Isotope-Powered Satellites for Shuttle Launches

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Introduction

DEVELOPING technology and the transition period of the late 1970's from expendable launchers to reusable space shuttles and from single satellite designs to standardized and modularized configurations represents a strong motivation and unique opportunity to actively investigate new applications of nuclear power for satellites. Work reported here deals primarily with the 100-2000-We power range and consists of a many-faceted effort. Spacecraft problems associated with the incorporation of nuclear power, integration into the space shuttle, and effects on the power supply designs are addressed. A point design is included to illustrate a specific application and associated advantages.

Associated with the introduction of nuclear power into the design of satellites are several influences on subsystems and operations. With regard to shuttle interfaces, the primary considerations include thermal control during launch, structural interface, and deployment procedures. Nuclear power supply considerations include effects on overall configurations which are compatible with the space shuttle and with mission objectives of a particular satellite.

The shuttle capacity could be used to carry heavy objects into low Earth orbits, i.e., 29,500 kg (65,000 lb) into a 407-km orbit and inclination of 28.5 deg. This capability might also be used to launch combined payloads in a single flight, which would reduce the individual user launch cost. It is expected that the orbiter will have the ability to visit and/or return payloads to permit on-orbit checkout for final deployment and to retrieve satellites for on-orbit servicing or return. On-orbit checkout of payloads would appear to be highly desirable. This would permit the use of simple and nonredundant systems on future satellites. The ability to revisit and retrieve a satellite could also be very practical. This could permit the reuse of nuclear power supplies on future satellites.

Space nuclear power supplies are not new. The first one was flown in 1961 on Transit. A great deal of research and development has taken place over the past 16 years in perfecting and developing different nuclear power configurations. The latest one is on a Mariner Jupiter Saturn mission. In the shuttle era, many more missions will be established for nuclear power supplies. An Air Force Space Test Program Standard Satellite is one potential mission of interest. Furthermore, this mission has been used as a point design exercise that is described later. Many military communications and navigation satellites are also candidates for nuclear power. Probes for the outer planets use nuclear power and most likely will continue to do so.

An isotope power supply may have one of several configurations and sizes, depending on the power requirements and type of mission. For example, very low power requirements dictate the use of radioisotope thermoelectric generators (RTG's). These are completely solid-state devices that incorporate the physical phenomena of thermal electric energy generation. Power ranges for RTG's run from just a few watts up to about 500 We. The next range of power, running from about 500 We up to about 2 kWe, can be provided by dynamic isotope systems. These devices use isotopes for heat generation, as do the RTG's. However, heat generated is used to run a turbine that provides electrical power through a generator. Typical performance figures for each type of supply are given in Table 1.

Point Design Exercise (STPSS)

In order to demonstrate the impact of the space shuttle system on isotope-powered satellite design, a point design has been considered in detail. The exercise selected is a nuclear-powered version of the U.S. Air Force Space Test Program Standard Satellite (STPSS).[1] This may be a developing program that would fly in the 1980's. It is conceived primarily as a standardized satellite to be used for various experimental and operational demonstration-type payloads. A detailed consideration of the design provides a method to illustrate the effects of the shuttle constraints and requirements, as well as the impact of nuclear power on the satellite itself. The objective was to satisfy performance requirements and launch constraints, without optimizing the configuration because of limited time and effort.

Considerations began by assuming an STPSS preliminary configuration under consideration in October 1975. The basic configuration of the vehicle was maintained as closely as possible. Incorporation of RTG's must have a minimal overall impact on the satellite design. Specific areas affected are power management and thermal control. However, the primary areas of concern appear to be associated with space shuttle integration and safety-related procedures. Since the shuttle orbiter payloads must be thermally independent, a thermal control system (TCS) is required for the RTG's. Thus, a small number of launch support items needs to be developed. There are several clear-cut mission features that could be realized with RTG's. For example, consider a mission requiring a great deal of maneuverability associated with a variety of sensor directions. Since RTG's produce essentially constant power, independent of attitude and altitude, many sensors may be carried on a given mission. This may, in fact, minimize the overall number of missions through increased flexibility. Integration and safety aspects are handled with a unique design innovation. A payload interface unit is used to support the satellite and interconnect with the shuttle. This structure also supports the TCS and associated controls. Therefore, the "package" is loaded into the payload bay as late as possible in a countdown procedure. This unit is designed to fit the volume and location constraints associated with a philosophy of using a minimal volume in the shuttle bay. In this case, this means that the space above the Spacelab tunnel is utilized for the STPSS spacecraft. Figure 1 illustrates the volume and dimensional constraints assumed in this point design. The stowed STPSS configuration is included in this two-view drawing, but the deployed configuration is shown in Fig. 2. The baseline design consists of payload, core, and orientation/transfer modules. Nuclear power is provided by three RTG's, each supplying between 150 and 500 We, depending on the mission. Each unit has two radiators

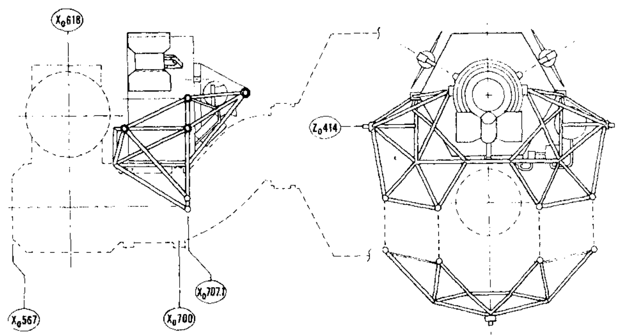

Fig. 1 Shuttle bay constraints with stowed STPSS.

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Table 1 Performance figures of isotope power systems

Type	Overall efficiency, %	Power range, We	Specific power, We/kg
RTG's			
Viking	6.3	43	2.6
Mariner Jupiter Saturn	6.6	159	6.5
Selenide Isotope Generator (SIG)	10-13	25-500 (1981-1985)	6.6-8.8
BIPS (Brayton Isotope Power System)	27 at 120 V dc	500-2000 (1300 nominal)	6.38
KIPS (Kilowatt Isotope Power System)	18.2 at 28 V dc 19.6 at 100 V ac	500-2000 (1300 nominal)	6.07

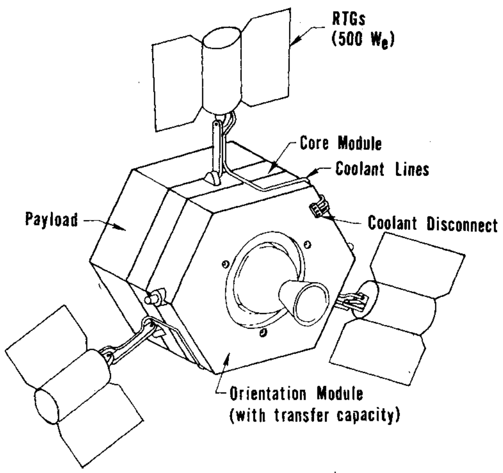

Fig. 2 STPSS with RTG's deployed.

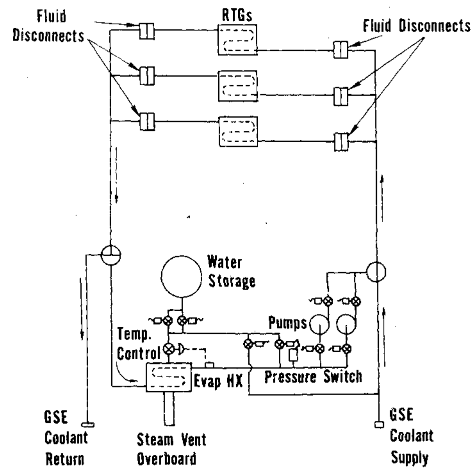

Fig. 3 Schematic of thermal control system.

capable of radiating heat from both sides. The selection of three units permits the balance of mass while still providing for growth and permitting a compact launch configuration.

The deployment sequence is somewhat a function of the mission and maneuvers to be completed by the spacecraft after leaving the shuttle. For example, if it is to be a spinning payload with the perigee kick motor to place it into a higher orbit, then the deployment procedure involves a spin-up maneuver before release. A typical sequence of deployment steps would include extension of the RTG's, rotation of the spacecraft upright, separation of the cooling lines, spin-up, final alignment, and ejection. The interface structure remains in the shuttle bay and is returned and available for future missions.

One of the major considerations was the provision required for cooling of the RTG's during launch. Since waste heat cannot be rejected within the payload bay, TCS carries it away and dumps it overboard via a water evaporation system. Three ways were considered to provide this cooling. The requirements were assumed to consist of a capacity for up to 15 hr of thermal isolation. Normally the payload bay doors would be open within 15 min of launch. However, contingency situations could require that the payload be returned intact with the payload bay doors closed. Such a mission could take up to 15 hr. The three methods reviewed were radiative cooling, direct fluid cooling, and in-flight fueling of the power supply. Radiative cooling permits each RTG to operate as in orbit while being encapsulated by a heat collector. Direct fluid cooling employs coils integrated into the RTG heat generator. Thus, the radiators do not receive heat until payload deployment. Finally, the technique of inserting the heat elements in orbit was considered. This would permit cooled capsules to carry the isotopes until the payload deployment sequence starts. Evaluations of the three methods indicate that the method of radiative cooling is impractical because of the large cooling jacket required at a very low temperature for a long period of time. Furthermore, the method of in-orbit fueling is not practical because of the difficulty in inserting the heat source into the RTG. In addition to the thermal shock problem, there is also a structural integrity problem. Therefore, the only practical method appears to be direct fluid cooling. This has been flight-proven on Viking/SNAP-19. The RTG must incorporate a heat exchanger, but this has a minimal impact on the design. Figure 3 illustrates a schematic diagram of the selected thermal control system. Basic elements are shown to include two fluids, with steam being vented through a pipe provided in the space shuttle itself. Redundancy is provided in the pumps and valves.

Conclusions

Several conclusions can be drawn from general considerations and specific aspects of the point design offered here. Launch of a nuclear-powered payload from the shuttle will require a limited number of hardware items peculiar to this type of device. Advantages of using isotopes depends on the mission, and no general statement concerning their areas of application can be made. In the case of a specific point design, the STPSS, results were quite enlightening and favorable for application of RTG's to a shuttle-launched payload of this type. No technical feasibility problems were encountered. The interface unit concepts provides "simple" shuttle loading and satellite deployment. Broad mission flexibility and diversity is provided through the use of RTG's. This point design has illustrated the influence of the shuttle and isotope power supplies on spacecraft designs of the future. In general, advantages include simplified operational requirements on attitude control, constant power available, and long mission life.

Acknowledgment

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References

[1] Kaplan, M.H., "A Nuclear Powered Version of the USAF Space Test Program Standard Satellite," Aerospace Systems Lab., Princeton Univ., Princeton, N.J., May 1976.