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An Overview of the Radioisotope Thermoelectric Generator Transportation System Program

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Westinghouse
Hanford Company Richland, Washington

Management and Operations Contractor for the
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AN OVERVIEW OF THE RADIOISOTOPE THERMOELECTRIC GENERATOR TRANSPORTATION SYSTEM PROGRAM

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Abstract

Radioisotope Thermoelectric Generators (RTG) convert the heat generated by radioactive decay to electricity using thermocouples. RTGs have a long operating life, are reasonably lightweight, and require little or no maintenance once assembled and tested. These factors make RTGs particularly attractive for use in spacecraft. However, because RTGs contain significant quantities of radioactive materials, normally plutonium-238 and its decay products, they must be transported in packages built in accordance with Title 10, Code of Federal Regulations, Part 71. The U.S. Department of Energy assigned the Radioisotope Thermoelectric Generator Transportation System (RTGTS) Program to Westinghouse Hanford Company in 1988 to develop a system meeting the regulatory requirements. The program objective was to develop a transportation system that would fully comply with 10 CFR 71 while protecting RTGs from adverse environmental conditions during normal conditions of transport (e.g., shock and heat). The RTGTS is scheduled for completion in December 1996 and will be available to support the National Aeronautics and Space Administration's Cassini mission to Saturn in October 1997. This paper provides an overview of the RTGTS and discusses the hardware being produced. Additionally, various program management innovations mandated by recent major changes in the U.S. Department of Energy structure and resources will be outlined.

INTRODUCTION

Radioisotope Thermoelectric Generators (RTG) are typically fueled with plutonium-238 oxide, which generates approximately 0.40 W/g of thermal energy. Thermocouples are used to convert this thermal energy into electricity. Although the efficiency of RTGs is low, generally less than 7%, they are very reliable, have long operating lifetimes, and are reasonably lightweight. These characteristics make RTGs suitable for use in spacecraft when other power sources are not feasible. The RTGs that have been used on several unmanned space missions have met or exceeded all expectations. RTGs are planned for the National Aeronautics and Space Administration (NASA) Cassini mission to Saturn, scheduled for launch in October 1997, and the Pluto Fast Flyby scheduled for launch in 1999.

Because RTGs contain several kilograms of plutonium-238 and other radionuclides, they must be packaged in special containers meeting the requirements of 10 CFR 71 during transport over public highways. If they are unable to meet the 10 CFR 71 requirements, they must be specifically exempted. Although certain exemptions to 10 CFR 71 may be granted by the U.S. Department of Transportation (DOT), the U.S. Department of Energy (DOE) has determined that future RTG shipments will be in compliance.

In order to obtain a transportation system that would meet the regulatory requirements as well as RTG operational requirements, the DOE assigned the Radioisotope Thermoelectric Generator Transportation System (RTGTS) Program to Westinghouse Hanford Company (WHC) in 1988. At that time, the RTGTS Program was part of the Hanford Space Power Systems mission and RTGs were to be fueled at the Hanford Site in the Radioisotope Power Systems Facility (RPSF). However, in 1989 the production of plutonium was halted and in 1993, the RPSF was canceled. The ultimate RTGS Program custodian was changed to EG&G Mound Technologies, Inc., in Miamisburg, Ohio; however, responsibility for the design, analysis, fabrication, and testing remained with WHC.

Currently, the RTGTS Program is nearing completion with a delivery date of December 15, 1996. The Program deliverables consist of two complete RTGTSs. Each system will consist of one RTG package, one custom built semi-trailer, and one set of special tools and support equipment. An extra RTG package with necessary special tools and support equipment will be provided for training or for use as a system spare.

PROGRAM DESCRIPTION

System 100, Systems Integration

Systems Integration, System 100, is the focal point of the entire RTGS Program. System 100 comprises the pro ect management activities, overall systems testing, and integration control for all of the other systems. System 100 is also used to refer to each completed RTGTS.

System 120, RTG Packaging

An assembled RTG Package, System 120, with a General Purpose Heat Source (GPHS) RTG payload is shown in Figure 1. The GPHS is the RTG type to be used for the NASA Cassini and Pluto Fast Flyby missions. System 120 meets all DOT requirements for the transport of RTGs, including 10 CFR 71, and is designated a Type B(U) radioactive materials package. Because the GPHS RTG package is designed to transport up to 5.4×10^{15} Bq (147,000 Ci) of plutonium, the package has an inner containment vessel (ICV) and an outer containment vessel (OCV), both made of stainless steel. The ICV and OCV are sealed with O-ring face seals in a bolted flange on the bottom of each vessel. These seals have a leak rate of less than the allowed 10^{-7} standard cm^3/s of air. The package is equipped with a high-density, foam-filled impact limiter that protects the package flanges and seals. A loaded System 120 weighs approximately 4,355 kg (9,600 lb). This design has been shown to meet, through analysis and/or testing, the regulatory requirements of both the normal conditions of transport and hypothetical accident conditions in 10 CFR 71. The package design and conformance to the regulatory standards is discussed in the RTG Package Safety Analysis Report for Packaging (WHC 1995). The DOE Office of Facility Safety Analysis will approve the Safety Analysis Report for Packaging and issue the Certificate of Compliance (CoC), which allows the package to be used.

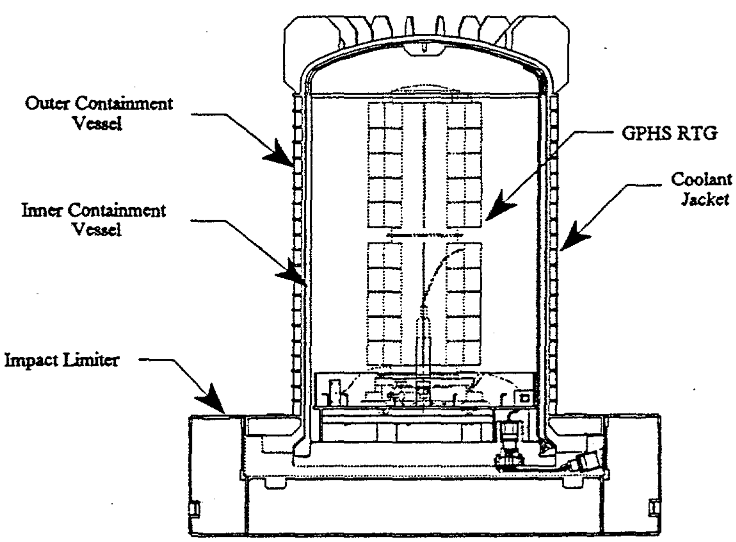

FIGURE 1. RTG Packaging, System 120, with GPHS RTG Payload (Simplified View)

The GPHS continuously generates approximately 4,500 W (thermal) and this energy must be dissipated to prevent damage to RTG components. To assist in heat removal, the package void spaces are filled with helium at a pressure of 138 kPa (20 lb/in^2). To remove the heat from the container, the OCV has a series of liquid coolant channels welded to its outer surface. These channels are filled with a 70 percent water and 30 percent propylene glycol mixture which is cooled and circulated by an external chiller system.

System 140, Trailer

System 140, shown in Figure 2, consists of a Custom Semi-trailer, Subsystem 141; a Power Supply System, Subsystem 142; an Instrumentation Data Acquisition System (IDAS), Subsystem 143; a Package Temperature Control System, Subsystem 144; and a Package Mount System, Subsystem 145. The trailer also carries special tools and equipment required to assemble and disassemble the package. Typically, the trailer will carry only one RTG Package, but has provisions for two.

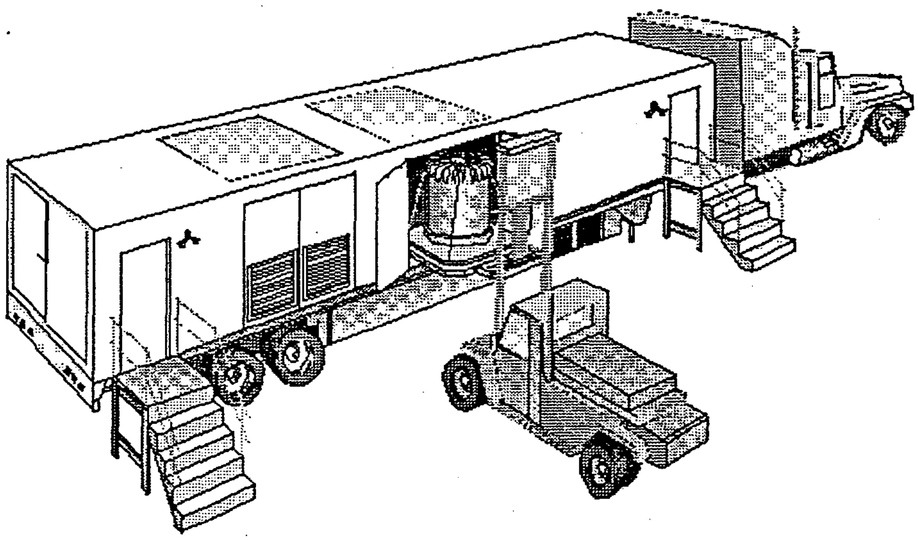

FIGURE 2. Trailer, System 140

The Custom Semi-trailer, Subsystem 141, consists of a specially built light weight trailer assembly. The trailer has a manually operated leveling system, uses air ride suspension to limit shock to the payload, and is mounted on spread axles to improve the weight distribution. The trailer is mostly of aluminum construction and has provisions for two RTG Packages, which may be loaded from the curb side or through roof hatches.

The Power Supply System, Subsystem 142, consists of two 40-kW diesel generators, a power distribution system, and two separate fuel tanks. The generators supply 208V, 3-phase and 110V, single-phase power to the power distribution system. The power distribution system can also be connected to an external power source instead of the on-board generators if desired.

The IDAS, Subsystem 143, is used to monitor and record RTG temperatures, coolant conditions, electrical supply parameters, and accelerations recorded using a triaxial accelerometer mounted to the base of the package mount system. The IDAS is connected to a remote alarm system in the tractor cab and will annunciate an off-normal condition with an alarm and panel light. The IDAS has a battery backup for maintaining data storage in case of a power supply interruption.

The Package Temperature Control System, Subsystem 144, includes two custom built chillers (7.5-kW capacity each), four pumps, and a standard high-volume air conditioning unit. This system cools the water/propylene glycol mixture to 4°C (40°F) and pumps it through the RTG package at a flow rate of 18.9 L/min (5 gal/min) at a pressure of 344.7 kPa (50 lb/in^2). Only one chiller and generator will operate at a time. If the generator fails, the other generator will automatically start. However, if a chiller fails, human intervention is required to determine the cause of the failure and start the backup.

In order to limit shock to the RTGs to less than 15 g's, the trailer is equipped with air-ride suspension and the RTG Packages are mounted on a Package Mount System, Subsystem 145 (Figure 3). The mount is essentially two aluminum or steel pallets separated by a spring suspension system. It has been shown through testing that the Package Mount System will limit shock to a RTG to less than 15-G for frequencies below 100 hZ in a 45.7 cm (18 in) edge or bottom drop.

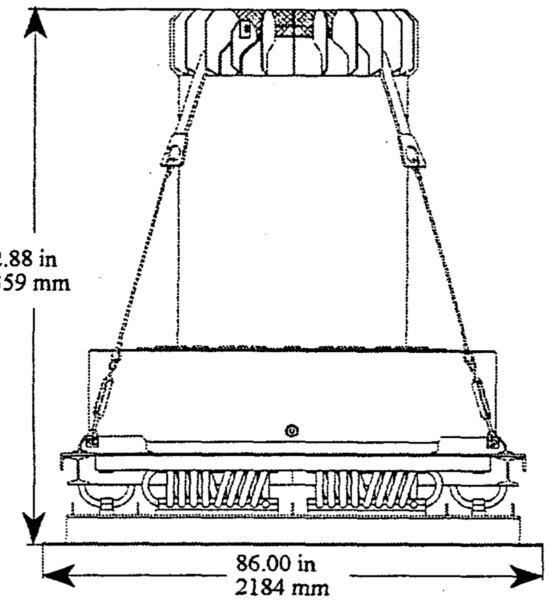

FIGURE 3. Package Mount System

System 160, Operations and Ancillary Equipment

The Operations and Ancillary Equipment, System 160, consists of the system operations and maintenance manuals and special tools and support equipment necessary for the assembly and disassembly of the RTG Package. Special tools include torque wrenches, special adapters, sockets, guide pins, spacer blocks, and set-down pads that support the assembly and disassembly of System 120. The support equipment consists of a cart-mounted Gas Management System (GMS) and a low-clearance sling. The GMS is used to evacuate and fill the RTG Package System 120 with helium; it does not support leak testing of the package seals.

System 180, Facility Transporter System

The Facility Transporter System, System 180, was designed to move System 120 outside the Trailer, System 140. However, the current facilities that will handle System 120 do not require the actual transporter chassis, Subsystem 181. The design is complete and the system may be built if needed in the future. In addition, Subsystem 181, System 180 also includes a portable IDAS, Subsystem 182, to monitor the RTG temperatures and a g-limiter, Subsystem 183. Although Subsystem 181 will not be built at the present time, three portable IDAS units, one per RTG Package, will be completed and supplied along with the other system hardware and equipment. However, unlike the trailer IDAS, the portable units will only monitor and record RTG temperature, not coolant parameters or accelerations. The g-limiter, Subsystem 183, was originally designed to be used instead of the transportation impact limiter when using the transporter. Like Subsystem 145, Subsystem 183 provides 45.7 cm (18 in) drop protection. Subsystem 183 is currently being considered for use as a set-down pad to protect a packaged RTG during crane operations when Subsystem 145 and the transportation impact limiter is not used.

PROGRAM MANAGEMENT

In addition to the technical challenges, changes within the DOE in the post-Cold War era have significantly impacted the program. For example, the cancellation of the Hanford Site RPSF changed the program workscope and direction in 1993. Following the Hanford Site mission change, workforce and budget reductions in Fiscal Year s 1994 and 1995 have impacted the availability of resources. By early 1995, it was clear that the December 1996 delivery date was in serious eopardy and program activities would have to be accelerated. To meet these challenges, a concerted effort was made to remove as much of the administrative and procedural burden from the RTGTS Program as possible. In removing these requirements, some risk was added to the Program.

Initial changes consisted of relieving the requirement that all design work be placed in the WHC control system prior to fabrication. The main benefit of this change was seen in fabrication of the trailer systems. As it had been decided that commercial equipment was to be used where possible within the trailer, reliance on the manufacturer's procedures and experience in the design controlled costs and conserved schedule. The subcontractor design drawings will be put in the WHC system after the fabrication and testing is completed and all changes are posted.

Next, the design review and fabrication process was changed. Extensive design reviews involving not only WHC but also the RTG User Community, which had to review everything before fabrication of most components and systems could begin. . The schedule could not continue to support such extensive reviews. Therefore, the process was changed to allow design and fabrication to proceed concurrently on many systems and subsystems using the RTGTS specification and functional design requirements as a guide. These documents had been reviewed and approved by the RTG User Community and provided the baseline program guidance. Additionally, a system allowing design changes to be made as required was instituted. This allowed fabrication to continue quickly with the formal design changes to be posted after fabrication was complete. In some cases, components were fabricated in parallel with a minimum of design and as-built drawings being produced at the completion of the fabrication. To ensure that multiple units would be alike, the as-built design drawings were completed after fabrication of the first unit. These changes carried a small risk that systems might not interface or requirements could be overlooked. In order to prevent such errors, intense management and coordination was required, especially as fabrication was carried out in several locations within WHC and among several subcontractors. When problems were encountered, the user-approved specifications and requirements were referred to. If the guidance was incomplete, problems were then referred to the RTG User Community for resolution. To limit decision turnaround time, the preferred course of action was recommended and a time limit for comment was instituted. If no ob ections were voiced by the deadline, the preferred course of action was adopted.

In con unction with the changes to the design and fabrication processes, unnecessary quality assurance (QA) standards were removed. The RTGTS Program has been encouraged to make the maximum use of commercial equipment to save cost, but some QA standards that were originally imposed were not consistent with commercial practices. Although some RTGTS systems, such as the RTG Packaging, require strict adherence to various codes and standards, other systems do not. The relaxation of the QA requirements was especially beneficial in the procurement of the trailer systems. If the QA requirements had not been relaxed, the trailers would have taken 2 to 6 months longer to complete.

The acceptance testing philosophy for the RTGTS was also changed. The original testing concept was to deliver all the RTGTS hardware to WHC for testing prior to integration into System 100. Following the testing of each individual component, the entire System 100 was to be tested. However, much of the component testing would have been duplicated in the Final System Acceptance Test (FSAT) of System 100. Therefore, verification testing demonstrating that an individual component met the requirements was performed only when necessary. To ensure that each component could be successfully integrated into the overall system, a Functional Assessment (FA) was planned. The FA will not be documented as a formal test, instead, the FA will evaluate each systems ability to perform in System 100 and serve as preparation for the FSAT. As a result of these changes, the number of RTGTS tests was reduced by 50% (from 16 to 8).

CONCLUSIONS

The RTGTS is one of the most unique radioactive materials packages ever conceived. It is the only Type B(U) package that meets the requirements of 10 CFR 71 and provides active cooling and shock mitigation for the payload. In the process of completing the RTGTS, challenges were met through the use of innovative approaches not normally implemented in programs of this type. It must be noted that the success of this program thus far would not have been possible without the close coordination and cooperation of many diverse organizations. Among these are various DOE management elements and operations offices, the RTG User Community, WHC subcontractors, WHC support organizations, and the WHC team assigned to the RTGTS Program. If such programs are to be successful in the future, especially considering the post-Cold War environment within DOE, the lessons learned in the RTGTS Program should be applied.

Acknowledgements

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