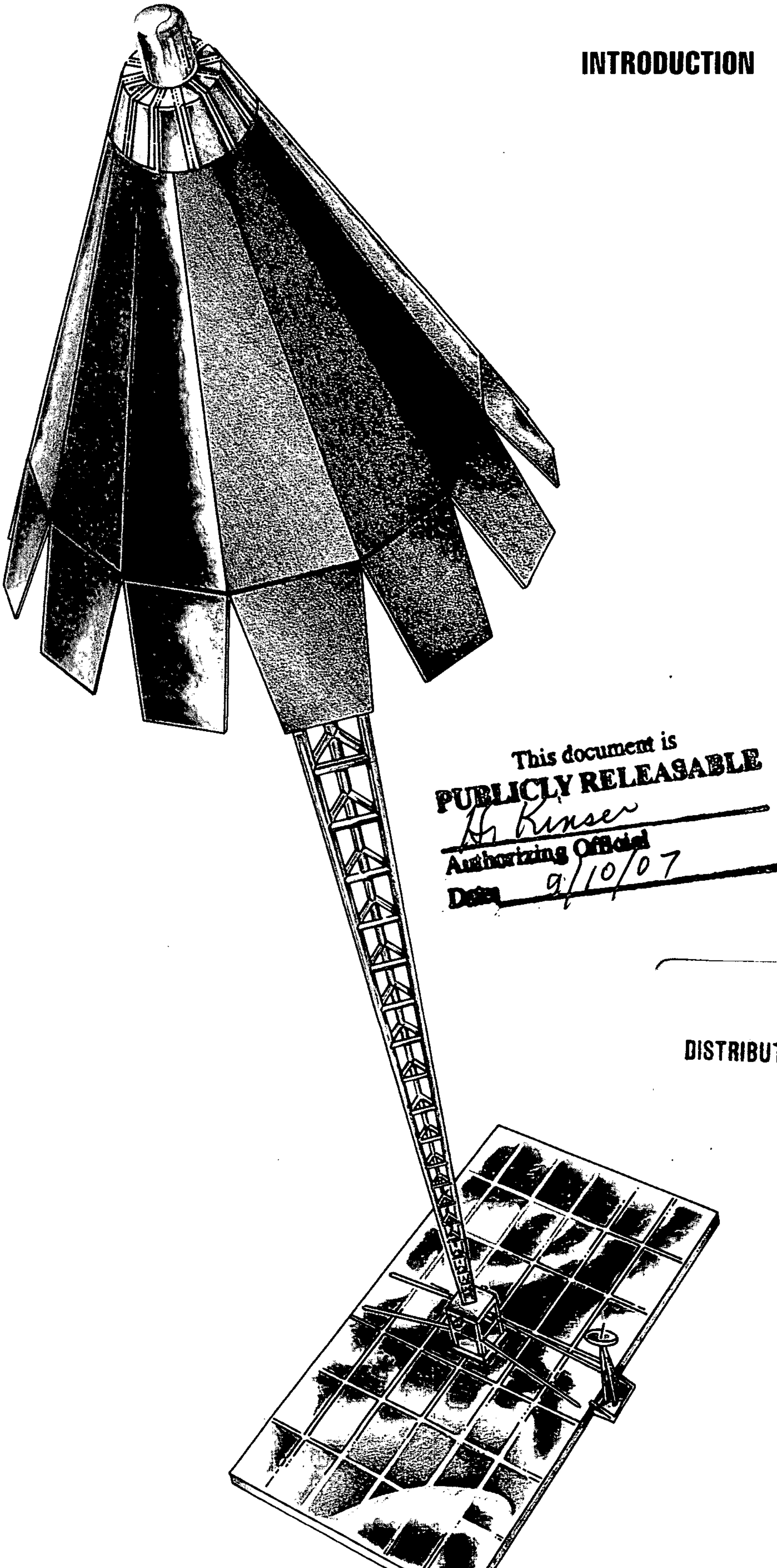
INTRODUCTION

All space missions require a reliable source of electrical energy. Space experiments and applications, the monitoring and maintenance of spacecraft, and the transmission of information back to earth can not be accomplished without electrical power.

Past U.S. space missions have used batteries, fuel cells, solar cells or nuclear radioisotope power sources. These power systems have provided the levels of electrical power required to date and will continue to do so as long as the power requirements remain relatively low. However, further accomplishments in space are limited by the amount of electrical power that is available.

The SP-100 space reactor power system is being developed to meet the large electrical power requirements of civilian and military missions planned for the 1990's and beyond. It will remove the restrictions on electrical power generation that have tended to limit missions and will enable the fuller exploration and utilization of space.

This booklet describes the SP-100 space reactor power system and its development. Particular emphasis is given to safety. The design and operational features as well as the design and safety review process that will assure that the SP-100 can be launched and operated safely are described. Additional information can be obtained from the source listed inside the back cover.



Conceptual illustration of an 100-kilowatt SP-100 space reactor power system coupled to a space based radar array.

WHAT IS SP-100?

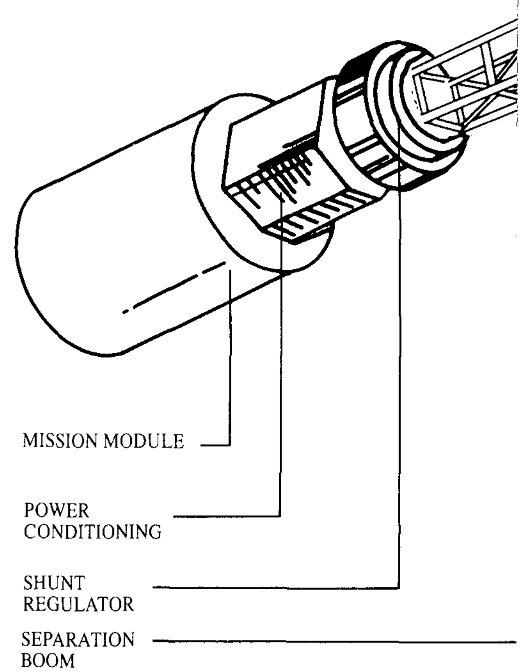
SP-100 is an electric power generating system being developed for use in space. It converts heat generated within a compact high-temperature nuclear reactor directly into electricity through the use of thermoelectric cells. The overall size of a 100 kilowatt reactor core is about 1 cubic foot or about the size of a 5 gallon can. The controlled fission process in the reactor heats a liquid metal coolant. The heated coolant is pumped from the reactor through a closed heat transfer loop to panels of thermoelectric elements that convert the heat directly into electricity. Excess heat is directed to radiator panels and dissipated to space.

The SP-100 technology is being developed to meet space electrical power requirements that range from about 10 kilowatts up to about 1,000 kilowatts. Although the size and weight of the power system will be tailored to a particular power level for a specific mission, the same basic technology can apply over the entire power range.

In 1983, the Department of Energy, the Department of Defense and the National Aeronautics and Space Administration (DOE, DOD, and NASA) initiated a three-phase SP-100 development program. During the initial phase of the program (1983-1985), several conceptual designs were analyzed. Safety as well as technical feasibility studies were conducted. In 1985, the present design concept was selected for further engineering development and testing based on criteria that included safety, performance and reliability requirements.

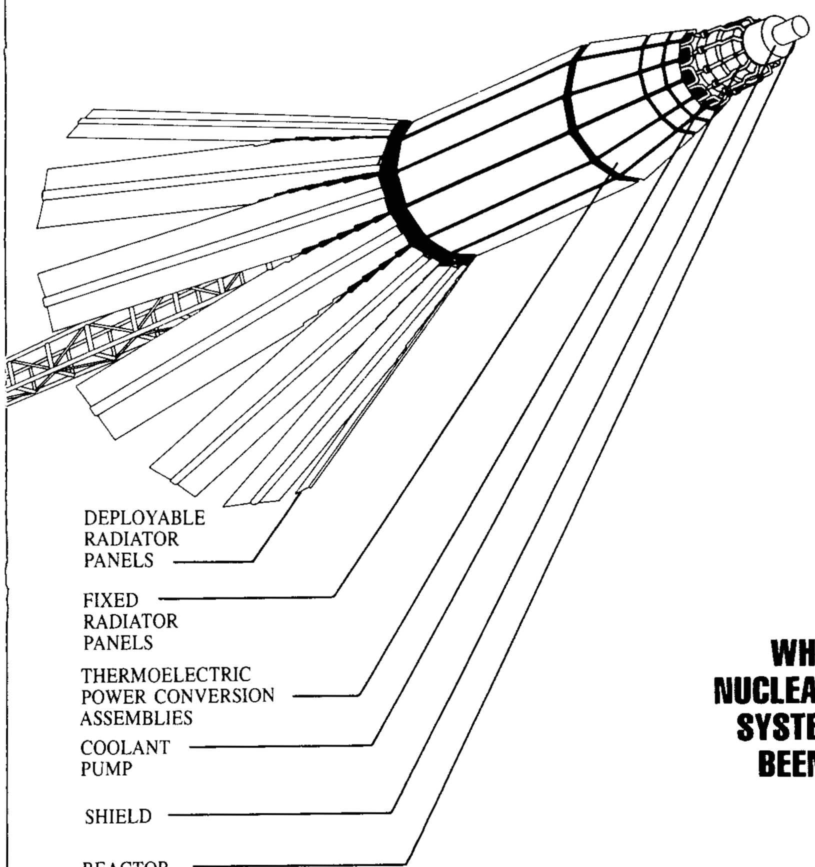
During the current phase of the program (1986-1991), a prototypical SP-100 system is being designed. Major components will be built and tested on the ground in a simulated space environment. The nuclear reactor will be tested at the Hanford Engineering Development Laboratory, near Richland, Washington. The reactor test will be conducted in an existing reactor containment structure to maximize the use of existing facilities and equipment. Other major modules of the power system, including the thermoelectric power conversion and heat rejection subsystems, will also be tested. These tests will be conducted using a non nuclear heat source. Demonstrating compliance with safety and performance requirements is a key objective of the current technology development effort. If successfully demonstrated, SP-100 technology can be available in the 1990's for initial spaceflight demonstration and subsequent use to support civilian and military space missions.

Major components of a typical SP-100 space reactor power system.



WHY IS NUCLEAR REACTOR POWER NEEDED IN SPACE?

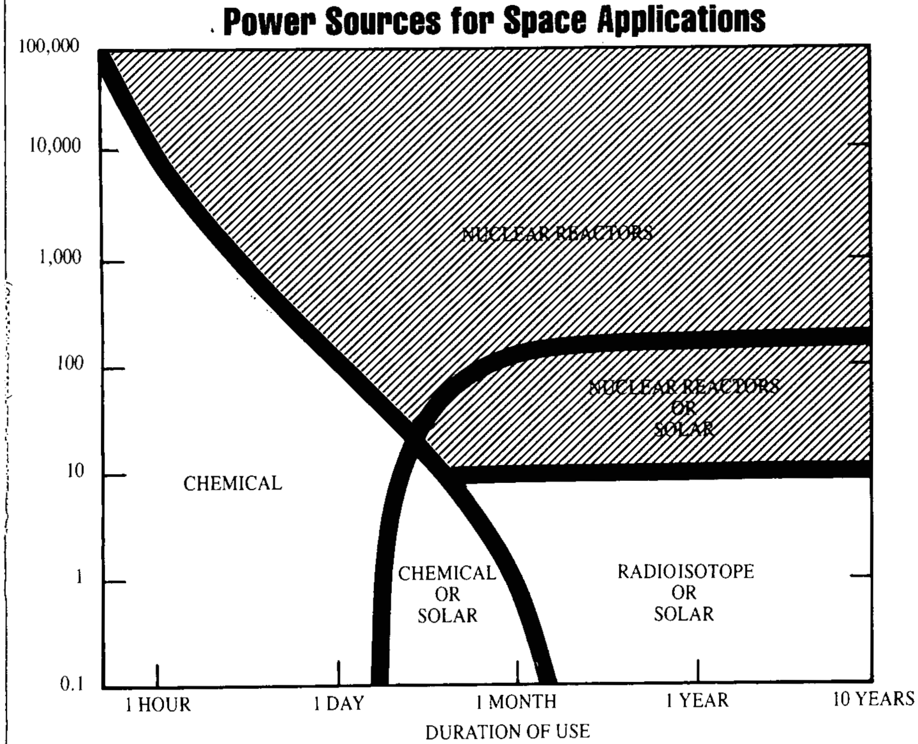
A reactor system can provide power independently of its orientation or proximity to the sun, is extremely compact, and is both durable and reliable. Reactor power systems can provide high levels of electric power for extended periods in space. Short-term power requirements can be met with chemical systems. Longer-term power requirements can be met with solar energy systems or nuclear radioisotope or nuclear reactor systems—depending on the particular mission requirements. However, only nuclear reactor systems can meet the higher-level, long-term electrical power needs of many future space missions. With such features, SP-100 reactor power systems can support a broad spectrum of space activities that will require large amounts of electrical power including communications, navigation, surveillance, and materials processing. It will also enable the use of electric propulsion for attitude control, orbital transfer, and interplanetary transportation.



WHAT OTHER NUCLEAR POWER SYSTEMS HAVE BEEN USED IN SPACE?

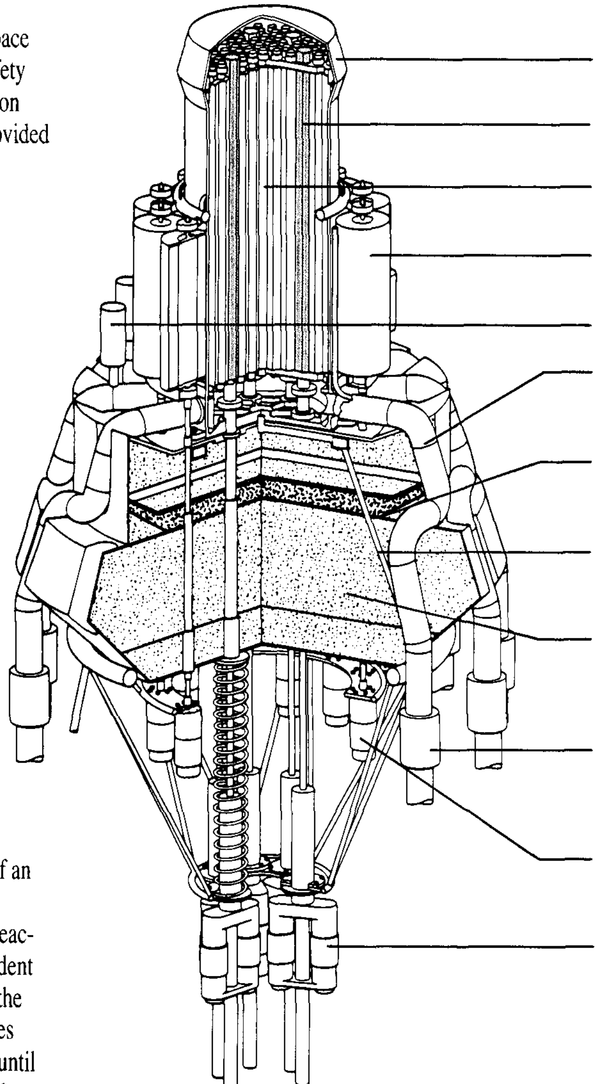
The United States has launched 37 nuclear radioisotope power systems in support of both civilian and military space missions over the last 25 years. These missions have included the Apollo lunar landings, the Viking mission to Mars, several Navy navigation satellites, and the Voyager and Pioneer spacecraft exploration of the outer planets. In 1965, the U.S. successfully launched SNAP-10A, the first nuclear reactor to be operated in space. Since then the Soviet Union has used reactors routinely in low, short-term orbits for ship surveillance.

Power Sources for Space Applications



WHAT ARE SOME OF THE MORE IMPORTANT SAFETY FEATURES OF THE SP-100 SYSTEM?

An important safety feature of the SP-100 system is that it contains no radioactive fission products when launched and will remain inactive until reaching its planned operational orbit. Once the reactor starts operating (and generating radioactive fission products) it would remain in space indefinitely. Additional information relating to safety during launch, operation in space and post operation shutdown of an SP-100 reactor power system is provided in the following sections.



Schematic of SP-100 reactor, shield and heat transport subsystems.

SAFETY DURING LAUNCH

Features that ensure safety during launch of an SP-100 system are an integral part of the design. These features will maintain the reactor in an inoperable condition even if a launch accident were to occur—including one such as occurred on the Space Shuttle Challenger. Two independent features will ensure that the reactor will remain inoperable until reaching its planned orbit. Both the external control drums and the internal safety rods will be physically locked in place to preclude reactor operation until the planned orbit is reached. Removal of a fail-safe mechanism by an astronaut or through coded telemetry will be required to permit reactor start up and operation. Until that time the uranium-235 fuel will remain inactive and no radioactive fission products can be generated. By maintaining the inactive condition of the reactor and its fuel through these design features, the safety of the SP-100 system during launch will be ensured.

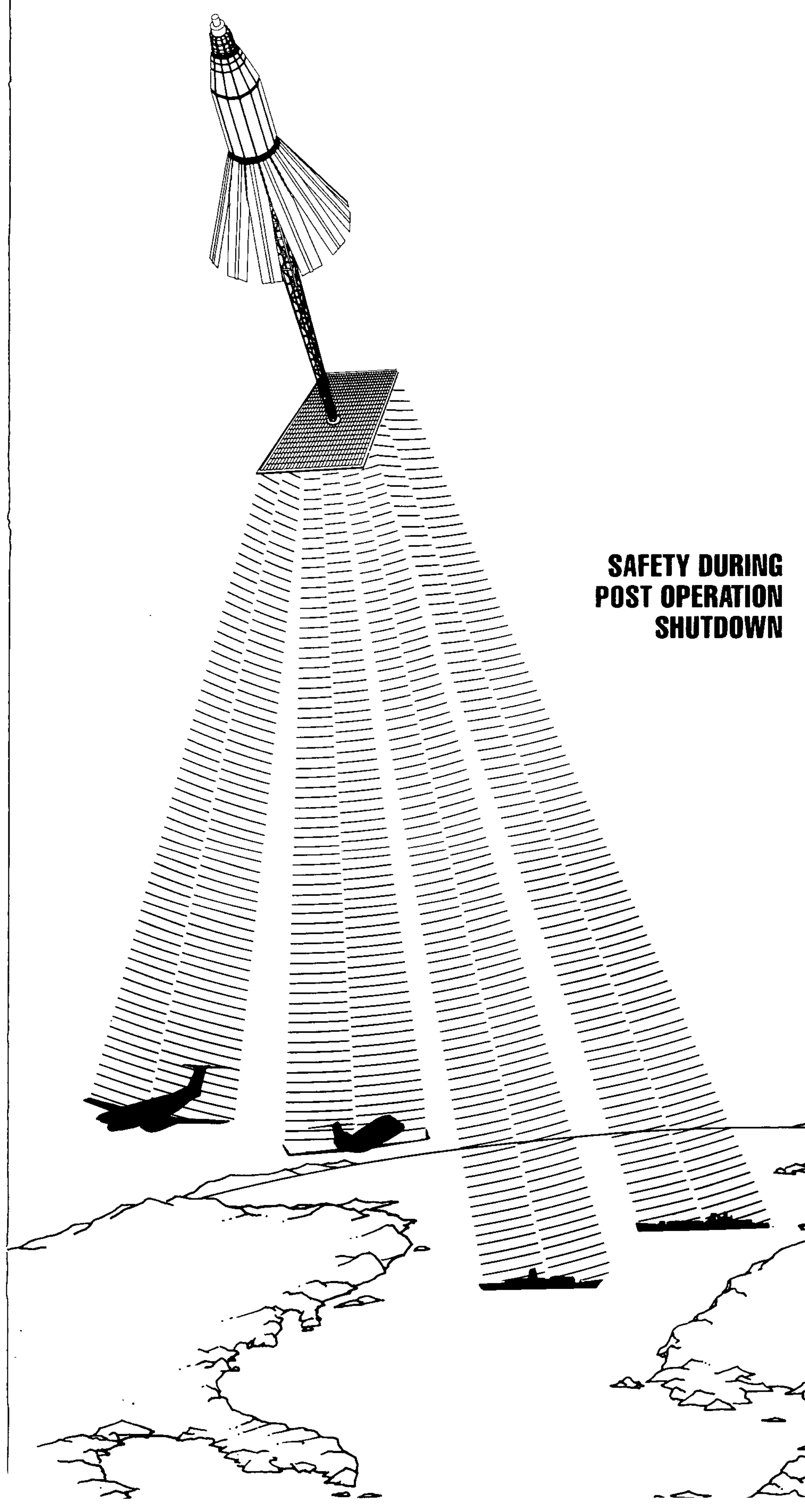
SAFETY DURING OPERATION

The SP-100 will not be operated until it has reached its planned orbit. It will remain in this orbit until the end of its operating life unless it is moved to a higher orbit or used for interplanetary missions. During operation it will not pose a threat to the earth's environment. If it were to be used in conjunction with manned space missions, additional shielding would be provided to protect the astronauts. The SP-100 reactor will be designed to remain intact for accidents that could occur in space. It would retain all radioactive materials that would be produced during operation and would have no impacts on public health and safety or the environment.

The reactor will be designed to operate reliably without continual actions from ground control. Particular emphasis is being placed on assured heat removal and reliable safety and control systems. External damage to the SP-100 system or a component failure during operation in space would simply result in a loss of power through an orderly shutdown of the reactor. No risk would exist from such a reactor shutdown, even though the spacecraft mission might be shortened.

SAFETY DURING POST OPERATION SHUTDOWN

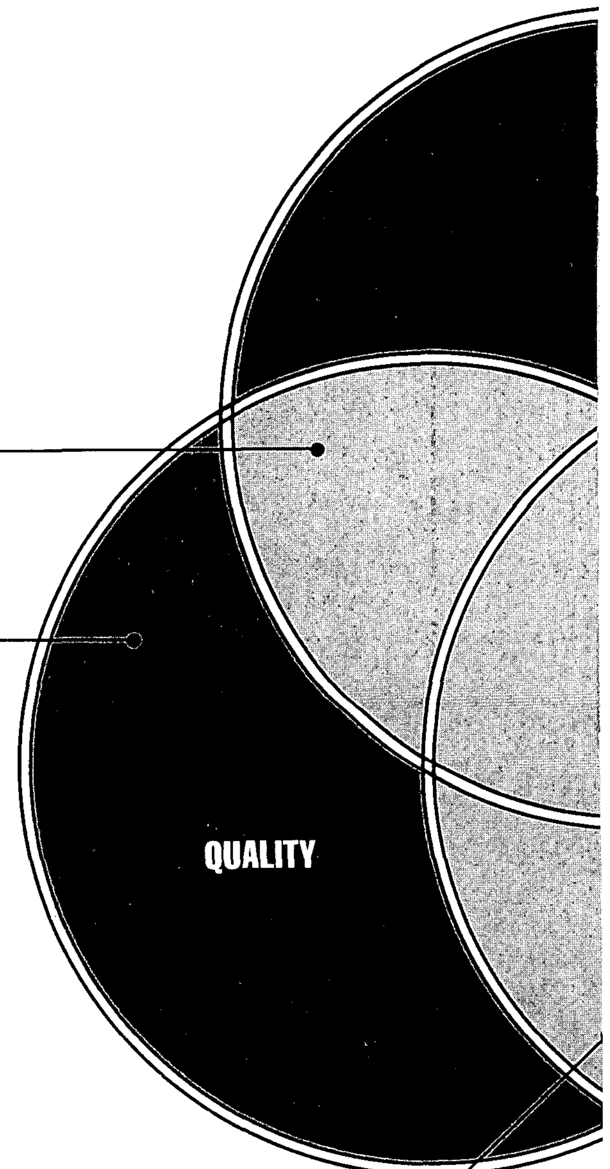
After completion of its mission, an SP-100 reactor will be shut down using redundant systems designed to function reliably without interaction with the spacecraft. Several alternatives are being considered to eliminate risk to the environment after the reactor is shutdown. These include: leaving it in its operating orbit (if it is already in a long duration orbit); raising it to a higher orbit; or sending it out of earth orbit entirely. These actions would be designed to avoid reentry. If reentry were to occur after centuries in space, most of the reactor's radioactivity would have decayed. However, as an added safety precaution, the system will be designed to safely accommodate accidental reentry. It will be designed to remain inoperable and to survive the intense heat and aerodynamic forces of reentry and to bury itself on impact in water, soil or pavement.



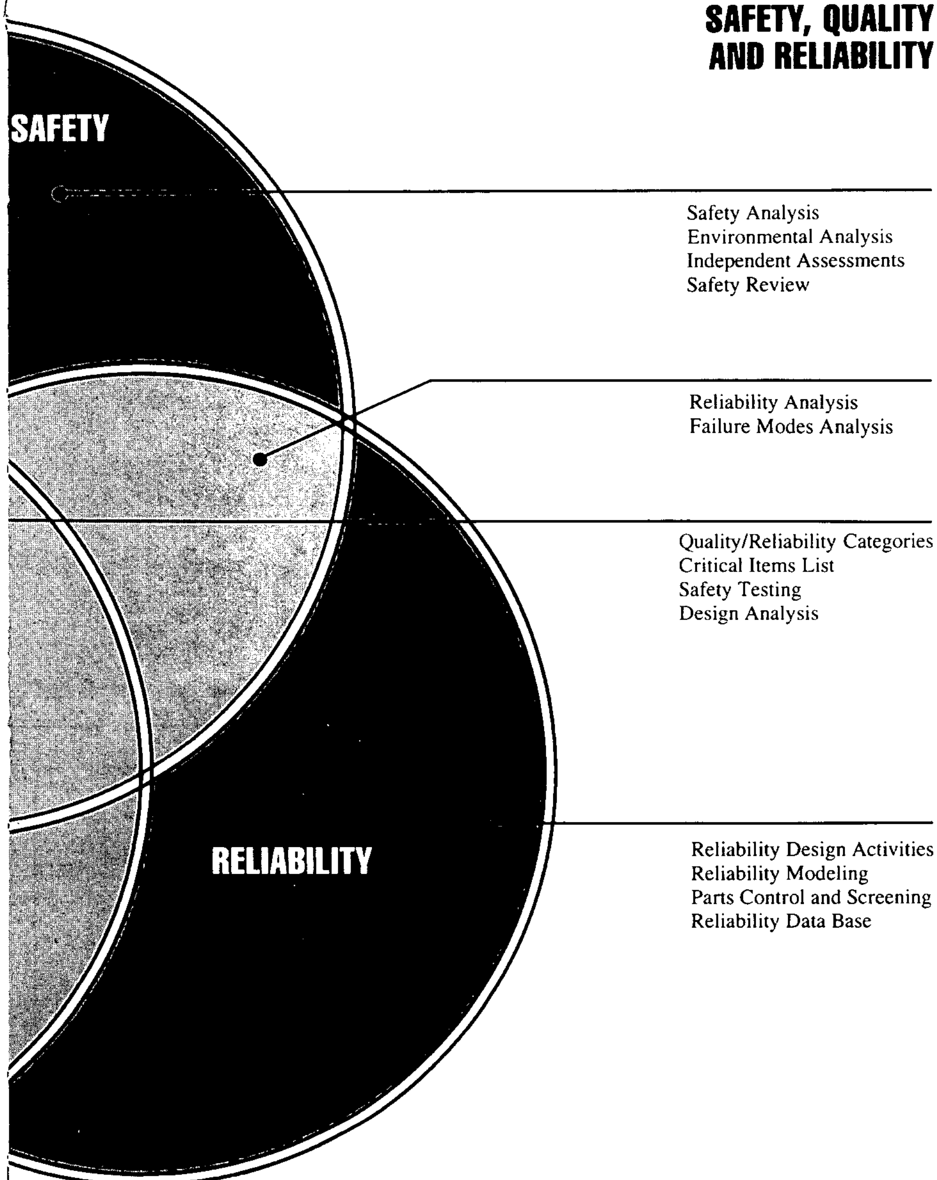
Conceptual illustration of 300-kilowatt SP-100 space reactor power system used for trans-oceanic air and sea navigation assistance.

HOW WILL THE SP-100 PROGRAM ASSURE THAT A FLIGHT/MISSION WILL MEET SAFETY REQUIREMENTS?

Although the current phase of the SP-100 Program is restricted to design, fabrication, analysis and ground testing of the reactor and other components of a prototype SP-100 system, safety and performance analyses will be performed based on an assumed flight mission. After successful completion of the ground testing phase, a flight system development phase is expected to follow during which more detailed mission and system specific analyses and tests will be required prior to space flight approval.

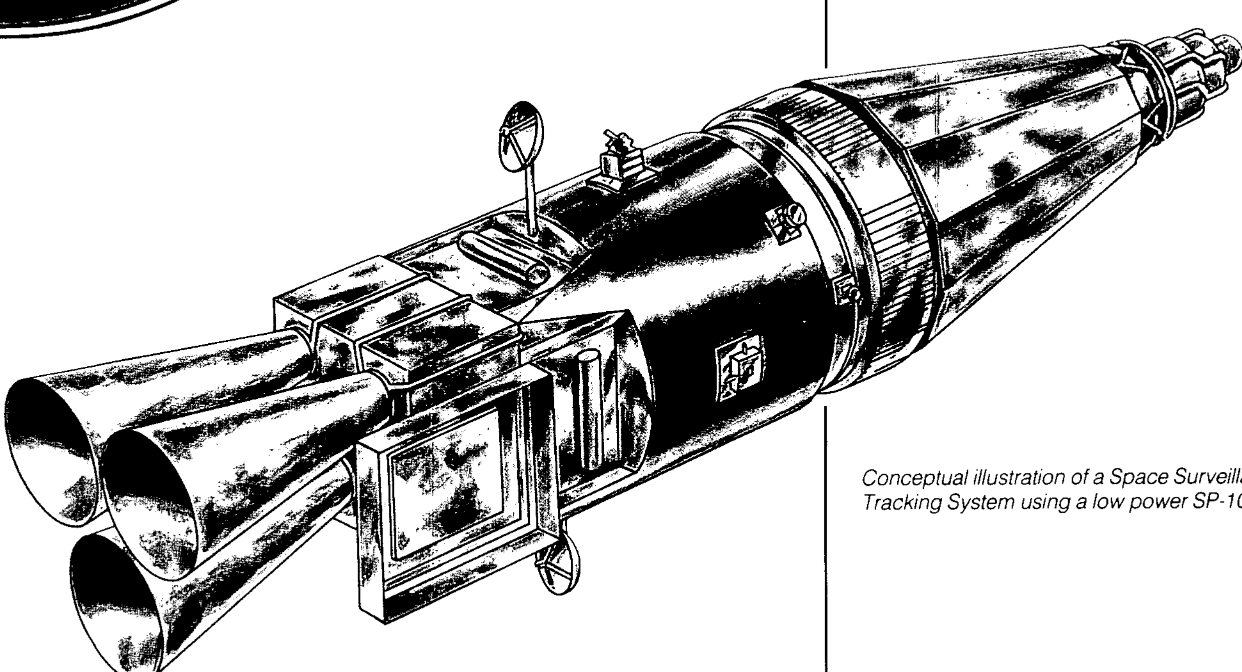


SAFETY, QUALITY AND RELIABILITY



The SP-100 safety, quality and reliability programs are closely related and are being managed in a coordinated manner. This effort is being made to assure that the SP-100 space power system meets its performance objectives, while also ensuring public health and safety as well as environmental protection. A key example of the close interrelationships among safety, quality and reliablity is reflected in the development and use of the "Critical Items List." This list identifies the level of importance of each component and function of the SP-100 system based on safety and reliability considerations. The list is then 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. Finally, the list is used as a management tool to continually track and document that all critical issues are addressed throughout the design, fabrication, testing and integrated assembly of the system.

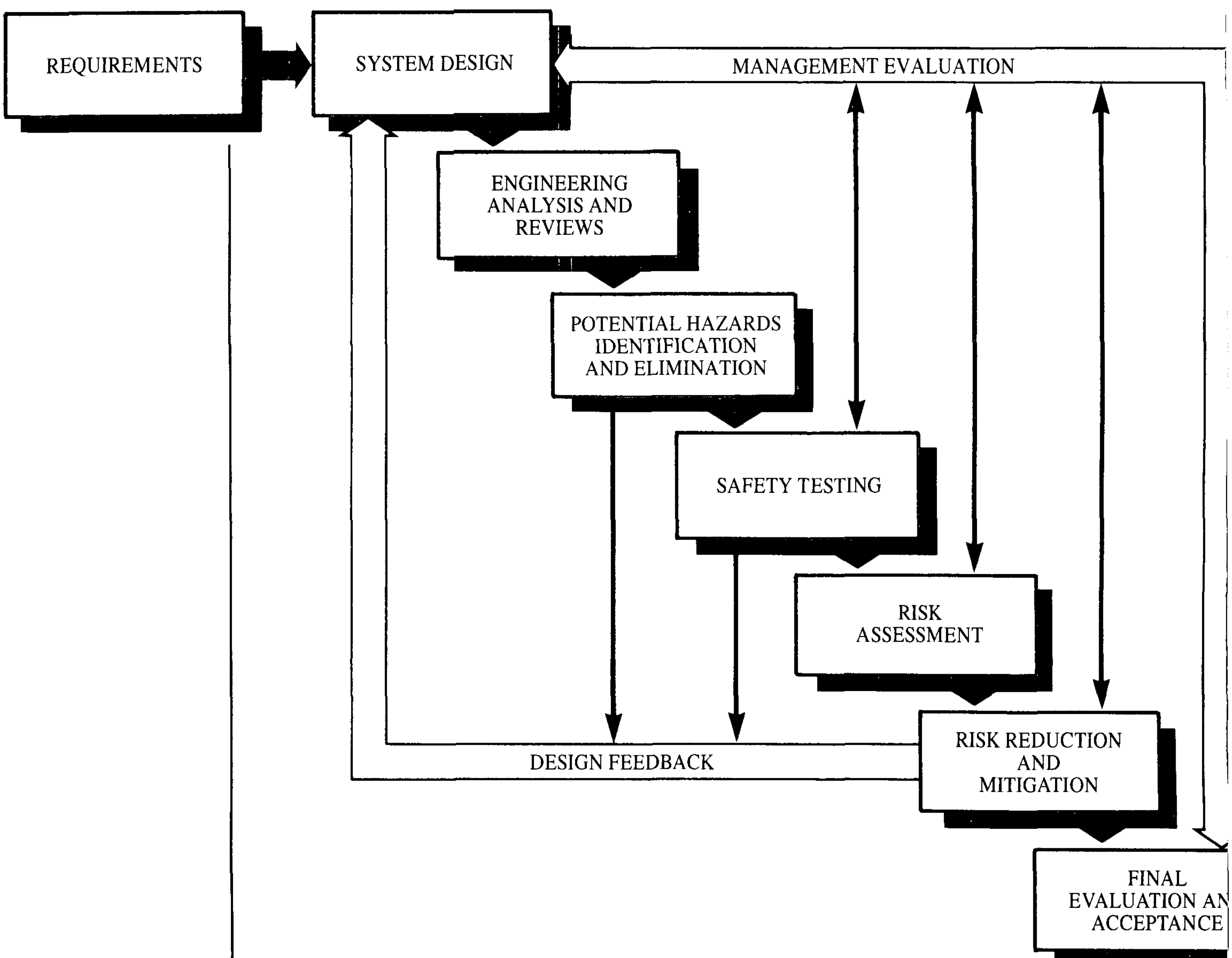
The SP-100 Safety Program Plan formalizes the roles and responsibilities of all program participants to implement, audit, oversee and independently review all safety-related activities. A similar program plan has also been developed to assure system quality and reliability throughout SP-100 development. The Quality and Reliability (Q&R) Program Plan also establishes requirements for quality control, corrective action, documentation and audits of all hardware and software items. The requirements of the Safety Program Plan and the Q&R Program Plan are imposed on all SP-100 Program participants.



Conceptual illustration of a Space Surveillance and Tracking System using a low power SP-100 system.

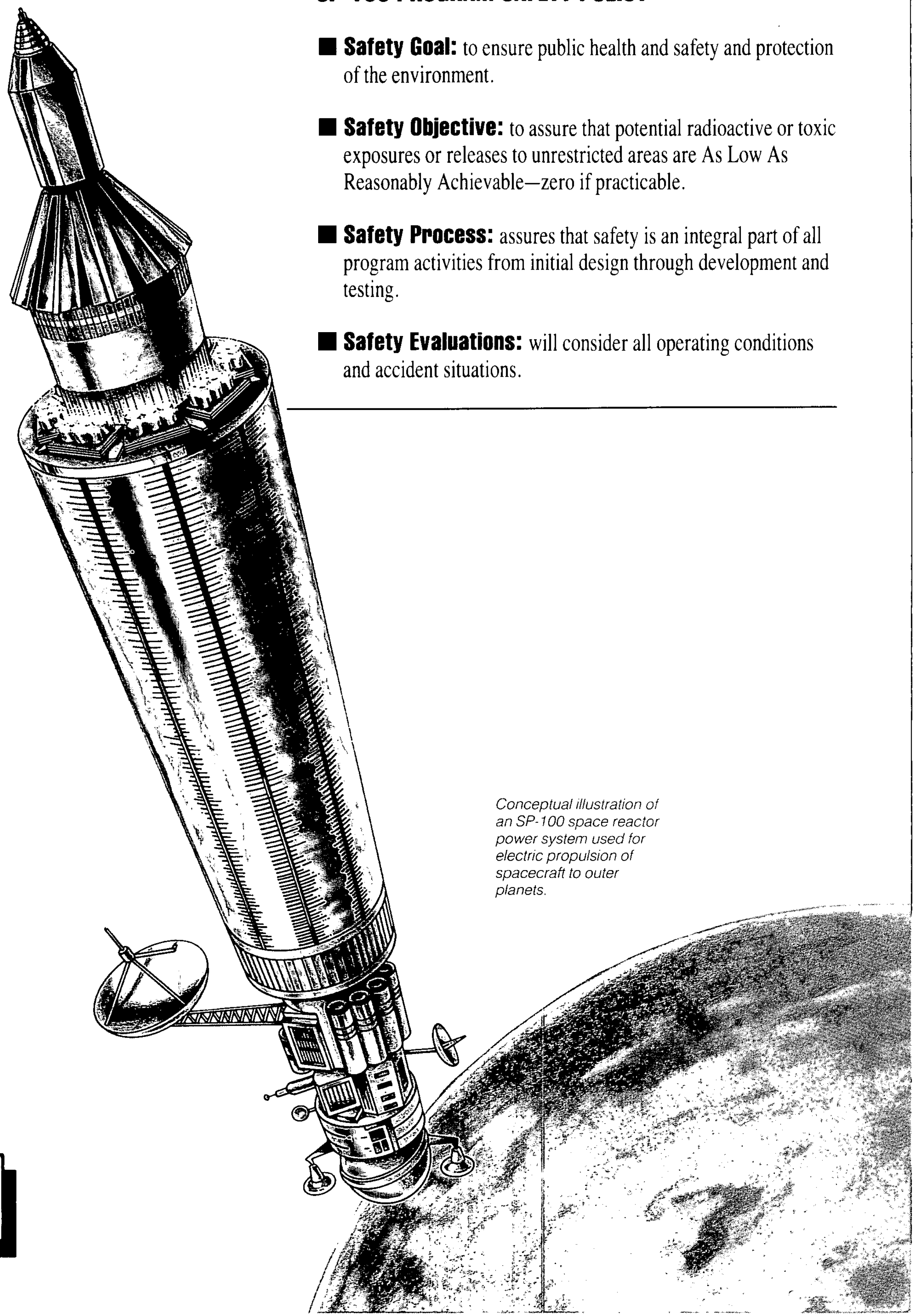
HOW IS SAFETY CONSIDERED IN THE DESIGN PROCESS?

The SP-100 design process is structured to assure the ongoing consideration and independent review of safety throughout all aspects of the design, fabrication, testing, and, ultimately, the use of the reactor power system. At the outset, safety requirements are established. The system must meet these requirements. Engineering analyses and reviews are performed to identify and eliminate or control potential hazards. Safety testing and risk assessments are used for safety design confirmation and quantification of any remaining risks. The results of these analyses and tests provide important design feedback so that modifications can be made to the design to enhance its safety by continuing to reduce any risk. Finally, extensive and independent reviews are conducted to assure that the final design meets all safety requirements.



SP-100 PROGRAM SAFETY POLICY

- **Safety Goal:** to ensure public health and safety and protection of the environment.
- **Safety Objective:** to assure that potential radioactive or toxic exposures or releases to unrestricted areas are As Low As Reasonably Achievable—zero if practicable.
- **Safety Process:** assures that safety is an integral part of all program activities from initial design through development and testing.
- **Safety Evaluations:** will consider all operating conditions and accident situations.



Conceptual illustration of an SP-100 space reactor power system used for electric propulsion of spacecraft to outer planets.

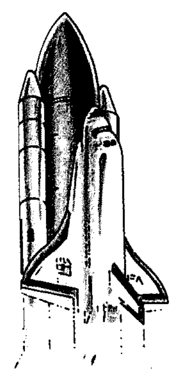
FINAL DESIGN

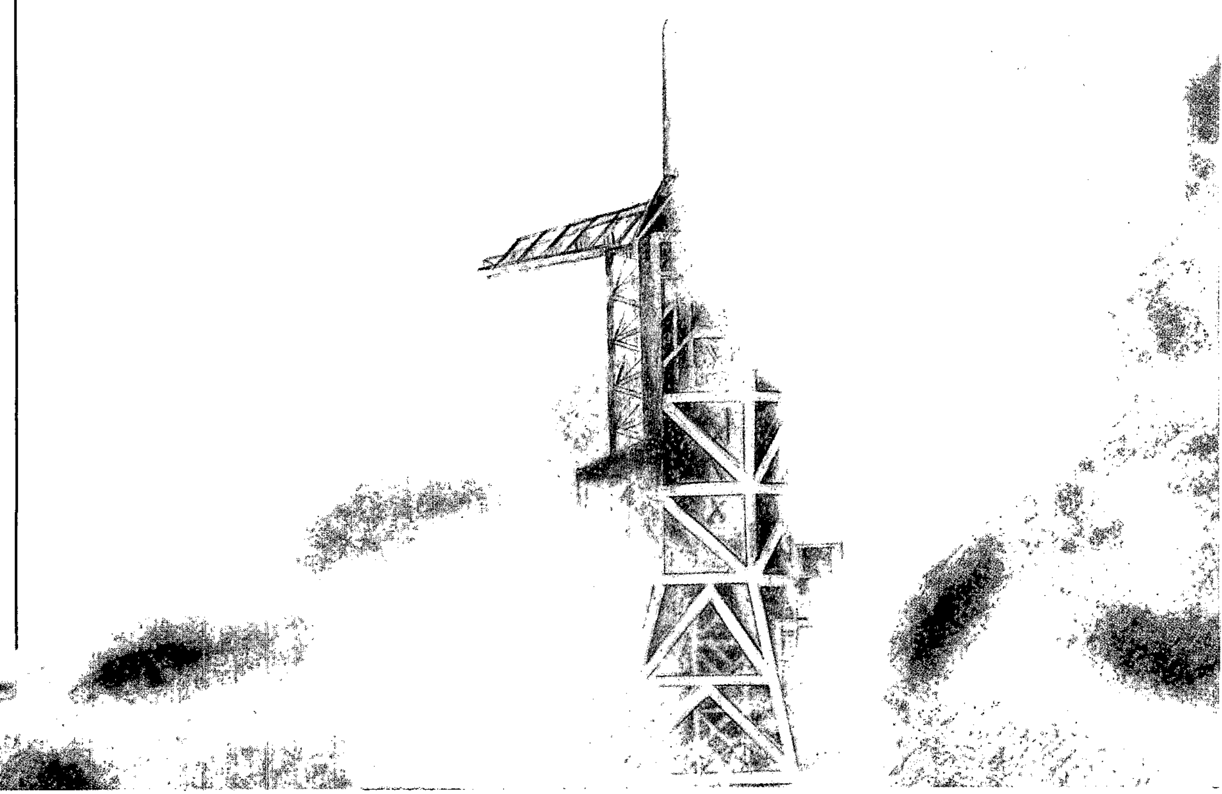
WILL THE REACTOR BE SAFEGUARDED?

Because SP-100 uses highly enriched U-235, safeguards must be provided for both the reactor system and its fuel throughout all phases of the reactor's life. Prior to launch, existing safeguards and security regulations will be followed. Safeguards must also be considered during the design of the system. Special features will be incorporated into the design to enhance the physical protection and security of the system and its special nuclear materials. Such safeguard features will not degrade SP-100 mission performance or its safety. To ensure optimum security and safeguards effectiveness, specific details of such features are protected from disclosure.

HOW WILL THE SP-100 REACTOR BE PUT INTO SPACE?

An SP-100 space power system can be launched by either a reusable space shuttle or an unmanned expendable launch vehicle. Present design evaluations consider both types of launch vehicles, but emphasize a shuttle launch because it is a manned launch and, therefore, demands a more rigorous pre-launch evaluation.

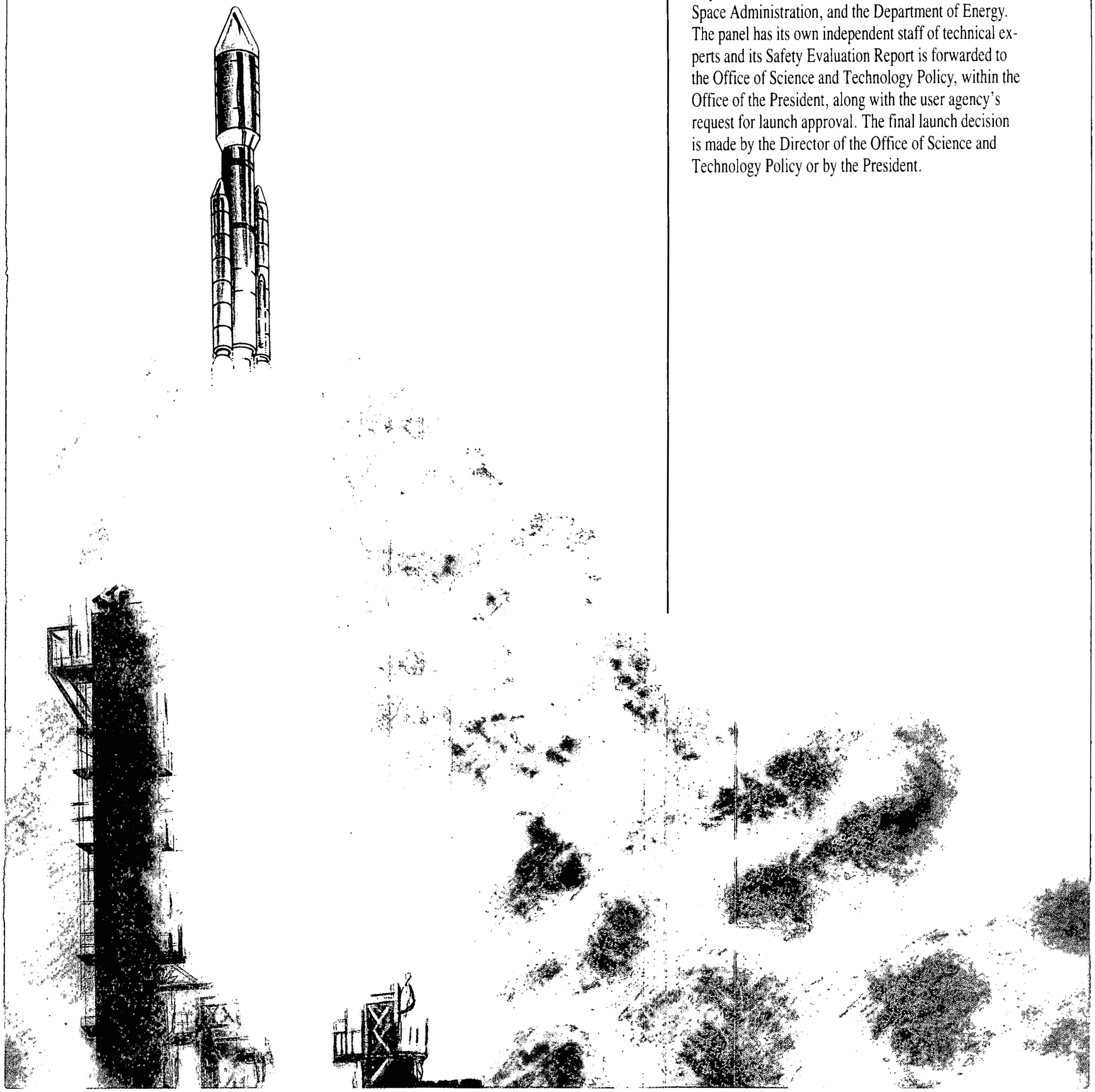




Possible launch vehicles for space missions using SP-100 space reactor power systems.

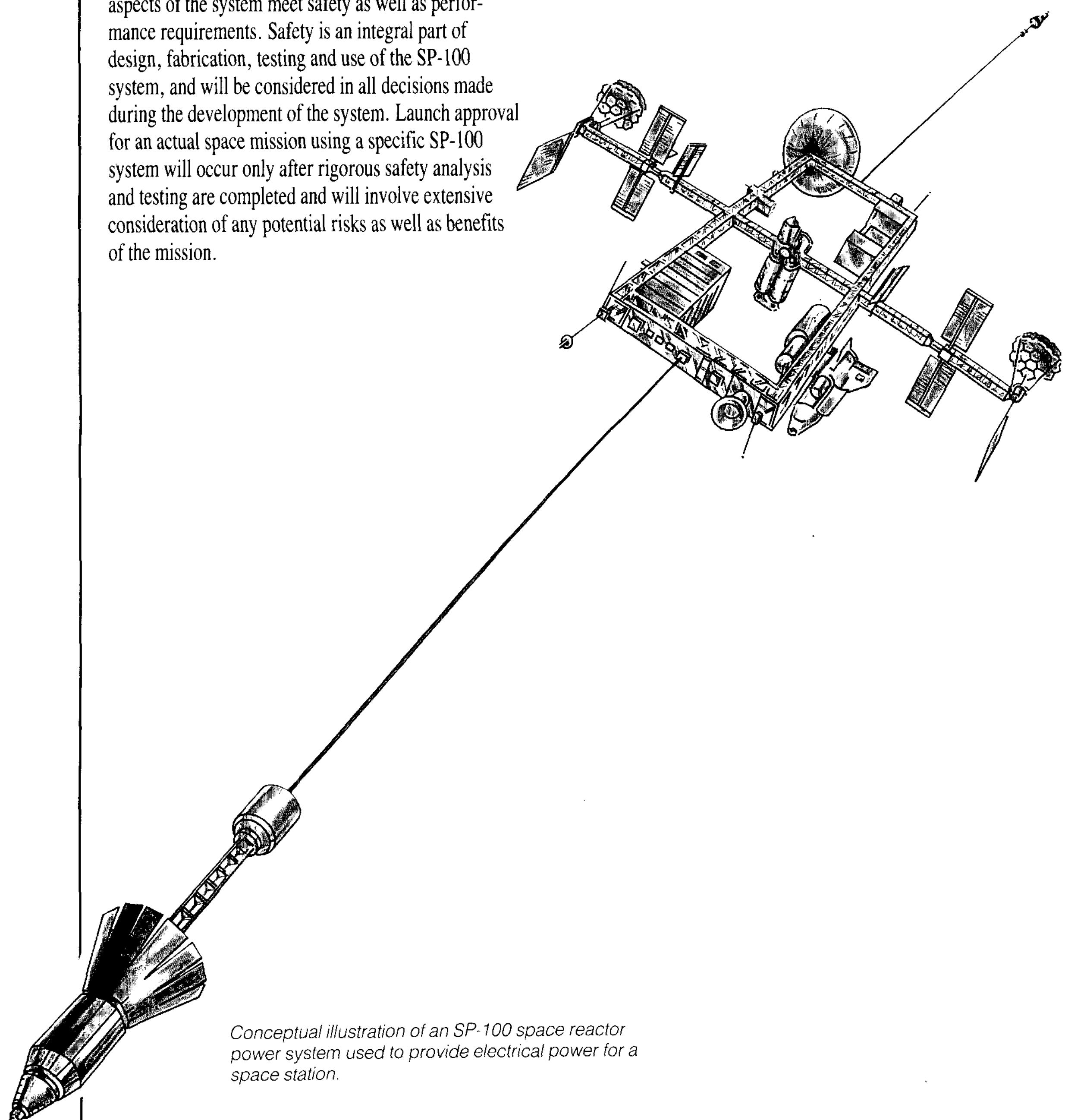
WHO WILL MAKE THE DECISION WHETHER TO LAUNCH THE SP-100 REACTOR?

Every nuclear power system which is considered for use in a space application by the United States undergoes a comprehensive safety review to identify and characterize the risks posed and the benefits to be derived from its use. A formal review process that was first established in the 1960s, is used for this purpose. At the center of this process is the Interagency Nuclear Safety Review Panel. The panel is chaired by three appointees, one each from the Department of Defense, the National Aeronautics and Space Administration, and the Department of Energy. The panel has its own independent staff of technical experts and its Safety Evaluation Report is forwarded to the Office of Science and Technology Policy, within the Office of the President, along with the user agency's request for launch approval. The final launch decision is made by the Director of the Office of Science and Technology Policy or by the President.



SP-100 AND SAFETY: A SUMMARY

A successfully developed SP-100 reactor power system will facilitate exciting new space exploration and exploitation opportunities and will support national defense objectives. The tri-agency sponsors of the SP-100 Program (DOE, DOD and NASA) are committed to ensuring that all aspects of the system meet safety as well as performance requirements. Safety is an integral part of design, fabrication, testing and use of the SP-100 system, and will be considered in all decisions made during the development of the system. Launch approval for an actual space mission using a specific SP-100 system will occur only after rigorous safety analysis and testing are completed and will involve extensive consideration of any potential risks as well as benefits of the mission.



Conceptual illustration of an SP-100 space reactor power system used to provide electrical power for a space station.

For more information write:

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