End of an Era and Closing the Circle – Disposal of Strontium-90 Radioisotope Thermoelectric Generators – 9415

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ABSTRACT

For more than 50 years, radioisotope thermoelectric generators promised reliable low-wattage electrical power supplies for specialty and remote applications. While miniature reactor-based power systems never came to fruition, isotope based systems have been used in a number of applications. Plutonium-238 continues to be produced and used for remote space exploration missions. Stronium-90 was applied to terrestrial uses. However, owing to newer technologies, and increased security concerns, strontium-90 RTGs have nearly been completely retired from use. Despite their reliable service, the U.S. Department of Energy has now recovered and disposed of nearly all domestically produced strontium-90 RTGs. This unique and creative use of nuclear technology is fading into obscurity and soon will be forever a thing of the past.

HISTORY

The U.S. Radioisotopic power program made an auspicious public debut. On January 16, 1959, a device that transformed heat from radioactivity into electricity was demonstrated publicly for the first time on the desk of the President Eisenhower. The small, lightweight, grapefruit- sized device (Figure 1) on the President's desk was a radioisotope-fueled thermoelectric generator (RTG). It weighed 4 pounds and was capable of delivering 11,600 watt-hours of electricity for about 280 days.

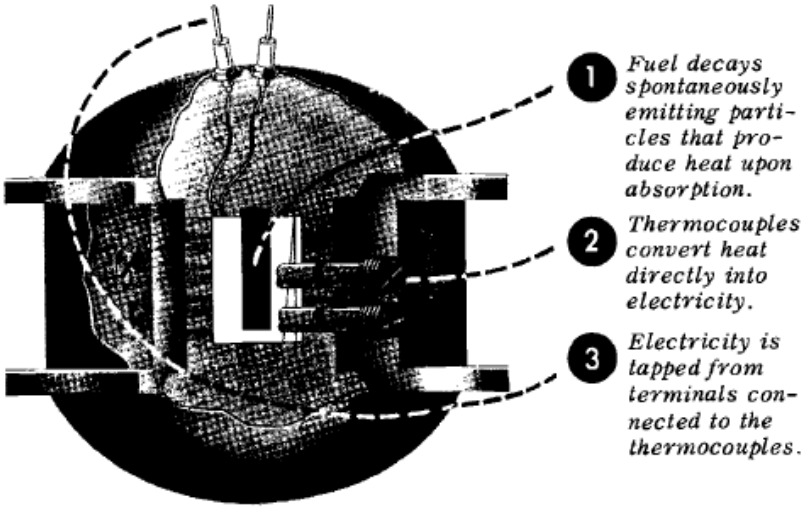

Figure 1: How a radioisotope thermoelectric generator works

The U.S. Atomic Energy Commission (AEC) began developing a series of these compact devices in 1956 to supply power for space, terrestrial and marine applications. These devices were all described by the general title: Systems for Nuclear Auxiliary Power (SNAP).

Two entirely different types of SNAP systems were developed. Both converted heat into electricity. In one system, the heat was obtained from small nuclear reactors; in the other, the subject of this paper, from the decay of certain radioisotopes. These are known as radioisotope thermoelectric generators (RTGs).

There are many remote settings where electrical power is needed. These include overt applications, such as weather monitoring stations and navigational buoys. The potential uses also include overt military and national security missions. In isolated unmanned locations involving high operational costs, the need for cheap, reliable long-term power sources required development and use of RTGs with no moving-parts and freedom of maintenance as power sources.

Selection of Strontium-90 as Fuel

The first selection criterion is safety. The fuel and shielding design should minimize radiation as low as reasonable achievable. The second criterion is reliability. In remote locations, long-lived and maintenance-free generators were essential. Two other criteria, weight and cost, vary in priority based upon the applications in which the RTGs are selected for use. Space missions required minimal payload weight. Therefore, more costly plutonium-238 and decreased shielding weight were selected for this application. Meanwhile, terrestrial or marine applications could accommodate additional shielding weight to reduce costs. Therefore, strontium-90 was selected even though heavy shielding is required for the beta-emitting isotope. Generator designers made every effort to produce a safe, reliable, inexpensive and light-weight RTG. The fuel must meet the four performance criteria list above and be contained in a rupture-proof container that produces a large amount of heat per unit volume. The fuel should be inexpensive and easily shielded.

Table I: Comparison of Potential RTG Fuels

Radioisotope Fuel	Half-life (Years)	Initial Power Density (watts/gram)	Melting Point (^{0}C)	Major Radiations
Strontium-90	28	0.93	770	Beta, a few gammas
Cesium-137	30	0.26	28	Beta, a few gammas
Cerium-144	0.78	25	800	Beta, many gammas
Promethium-147	2.5	0.36	1300	Beta, a few gammas

A significant portion of the of the heat associated with spent nuclear reactor fuel results from the decay of Sr-90 and its decay daughter Y-90. Because of its relative abundance, moderately long half-life and heat output, Sr-90 was selected as fuel for terrestrial and marine applications of RTGs. The Energy Research and Development Administration (ERDA) and its predecessor, the Atomic Energy Commission (AEC) sponsored programs at the Pacific Northwest Laboratory (PNL), the Martin Company, and the Oak Ridge National Laboratory (ORNL) to develop ^{90}Sr-fueled isotopic heat sources.

Terrestrial and marine RTGs have used strontium titanate ($SrTiO_3$), strontium orthotitanate (Sr_2TiO_4) or strontium fluoride (SrF_2). In addition, two RTGs used strontium oxide as the fuel form. Sr-90 was recovered at Hanford from plutonium-production reactor fuel processing residues. Up to the present time no significant quantities of strontium have been recovered from commercial power reactor fuels in the United States.

Strontium-90 Production History

The first large-scale purification of Sr-90, about 7,000 curies, was carried out in the Fission Products Development Laboratory (FPDL) at ORNL in the summer of 1960. Production of ^{90}Sr-90 was then transferred to Hanford, where there was developed a head-end precipitation and an ion-exchange process for purifying 75,000 curies of Sr-90 in the period August 1960 to February 1961. From 1961 to 1964, more than 8 million curies of Sr-90 was processed at Hanford by a solvent-extraction method.

Hanford's B Plant was constructed in 1944 and originally used in plutonium recovery. It was shut down in 1952 when REDUX came on line. The plant was modified and restarted in 1958 to separate cesium and strontium from tank waste generated by nuclear fuel processing.

The strontium recovered at Hanford was shipped to ORNL and the Martin Company for conversion to desired RGT fuel forms. ORNL or the Martin Company's Quehanna Site in Pennsylvania prepared all of the Sr-90-90 titanates produced in this country for heat source applications.

In 1974 cesium and strontium were separated from all Hanford weapons production waste for waste management considerations. Recovering these isotopes reduced the decay heat load in the underground storage waste tanks. The cesium and strontium were converted to stable salts (cesium chloride and strontium fluoride). Once the strontium waste was converted to SrF_2, ORNL no longer had a source of Sr-90 to for production of strontium titanates. The equipment at ORNL was largely dismantled and the only major subsequent source of ^{90}Sr-90 was SrF_2.

PNL began a qualification program for ERDA to qualify a SrF_2 fuel form for use in RTG in 1977. In 1980 and 1981 seventeen RTGs were produced using SrF_2, the Sr-90 used in these was separated at Hanford.

History of Strontium-90 RTG Applications

More than 100 Sr-90 fueled RTGs were fabricated. Most RTGs were employed in government-sponsored activities, especially military support applications. The principal use was to provide electrical power for various monitoring activities. These included data storage and telecommunications related to meteorological and oceanographic monitoring, principally by the U.S. Navy. The U.S. Air Force also used strontium-90 RTGs for these purposes at seismic monitoring stations in Alaska. In the former Soviet Union several hundred RTGs were manufactured to provide power to navigation beacons on remote Arctic coasts.

Most domestic Sr-90 RTGs have completed their missions. Many have been returned to the DOE and are now being disposed as low-level radioactive waste at the Nevada Test Site (NTS). Two examples of RTG models and applications are described below.

Model LCG-25A

The Oceanographic Telemetry Data System on Fairway Rock in the Bering Strait was powered by RTG model the LCG-25A (Figure 2). It operated underwater and powered sensors measuring salinity, water speed, current direction, temperature, and mass transport. It transmitted data 15 miles to Cape Prince of Wales on the Alaskan mainland. After completing it's mission LCG-25A was shipped to the Yorktown Naval Station and stored until June of 2008.

Figure 2: RTG model LCG-25A being loaded for shipment from Yorktown Naval Station to NTS for disposal, June 2008.

MW 3000

The MW 3000 underwent laboratory and undersea testing at the Naval Civil Engineering Laboratory, Port Hueneme, California. This program qualified the generators for long duration, unattended operation at seawater depths of several hundred feet. Operational use was in conjunction with position-marking acoustic pingers and transponders. These devices were returned from use to the DOE in 2005. They were accepted for disposal by NTS in September 2007.

PATH TO DISPOSAL

A disposition path as low level radioactive waste (LLW) was established for Sr-90 fueled RTGs owned by DOE. To establish a disposition path for DOE-origin RTGs, the DOE's Offsite Source Recovery Project (OSRP) proposed to manage the Sr-90 sources used to fuel the RTGs as radioactive waste derived from atomic energy defense activities. DOE's General Counsel provided guidance to determine if waste was derived from atomic energy defense activities. The history of Sr-90 fueled RTGs correlated to the following three questions:

Where did the radioactive materials become radioactive? The Sr-90 used to fuel US origin terrestrial and undersea RTGs became radioactive in AEC defense production reactors at Savannah River and Hanford reservations. The Sr-90 was derived as a fission product from the irradiation of uranium and depleted uranium targets used to produce plutonium for defense atomic energy purposes.

What was the purpose of the process that generated the waste? The AEC Savannah River and Hanford plutonium production facilities operated reactors for the sole purpose of weapons production. Strontium was produced as a fission product during the nuclear fission of uranium and depleted uranium targets. The fission products were separated from the fuel reprocessing residues. Sr-90 was removed and separated at the Hanford plant and purified at ORNL. Sr-90 was further processed to a qualified fuel form suitable for use in RTGs at ORNL, Quehanna and Hanford plants. Sr-90 was distributed through ORNL and Hanford.

At what point in the process was the waste generated? Sr-90 fueled RTGs contained concentrations too large for disposal in commercial radioactive waste disposal facilities. Users of Sr-90 RTGs returned them to the OSRP at Los Alamos National Laboratory. DOE examines options for reuse/recycle, then determines that the RTGs contain material in excess of defense program needs, can be discarded as DOE LLW from the production of nuclear weapons.

CLOSING THE CIRCLE

Documentation indicated all of the Sr-90 fuel used in the production of US origin RTGs was a fission product separated from the fuel reprocessing residues. Therefore the RTGs require disposal by the federal government, as authorized in the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Public Law 99-240, Sec 3 (b)(1)(A)), because the Sr-90 waste was generated by the DOE. The history and background for Sr-90 indicates it is radioactive waste derived from atomic energy defense activities, and was suitable for disposal as DOE LLW.

These units are now reaching their end-of-life and are being disposed as LLW at NTS and Hanford. The significance of these disposal activities is the Sr-90 originally separated from high level waste to reduce heat loading went on to serve as a useful product and can now be disposed as LLW. NNSA and DoD in the past calendar year have disposed of 24 Sr-90 fueled RTGs at NTS. This amounts to approximately 650,000 curies of Sr-90.

Figure 3: 8 RTGs leaving Yorktown for disposal at NTS as LLW.

Figure 4: 4 RTGs awaiting burial at NTS in Area 5 disposal trench.