Disposition of Radioisotope Thermoelectric Generators Currently Located at the Oak Ridge National Laboratory – 12232

J. Glenn
U.S. Department of Energy, Oak Ridge Operations Office
200 Administrative Road, Oak Ridge, TN 37830

J. Patterson and K. DeRoos
SEC Federal Services Corporation (SEC)
2800 Solway Road, Knoxville, TN 37931

J.E. Patterson and K.G. Mitchell
Strata-G, LLC
2027 Castaic Lane, Knoxville, TN 37932

ABSTRACT

Under the American Recovery and Reinvestment Act (ARRA), the U.S. Department of Energy (DOE) awarded SEC Federal Services Corporation (SEC) a 34-building demolition and disposal (D&D) project at the Oak Ridge National Laboratory (ORNL) that included the disposition of six Strontium (Sr-90) powered Radioisotope Thermoelectric Generators (RTGs) stored outside of ORNL Building 3517. Disposition of the RTGs is very complex both in terms of complying with disposal facility waste acceptance criteria (WAC) and U.S. Department of Transportation (DOT) requirements for packaging and transportation in commerce. Two of the RTGs contain elemental mercury which requires them to be Land Disposal Restrictions (LDR) compliant prior to disposal. In addition, all of the RTGs exceed the Class C waste concentration limits under Nuclear Regulatory Commission (NRC) Waste Classification Guidelines. In order to meet the LDR requirements and Nevada National Security Site (NNSS) WAC, a site specific treatability variance for mercury was submitted to the U.S. Environmental Protection Agency (EPA) to allow macroencapsulation to be an acceptable treatment standard for elemental mercury. By identifying and confirming the design configuration of the mercury containing RTGs, the SEC team proved that the current configuration met the macroencapsulation standard of 40 Code of Federal Regulations (CFR) 268.45. The SEC Team also worked with NNSS to demonstrate that all radioisotope considerations are compliant with the NNSS low-level waste (LLW) disposal facility performance assessment and WAC. Lastly, the SEC team determined that the GE2000 Type B cask met the necessary size, weight, and thermal loading requirements for five of the six RTGs. The sixth RTG (BUP-500) required a one-time DOT shipment exemption request due to the RTG's large size. The DOT exemption justification for the BUP-500 relies on the inherent robust construction and material make-up of the BUP-500 RTG.

INTRODUCTION

RTGs generate electrical energy by means of the direct conversion of thermal energy from radioactive decay via a thermoelectric generator. The generator uses thermocouples arranged in an electrical circuit and maintained in a temperature gradient between a heat source (hot junction) and a heat sink (cold junction). This temperature gradient creates an electrical potential, via the Seebeck effect, which will generate a current flow when connected to an electrical load. Radioactive sources for the RTGs were developed by DOE or its predecessor the Atomic Energy Commission (AEC).[1] The RTG design, manufacture, and assembly were performed by commercial partners of DOE and AEC. The RTGs were deployed by several different United States civil and military entities to provide electrical and thermal energy in remote locations (e.g., power for a weather station in Antarctica).

Figure 1 shows six RTGs that are currently stored outside and adjacent to Building 3517 at ORNL. The RTGs have been deemed excess to DOE programmatic needs and are therefore slated for disposal.[2] The radionuclide fuel in these RTGs is Strontium-90 (Sr-90). Attempts to reuse or recycle the RTGs have not been successful mainly due to the fact that RTGs produced in recent years are fueled by more efficient Plutonium-238 sources and thus Sr-90 sources are no longer used.

Figure 1 – RTGs stored outside Building 3517

This paper describes the technical challenges and successes associated with characterization, profiling, and planning for transportation and disposition of the six ORNL RTGs.

BACKGROUND

The six RTGs have been stored at ORNL for over 40 years within the foot print of Building 3517, a category 2 Nuclear Facility. Five of the six RTGs still have all of their mechanical and electrical components. The Radio Corporation of America (RCA) is technically only a source within a shielded cask. The RCA source has already been removed from the RTG components. Generally, each RTG source was created in the same manner. Hanford tank waste from the plutonium extraction (PUREX) process was used as the source for Sr-90. Liquid tank waste was fed over zeolite columns which were used to extract and isolate Sr-90 from other isotopes. Casks and/or high integrity containers (HICs) with the zeolite columns saturated with Sr-90 were then brought to ORNL Building 3517 where the material (Sr-90) was chemically removed from the zeolite and unloaded. ORNL then created the Sr-90 fuel for the RTGs in the form of compressed and encapsulated titanate ($SrTiO_3$) pellets. The pellets were typically formed from $SrTiO_3$ precipitate powder that was cold-pressed and then sintered at 1700K. The size and activities of the Sr-90 fuel sources varied for each RTG.[3]

These individual RTGs were some of the very first prototypes developed and were used by the National Aeronautics and Space Administration (NASA), U.S. Department of Defense (DoD), and the Weather Bureau. These RTGs have been used for weather data collection systems in Antarctica and the Gulf of Mexico and the U.S. Coast Guard used one RTG to support a remote location light house.[4,5]

Figure 2 depicts a typical RTG fuel source including immediate shielding for the source. The fully assembled RTGs had a much more robust shielding design that will be discussed in depth later.

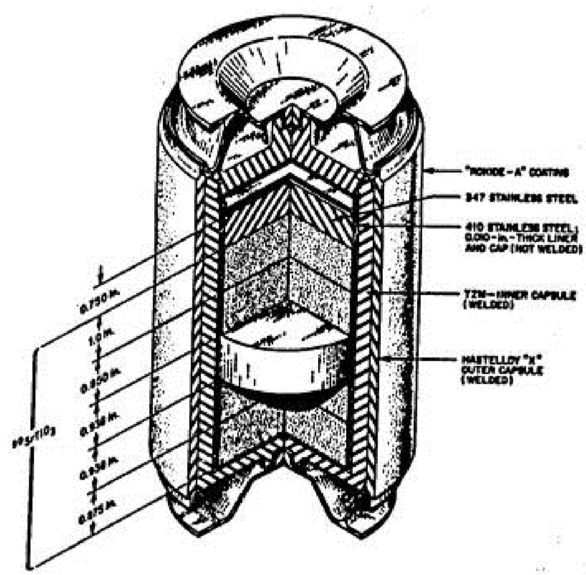

Figure 2 – Typical Configuration of an RTG Fuel Source

As previously mentioned, each RTG source was unique and placed in service for specific purposes. A key component to ensuring protection of human health and the environmental during deployment or while in storage was the shielding used. Given the extremely high concentration of radioactive materials, the selection and design of shielding for the RTGs was critical. Table 1 summarizes key radiological and physical characteristics of the six ORNL RTGs.

Table 1 − General Characteristics of RTGs[6]

RTG	Built	Initial Activity (kCi)	*Current Activity (kCi)	*Current Thermal Output (W)	Weight (kg)	Shielding
Weather Bureau	1961	17.5	6.0	40	800	DU, Lead
SNAP-7C	1961	39.8	14	91	840	DU
SNAP-7B	1962	224	79	530	2100	DU
SNAP-7D	1962	224	79	530	2100	DU
RCA Source	1964	83.5	31	210	740	DU
BUP-500	1986	1094	688	4600	3600	Tungsten

Notes
*Information current as of 2006.
DU = depleted uranium; RTG = Radioisotope Thermonuclear Generators; W = Watts; kCi – kilo curies (i.e., curies X 1,000);
Kg = kilograms; SNAP = Systems Nuclear Auxiliary Power; RCA=Radio Corporation of America; BUP =Byproduct Utilization Program

Figure 3 below shows five of RTGs currently stored within the caged area outside of ORNL Building 3517.

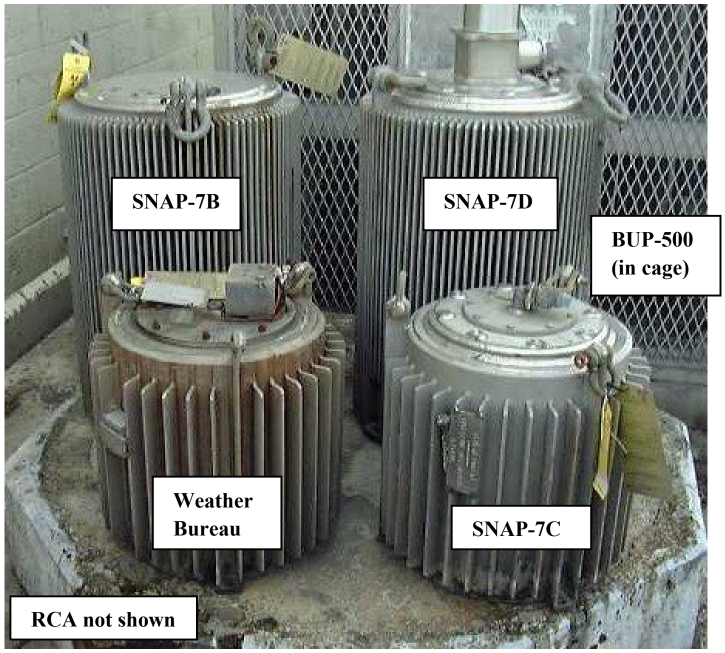

Figure 3 – Current RTGs storage configuration outside Building 3517

Weather Bureau and SNAP-7C[7]

This particular RTG was originally used to power a data telemetry package at a remote Arctic weather station on Axel Heiberg Island. Since the customer for this RTG was the U.S. Weather Bureau, it is typically referred to as the 'Weather Bureau' RTG. The Weather Bureau RTG was the first large radioisotope-fueled RTG ever used for practical terrestrial use. It was essentially the prototype for the Systems Nuclear Auxiliary Power (SNAP)-7 series of RTGs that immediately followed, and shares many design features with the SNAP-7 RTGs. Figure 4 shows the Weather Bureau RTG in its current condition.

Figure 4 – Close-up of modified Weather Bureau RTG

The Weather Bureau RTG was fabricated, fueled, and tested by the Martin Company in 1961. It was fueled with 17.5 kCi of Sr-90 at ORNL in May of 1961. After testing, it was shipped to the Artic and installed on uninhabited Axel Heiberg Island (700 miles from the North Pole) on August 17, 1961, where it powered the data telemetry system through August of 1964. After successful completion of the U.S. Weather Bureau's tests and evaluation, it was returned to ORNL in July of 1965. In the late 1960s the Weather Bureau RTG was modified. The thermoelectric generator assembly was removed from the original lead-lined biological shield assembly and adapted to the depleted uranium (DU)-lined shield housing of the SNAP-7A RTG. The SNAP-7A RTG had already been fully disassembled and extensively examined in 1967. After this modification the Weather Bureau RTG was incorporated into an operating exhibit on display at ORNL in 1969.

The metals of concern under the Resource Conservation and Recovery Act (RCRA) in these RTGs include mercury and lead. Mercury was used as a heat transfer fluid in the Weather Bureau and SNAP-7C. Lead and DU were used as shielding in the majority of these RTGs. Figure 5 is a schematic diagram of the Weather Bureau and SNAP-7C designs. Of particular interest is the process knowledge showing the mercury used for "seating" the source within the shielding and potential for the presence of lead. As discussed above, it is possible that as the original Weather Bureau source was removed from this alignment to the newer SNAP-7A shielding arrangement, the mercury was not replaced.

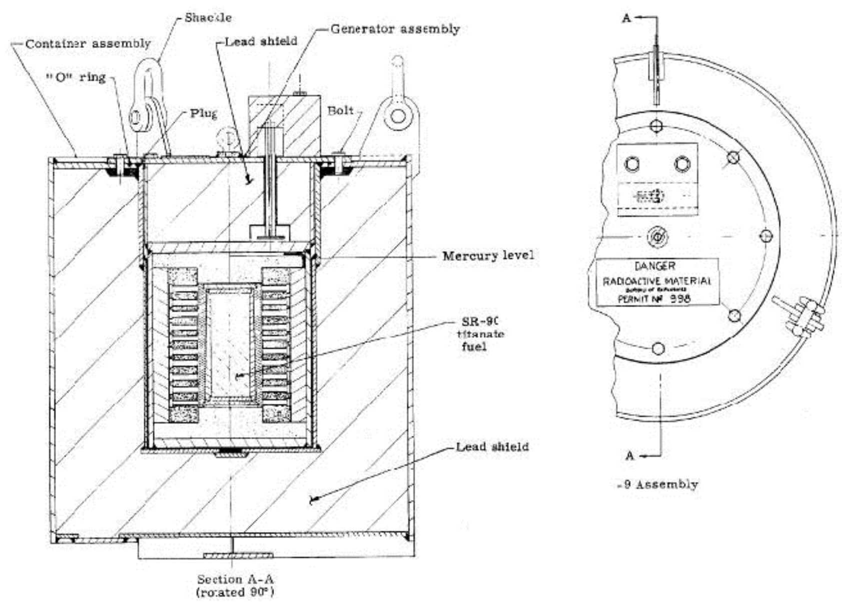

Figure 5 – Schematic of the Weather Bureau and SNAP-7C RTG

SNAP-B/D[8]

The SNAP-7B and SNAP-7D RTGs were designed to be rugged, long-life, reliable electrical generators for use in remote terrestrial applications. These particular RTGs were also designed and built in the early 1960s by the Martin Company for the AEC. The SNAP-7B was fueled with ~224 kCi of Sr-90 in 1963 and placed into service in 1964 as the power source for a U. S. Coast Guard automatic light station. The SNAP-7D was fueled with ~224 kCi of Sr-90 in 1962 and used for a U. S. Navy floating weather station in the Gulf of Mexico from 1964 through 1969. Both the SNAP-7B and SNAP-7D have been in storage at ORNL since 1969.

There are no known, or suspected, hazardous wastes associated with the SNAP-7B and SNAP-7D RTGs. Figure 3 above shows the SNAP-7B and 7D RTG in storage.

The SNAP-7B and SNAP-7D are essentially identical designs, although intended for use in different systems. Assuming a 43-year decay period (i.e., 1963 – 2006), these RTGs are assumed to contain 79 kCi of Sr-90 each. Sr-90 has a half-life of 29 years.

RCA Source[9]

In June 1963, the Astro-Electronics Division of the Radio Corporation of America (RCA) was granted use of Sr-90 from the AEC for testing a laboratory model of an RTG for space-power use. Alpha-emitting radioisotopes would normally be used for space-power purposes in order to avoid the weight of the significant biological shielding required when using Sr-90. However, since sufficient amounts of such alpha isotopes were not available at the time, Sr-90 was chosen as the radioisotope for this particular test unit. The Sr-90 fuel was fabricated and encapsulated by ORNL in July of 1964. The primary purposes of this testing were to demonstrate improved thermoelectric conversion efficiency using advanced thermoelectric semi-conductor materials with higher hot-junction temperatures, and to determine the compatibility of the thermoelectric generator material with the heat source capsule (i.e., the RCA Source) containing the Sr-90 fuel.

A photo of the isotope fuel capsule referred to as the RCA Source is shown in Figure 6 below.

Figure 6 – Photo of RCA Source Outside of Building 3517

At the conclusion of the space-power RTG testing, for which the RCA Source was primarily intended, another experiment was conducted at ORNL to estimate the extent of high-temperature corrosion of the outer surfaces of the RCA Source capsule. This corrosion test was run for at least 142 days at approximately 1,000°C, after which the outside surface of the RCA Source showed no significant changes. At a later date the RCA Source was configured for use as a heat supply for the Sea Lab II Way Station. The RCA Source inside the Sea Lab II Way Station Heat Source Shield was subsequently stored within a welded cask at ORNL and it remains in that configuration to the present day.

BUP-500[10]

The Byproduct Utilization Program (BUP)-500 is the largest RTG ever constructed. It was built in 1986 by Teledyne Energy Systems in support of the DOE's Byproduct Utilization Program (BUP), whose objective was to promote the beneficial use of byproduct materials recovered from radioactive waste, and Defense Energy Program, whose objective was to develop secure and reliable power sources for defense needs. The BUP-500 was named after the amount of electrical power (500 Watts) it was designed to produce after five years. It was intended to be a prototype to demonstrate the viability of an extremely reliable, long-life, maintenance-free power source in the 500 Watt range. The Sr-90 fuel was fabricated in 1985 and the RTG was loaded in August of 1986 with fuel capsules producing a total of about 7.5 KW (thermal).

The RTG is mounted in a cubic, shock-absorption frame that serves as the shipping and handling container for the BUP-500. This container is an integral part of the RTG assembly, with nominal outer dimensions of 1.8m X 1.8m X 1.5m tall. An illustration of the BUP-500 mounted in its shipping/handling container is shown in Figure 7.

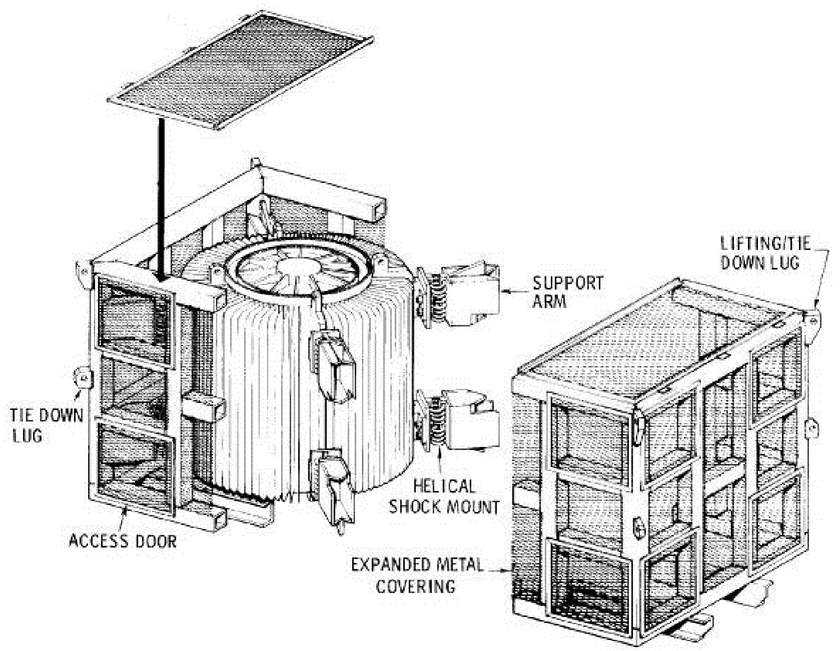

Figure 7 – Illustration of the BUP-500 RTG in its Present Container

DISPOSITION APPROACH

The plan to dispose each of the RTGs described above is comprised of two major parts:

1. Acceptance at NNSS for disposal, and
2. Transportation to NNSS.

Each of these components is addressed in the following sections.

Acceptance at NNSS

Based on review and understanding of the historical process knowledge, relevant State and Federal regulations, and current DOE waste management policies, the preferred disposition option for the RTGs is NNSS. The NNSS has both LLW disposal capacity and mixed waste disposal capacity. For the RTGs with potentially hazardous constituents, namely the Weather Bureau and SNAP-7C, disposal in the NNSS permitted mixed waste disposal facility will be necessary after RCRA LDR requirements are satisfied. Numerous RTG units from other DOE sites have already been disposed of at NNSS thus ensuring relevant precedence and necessary experience for sharing lessons learned.

The SEC Team started the disposition process with gathering all relevant and available process knowledge, or PK. Through the course of many decades, substantial PK on each of the RTGs has been developed and even published. Using an informal data quality objective (DQO) process, the NNSS WAC was evaluated to identify data gaps.[11] The data gaps represent information voids that need to be filled through either additional PK of physical measurement or sampling means. Analysis by the SEC Team indicated that only one data gap existed which was whether the Weather Bureau and SNAP-7C RTGs definitively contain mercury in the annulus between the fuel source component and the shielding housing. The mercury was used in early RTG designs to serve as a heat transfer mode in favor of an air gap. The assumption was made, with DOE support, to assume mercury still exists within those RTGs.

The next step was to develop NNSS waste profiles for the RTGs. This exercise is necessary to be performed early on for any waste stream to quickly identify potential roadblocks and specifically determine if any WAC elements would either preclude disposal or would necessitate an approved variance or waiver prior to disposal. The SEC Team met with NNSS and other RTG subject matter experts (SMEs) to gain resolution and path-forward approaches. After resolution of the critical WAC elements, the waste profiles are under preparation and will be submitted for approval by the NNSS Radioactive Waste Acceptance Panel (RWAP) in accordance with the standard NNSS waste acceptance protocol. Approval of the RTG waste profiles will establish acceptance of the RTGs for disposal at the NNSS site and specifically the Area 5 LLW and mixed LLW disposal facilities.

The following key disposal technical challenges were identified and are being addressed:

Acceptance of Greater Than Class C-equivalent Waste

The NNSS WAC states that greater than Class C (GTCC) waste generated by NRC licensees shall not be accepted for disposal at NNSS, but does not impose any GTCC-equivalent waste restrictions for DOE waste. Since the RTG sources are DOE waste, only the NNSS WAC Action Limits for radioisotopes apply. Each of the RTGs presently exceed Class C thresholds and are thus GTCC waste under NRC terminology; however, they can be managed and safely disposed of at NNSS. This will be demonstrated by a *special evaluation* against NNSS performance assessment criteria. Analytical (numerical) WAC at the NNSS LLW and MLLW disposal facilities are back calculated to ensure the performance objectives of DOE Manual 435.1-1 "Radioactive Waste Management" are satisfied.[12] One of the exposure pathways examined is the inadvertent intruder drilling scenario in which an intruder drills down into the waste facility (seeking water or other resources) and pulls to the surface contaminated materials that are subsequently spread into garden plots, used for building foundations, etc. For a homogeneous waste form, this scenario is plausible albeit conservative. The RTGs are a very different waste form than typical contaminated soils or debris. The RTGs, as disposed, will be a solid monolith unable to be penetrated by routine drilling equipment due to its robust design and thick shielding elements. The *special analysis* anticipated to be developed and documented by NNSS will include a combined probabilistic and deterministic evaluation of the actual RTG waste forms to back calculate waste-stream specific WAC for the RTGs. If the RTGs still cannot satisfy the NNSS WAC developed for the RTGs, then the SEC Team would evaluate options for dismantling the RTGs and seeking approval from NNSS to dispose of the RTG sources in alternative concentrations and or forms.

Acceptance of Mixed LLW

NNSS can currently accept and dispose of mixed LLW that is LDR compliant. SEC is currently in the process to verify what, if any, treatment may be required to meet RCRA LDRs for hazardous constituents potentially associated with the RTGs. There are two hazardous constituents associated with the RTGs that are the focus of the analysis: lead and mercury.

The two mercury containing RTGs contain lead – as part of lead-telluride thermoelements; as a component of the tinned DU shield; and as two lead blocks on the exterior of the Weather Bureau RTG.

- The lead-telluride thermoelements were used for their resistance to corrosion and oxidation under extreme environmental conditions of temperature and moisture. Toxicity Characteristic Leaching Procedure (TCLP) testing results conducted as part of the prior NNSS waste profile efforts for a SNAP-21B RTG concluded that the RTG thermoelements will not leach lead at a concentration that causes the RTGs to exhibit the characteristic of toxicity (Technical Basis Document for Weather Bureau and SNAP-7C).
- Lead is present in the solder used to tin the inside and outside surfaces of the DU of the RTG radiation shield assemblies. This lead, which is bonded to the DU, is integral to the biological shielding design used for these RTGs and aids in shielding of the Bremsstrahlung radiation.
- There are two lead blocks secured to the exterior of the Weather Bureau RTG. Both are used for shielding. One block was bolted to the top of the Weather Bureau RTG to shield for radiation that would otherwise ‘leak’ through the electrical feed-through hole in the upper shielding of the RTG. The other block was installed on the side of the RTG to shield radiation after the biological shield was cored for examination after it was retrieved from the field.

The position of the SEC Team and DOE-Oak Ridge Operations (ORO) is the lead shielding has served, and continues to serve, as an important shielding component. The lead is still necessary to shield the Sr-90 sources to protect workers, transportation elements, and disposal operations personnel.

Mercury (Hg) analyses are not available but concentrations are assumed to exceed the TCLP regulatory level for mercury of 0.2 mg/L. It is estimated that 6 kgs of mercury was added to the RTG annulus. The Weather Bureau and SNAP-7C RTGs weigh 800 kg and 840 kg, respectively. By applying the *Rule of 20* to the total assumed mercury concentration in the RTGs, the estimated maximum leachate concentration that could result from a theoretical TCLP analysis of the entire RTG would be:

$$6{,}000{,}000 \text{ mg}/800 \text{ kg} = 7{,}500 \text{ mg/kg} / 20 = 375 \text{ mg/kg (ppm)} = 375 \text{ mg/L Hg}$$

In accordance with 40 CFR 261.24, the mercury regulatory limit is 0.2 mg/L. Therefore, the RTG material could be declared characteristically hazardous for mercury (D009) if the total concentration of mercury were considered and the Rule of 20 were applied. Figure 8 illustrates the assumed location of mercury within the Weather Bureau and SNAP-7C RTGs.

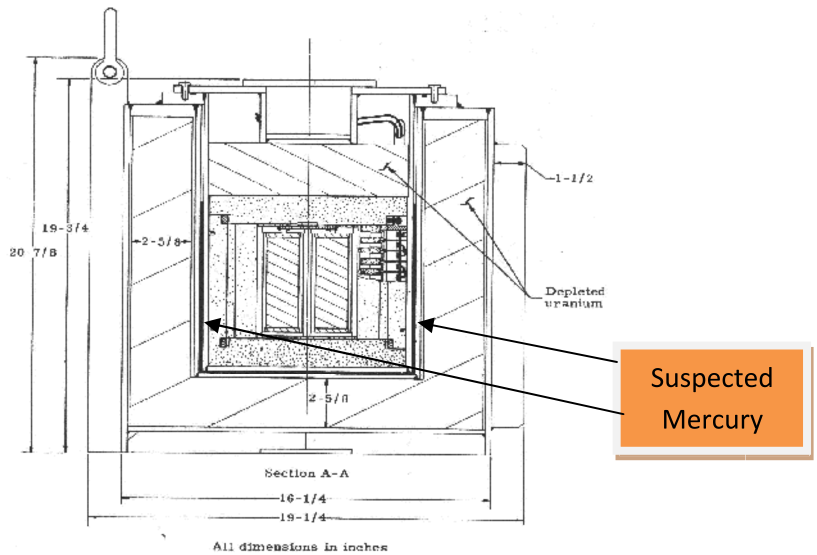

Figure 8 – Illustration of the Weather Bureau RTG with Mercury

Accepting the conclusion that the two RTGs would be characteristic hazardous waste for mercury, the management options include:

1. Removal of the mercury,
2. Mercury amalgamation, and
3. Macroencapsulation allowable via RCRA treatability variance.

Significant safety and operational challenges prohibit removing mercury from the RTGs, and amalgamation of the mercury while inside the RTGs is also not practical and is technically inappropriate. The SEC team recommended Option 3. In summary, the existing LDR treatment standards (which are based on metals recovery) that would apply to the mercury containing RTGs are technically inappropriate according to 40 CFR 268.44(h)(2), and viable treatment options are unavailable. A more appropriate treatment would be macroencapsulation. As such, a treatability variance petition was submitted to EPA that presents an alternative treatment method, macroencapsulation, which will substantially reduce surface exposure to potentially leaching media. EPA acceptance of this treatability variance is pending. Further, by identifying and confirming the design configuration of the mercury containing RTGs, the SEC team proved that the current configuration met the macroencapsulation standard of 40 CFR 268.45. Details of the treatability variance and macroencapsulation approach are discussed below.

The first step was to determine the LDR treatment standard for the mercury containing RTGs and whether that standard was appropriate. For wastes that exhibit the toxicity characteristic for mercury (D009 Waste Code), seven subcategories are identified for nonwastewaters. Under existing LDR standards, the mercury containing RTGs would be classified in the D009 High-Mercury-Inorganic Subcategory because the RTGs are inorganic, exhibit the toxicity characteristic for mercury, and contain greater than 260 mg/kg total mercury. As such, they are subject to the specified technology LDR treatment standard of RMERC (roasting/retorting with recovery of mercury). The objective of the RMERC specified technology LDR treatment standard is to volatilize the metals in a high temperature treatment unit and subsequently condense and collect them for reuse, while significantly reducing the concentration of metals in the waste residual. This approach is technically inappropriate for mercury containing RTGs because the recovered mercury would likely contain residual radioactive contamination and a facility does not exist with the capability to handle these mercury containing RTGs for recycle. As a consequence of radioactive contamination, there would be an extremely low probability of reuse for the recovered metals, and due to residual radioactivity, the recovered mercury would require amalgamation (i.e., the specified LDR treatment standard technology for elemental mercury contaminated with radioactive materials). Accordingly, the LDR treatment standards applicable to these mercury containing RTGs are not appropriate.

SEC requested a treatability variance, under 40 CFR 268.44(h), from the RCRA LDR treatment standards for the Weather Bureau and SNAP-7C RTGs. The petition proposed macroencapsulation as a protective alternative LDR treatment standard because mercury containing RTGs are similar to the types of materials that EPA has identified as inherently hazardous debris, for which EPA has already determined macroencapsulation to be an acceptable treatment technology. The variance request closely paralleled a very similar generic variance request submitted by DOE in 2002 related to radioactively contaminated cadmium-, mercury-, and silver-containing batteries, which was subsequently granted by EPA and published as a direct final rule.[13] The disposal problems that the applicable LDR specified treatment technology presented for these battery wastes, and the requested alternative treatment method provided in the variance request, are analogous to the mercury containing RTGs.

In DOE's 2002 variance request[14], DOE provided a justification for applying the treatment standard identified for inherently hazardous debris to the radioactively contaminated cadmium-, mercury-, and silver-contaminated batteries, even though these waste batteries did not meet the definition of debris. A similar justification was provided for the waste mercury containing RTGs. Macroencapsulation (as defined in 40 CFR 268.45 for hazardous debris) of waste mercury containing RTGs would be consistent with EPA's strategy for treating inherently hazardous debris. In the proposed hazardous debris rule [57 FR 958 (January 9, 1992)], EPA lists the following as examples of inherently hazardous debris: metal alloys containing chromium and nickel, battery casings that contain lead, lead pipe, and lead paint chips (57 FR 990). In the final hazardous debris rule [57 FR 37194 (August 18, 1992)], EPA states the following regarding proper treatment of inherently hazardous debris:

> *"When recycling of inherently hazardous debris is not practicable and it is to be disposed, today's rule requires treatment by an immobilization technology to reduce the likelihood of migration of hazardous contaminants, followed by disposal in a Subtitle C landfill"* (57 FR 372367).

RTGs are similar to the types of waste materials considered inherently hazardous under the hazardous debris rule. Accordingly, since the final hazardous debris rule established macroencapsulation as an acceptable method for immobilizing inherently hazardous debris when recycling is not a viable option, the macroencapsulation LDR treatment standard for hazardous debris offers an acceptable LDR treatment standard for waste mercury containing RTGs when recycling is not a viable option. In its 2002 variance petition, DOE noted that the undamaged waste batteries do not meet the definition of debris in 40 CFR 268.2(g) because of the debris exclusion for *"intact containers of hazardous waste that are not ruptured."* The waste mercury containing RTGs are similarly intact and therefore would not meet the debris definition. Regardless, EPA agreed in the October 7, 2002 direct final rule pertaining to the waste batteries that *"the appropriate treatment standard is macroencapsulation in accordance with the design and operating standards of 40 CFR 268.45,"* (67 FR 62621, column 2) and therefore the treatability variance requested that EPA apply this same determination for the waste mercury containing RTGs.

Finally, by identifying and confirming the design configuration of the mercury containing RTGs, the SEC team proved that the current configuration met the macroencapsulation standard of 40 CFR 268.45. For hazardous debris, a container may be used to meet the definition of macroencapsulation provided that the container is noncorroding (e.g., stainless steel) and meets the macroencapsulation performance and/or design and operating standard of substantially reducing surface exposure to potential leaching media (i.e., water), and encapsulating debris to be resistant to degradation by the debris and its contaminants and materials into which it may come into contact after placement (e.g., leachate, other waste, microbes). The combination of nested sealed RTG components substantially reduces surface exposure to leaching media (i.e., water), and the RTG vessel completely encapsulates the mercury and is resistant to degradation by any RTG components and by any materials into which it may come into contact after disposal in the NNSS mixed waste cell.

The RTGs are robust stainless steel containers with a pedigree of quality and conduct of operations that governed the handling, filling, and sealing of these containers. Also, performance testing was performed on these containers in the 1960s that could be considered comparable to testing done currently on Type B containers. The Weather Bureau and SNAP-7C RTG biological shields are constructed of one layer of DU and two layers of Hastelloy-C material, which is a stainless corrosion resistant material often used in the nuclear industry. RTGs have lids at the top which were sealed closed by fusion welds. The welds on the lid of the Weather Bureau have been broken and it has been bolted closed and caulked. RTGs will be inspected for minor defects or non-welded exterior joints. Minor defects or non-welded joints may be sealed with an approved geopolymer sealant material that restores the overall jacketing to that of a continuous encapsulating barrier. See Figure 9 below on current configuration of the SNAP-7C RTG.

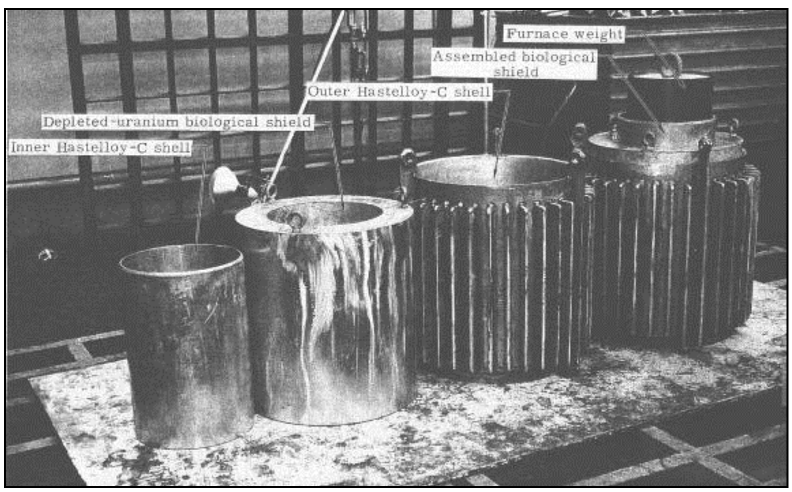

Figure 9 – SNAP-7C RTG current configuration

Transportation to NNSS

On-Site Transfers

On-site transfer of the RTGs is not expected; however, if necessary prior to shipment to NNSS, the RTG shipments will be subject to 10 CFR 830, Nuclear Safety Management and DOE Order (O) 460.1B, Packaging and Transportation Safety. Given the robust design of the specific RTG packages, these shipments can be moved with non-certified DOT packaging with administrative controls applied on the ORNL site during movements (e.g., limited speed, off-shift hours, security escorts, etc.). If an on-site transfer is needed, for example to optimize cask loading, a safety document will be prepared and submitted to DOE-ORO for approval prior to the shipment. This is done routinely by DOE contractors on the Oak Ridge Reservation. Notwithstanding, the goal of the SEC Team remains to transfer the RTGs only one-time to the final disposal location at NNSS.

Off-Site Shipment

Off-site shipment to NNSS will be subject to DOT and DOE O 460.1B. Given the age of the RTGs, it is unlikely the existing RTG packaging certification is still valid. This point has been reviewed and confirmed. Given that any certifications have expired, a search has been initiated concurrent with the review of the existing packaging certification to identify qualified NRC-licensed Type B packaging for some type of RTG over-pack. At present, qualified and compliant packaging has been identified for all of the RTGs with the exception of the BUP-500. Due to the robust nature of the BUP-500 and existing handling and shipping apparatus (see Figure 7), the SEC team developed a DOT special permit per 49 CFR. The special permit would allow one-time shipment (from ORNL to NNSS) in the non-certified packaging. All other DOE requirements including security can be met. After review by DOE-ORO, the special permit request will be transmitted to the DOE Office of Environmental Management (EM)-63. EM-63 will then submit the exemption request to DOT. Processing a permit request of this type typically takes 6-9 months, thus the BUP-500 would be expected to be the last RTG shipped and disposed.

The RTGs are included in the definition of sealed sources of DOE N 234.1, Reporting of Radiation Sealed Sources. They will be Category 1 or 2 sources. Accountability requirements must be met including transportation requirements. The transportation requirement is limited to notification by the receiver of the shipment delivery.

CONCLUSIONS AND STATUS

DOE-ORO, SEC, and the entire SEC RTG team are nearing the conclusion of the Sr-90 RTG disposition challenge – a legacy now 50 years in the making. Over 600,000 Ci of Sr-90 waste await disposal and its removal from ORNL will mark an historical moment in the clean-up of the cold-war legacy in the ORNL central industrial area. Elimination (i.e., removal) of the RTGs will reduce security risks at ORNL and disposal will permanently eliminate security risks. The RTGs will eventually decay to benign levels within a reasonable timeframe relative to radiological risks posed by long-lived isotopes. The safety authorization basis at ORNL Building 3517 will be reduced enabling greater operational flexibility in future clean-out and D&D campaigns. Upon disposition the Department of Energy will realize reduced direct and indirect surveillance and maintenance costs that can be reapplied to accelerated and enhanced clean-up of the Oak Ridge Reservation.

At present, waste profiles for the RTGs are developed and under review by NNSS RWAP staff and approval authorities. Disposition schedule is driven by the availability of compliant shipping casks necessary to safely transport the RTGs from ORNL to NNSS. The first disposal of the RCA RTG is expected in April 2012 and the remaining RTGs disposed in 2012 and 2013.

REFERENCES

1. Corliss, W. R.; Douglass, G. H., *Radioisotope Power Generation,* Prentice-Hall, Inc., 1964.

2. DOE (U.S. Department of Energy) 1999. *Remedial Investigation Report/Feasibility Study for Bethel Valley Watershed at Oak Ridge National Laboratory, Oak Ridge, Tennessee*. DOE/OR/01-1748&D2. Oak Ridge, TN.

3. Ottinger, C. L., *Preparation of SNAP-7D Fuel*, Intra-Laboratory Correspondence, 6/29/1962.

4. MND-P-2720, *Strontium-90 Fueled Thermoelectric Generator Power Source for Five-Watt U. S. Coast Guard Light Buoy, Final Report*, 2/2/62

5. MND-P-2836, *SNAP 7B--Strontium-90 Fueled Thermoelectric Generator Power Source. Thirty-Watt U.S. Coast Guard Automatic Light Station, Final Report,* June 1963.

6. Bechtel Jacobs Company LLC 2006. Process Knowledge and Characterization of Radioisotope Thermoelectric Generators Stored at Oak Ridge National Laboratory Building 3517. Oak Ridge, TN.

7. Idaho National Laboratory (INL) 2004a. Draft Nevada Test Site Waste Profile Sheet Form – Revision 1 – Weather Bureau (Sentry) Radioisotope Thermoelectric Generator. February 11, 2004.

8. INL 2004b. Draft Nevada Test Site Waste Profile Sheet Form – Revision 1 – SNAP 7B/7D Radioisotope Thermoelectric Generator. February 11, 2004.

9. INL 2004c. Draft Nevada Test Site Waste Profile Sheet Form – Revision 1 – RCA Heat Source. February 11, 2004.

10. INL 2004d. Draft Nevada Test Site Waste Profile Sheet Form – Revision 1 – BUP-500 Radioisotope Thermoelectric Generator. February 11, 2004.

11. Nevada Nuclear Security Site 2011. *Nevada Nuclear Security Site Waste Acceptance Criteria*. DOE/NV-325-Rev.8-01, January 2011.

12. DOE 2001. *Radioactive Waste Management*, DOE Order 435.1, Change Notice 1, U.S. Department of Energy, Washington, D.C., February 2011.

13. DOE 2002. *Petition for Treatability Variances From the Land Disposal Restrictions Treatment Standards Applicable to Certain Radioactively Contaminated Metal-Containing Waste Batteries.* Letter from Andy Lawrence, DOE to Elizabeth A. Cotsworth, EPA dated June 13, 2002.

14. Environmental Protection Agency 2002, Land Disposal Restrictions: National Treatment Variance To Designate New Treatment Subcategories for Radioactively Contaminated Cadmium-, Mercury-, and Silver-Containing Batteries, [FRL–7390–7; Docket Number: RCRA–2002–0027] RIN 2050–AE99, October 7, 2002.