# PACKAGING, SHIPMENT, AND DISPOSAL OF REMOTE-HANDLED LOW-LEVEL RADIOACTIVE WASTE FROM OAK RIDGE NATIONAL LABORATORY

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## ABSTRACT

Bechtel Jacobs Company LLC (BJC)[a,b], with support from subcontractors WESKEM, LLC and Duratek Federal Services (DFS), is retrieving and shipping twenty remote-handled containers ("canisters") from the US DOE Oak Ridge National Laboratory (ORNL) to Nevada Test Site (NTS) for disposal. The canisters hold activated metal and sources. Most of the canisters have contact dose rates over 10 Sv/hr (1,000 rem/hr) and one has a contact dose rate of 250 Sv/hr (25,000 rem/hr). The canisters are being retrieved from dry storage "wells" in a below-grade shielded facility at ORNL. A custom shielded overpack was designed to reduce the dose rates of the overpacked canisters to <0.2 Sv/hr (20 rem/hr) on contact for unloading at NTS. The overpacked canisters will be shipped to NTS using the CNS 1-13G and CNS 1-13C Type B shipping casks. BJC also designed a mobile concrete "burial vault" for use by NTS to load two overpacks into for permanent disposal. The dose rate on the outside surface of the burial vault while containing the two overpacks is "contact-handled" (i.e., <2 mSv/hr or <200 mrem/hr). BJC will begin shipping the twenty legacy waste canisters for burial at NTS in March 2005. BJC also plans to continue using the shield overpack, Type B shipping cask, and burial vault combination to ship and dispose of other high dose rate waste including newly-generated hot cell debris and activated metal.

## INTRODUCTION

The Department of Energy Oak Ridge Operations Office (DOE-ORO) has contracted Bechtel Jacobs Company LLC (BJC) to perform accelerated closure of the Environmental Management program on the Oak Ridge Reservation under contract number DE-AC05-98OR22700. Part of the contract scope includes the characterization, repackaging, and shipment of the legacy radioactive low-level waste (LLW) on the Oak Ridge reservation to the Nevada Test Site (NTS) for disposal. The LLW disposal project was started on October 1, 2003 and has a completion milestone date of September 30, 2005. The majority of the legacy LLW on the Oak Ridge Reservation has been packaged and shipped for disposal. The remaining LLW consists of difficult-to-manage waste streams such as waste with high dose rates that is referred to as "remote handled" LLW.

For several years, the Oak Ridge National Laboratory (ORNL) operated nuclear reactors and conducted various projects generating remote handled LLW. The waste was stored in shielded containers or facilities pending an off-site disposal option. Much of the highest dose rate waste was stored in stainless steel remote-handled "canisters" that were lowered into a below-grade concrete shielded storage facility that incorporates vertical shafts as storage positions (referred to as storage "wells"). The canisters were made in four sizes to accommodate project requirements, on-site shielded carrier internal dimensions, and remote handling equipment limitations (see Table I and Fig. 1).

**Table I. Physical Dimensions and Mass Limits for Canisters in Storage Wells**

| Canister | Diameter (cm) | Height (cm) | Maximum Gross Weight (Kg) |
|---|---|---|---|
| Type 1 | 12.1 | 82.6 | 45.4 |
| Type 2 | 12.1 | 88.9 | 45.4 |
| Type 3 | 31.8 | 87.6 | 136 |
| Type 4 | 28.0 | 55.9 | 136 |

Fig. 1. Empty Type 2 and 3 Canisters

The canisters hold sources from various ORNL facilities and activated metal from the High Flux Isotope Reactor (HFIR) at ORNL. The sources include approximately 3,700 TBq (i.e., 100,000 curies) of Sr-90 in Radioisotope Thermoelectric Generator (RTG) source pins and 60 TBq (i.e., 1,600 curies) of Co-60 in encapsulated metal rods. There are approximately 93 TBq (i.e., 2,500 curies) in the activated metal from HFIR. The dominant gamma-emitting isotopes in the activated metal are Co-60, Eu-152, and Eu-154.

The overall strategy for disposal of the canisters is to shield the canister dose rates to a level that can be managed by BJC and NTS. The shielding is provided by a combination of shielded "overpacks," Type B shipping casks, and concrete "burial vaults." The overpack reduces the dose rate to levels acceptable for remote-handling but not to levels acceptable for shipping or disposal. Additional shielding is provided by the Type B shipping cask during transport and burial vault for disposal at NTS.

Before beginning the engineering design phase, several constraints were identified. The canister overpack needed to be compatible with the available Type B shipping cask limitations (e.g., weight, size, activity, etc.). The size and handling features associated with the canister overpack needed to be suitable for operations in the storage facility where the canisters were located. The canister overpack needed to accommodate different canister sizes, dose rates, and attachment features, and still limit the variability of the packages that NTS would need to handle. Standardization of the overpack design was recognized as a key element for the feasibility of operations at ORNL and NTS. The burial vault design needed to support ease of loading, closing, and movement at NTS and provide adequate shielding for the highest dose rate overpack, Most importantly, robust designs and quick handling features for all of the required equipment was necessary to provide a high level of safety and reduce the overall radiation exposure and operational risk.

Providing adequate shielding is the key consideration for the packaging, shipment, and disposal of most of the canisters. The packaging, shipment, and disposal of the Sr-90 RTG sources, however, presents additional challenges that require a different approach than for the activated metal and Co-60 sources. The RTG sources are generating approximately 330 watts of decay heat per canister. The amount of decay heat limits which shipping casks may be used since many waste casks are limited to less than 100 watts. In addition, there are no shipping casks that are currently approved by the United States Nuclear Regulatory Commission (NRC) or DOE for the shipment of Sr-90 RTG sources. Another challenge is related to the disposal requirements at NTS. The NTS safety basis includes a "plutonium equivalent" criteria (PE-g) that is associated with minimum packaging standards. The canisters holding the Sr-90 RTG sources have a plutonium equivalent of 4,700 PE-g each. For shipments exceeding 750 PE-g, NTS requires the waste to be buried inside of a certified Type B shipping package. The type of shielded Type B shipping cask necessary for transport the Sr-90 RTG sources to NTS is expensive. Disposal of a certified Type B shipping cask is generally not economically feasible.

This paper presents the work being performed by BJC at ORNL to package, ship, and dispose of high dose rate canisters at NTS. The paper includes a discussion of the following project elements:

- The field preparation and measurement activities,

- The methods used to correlate dose rate and canister activities to augment the existing characterization information,
- The shipping cask selection process,
- The engineering design of the shielded canister overpack and burial vault,
- Potential applications of this equipment for ongoing disposal of newly-generated remote handled LLW from ORNL, and
- Current options for the packaging, shipment, and disposal of Sr-90 RTG sources.

## FIELD MEASUREMENT AND CHARACTERIZATION ACTIVITIES

Characterization information from the waste generator was documented for each waste canister at the time of original storage. A review of this documentation noted several instances where conflicting or inadequate information was provided. Before proceeding with the packaging and shipment activities, BJC needed to obtain non-intrusive field measurements to confirm or obtain the necessary information for disposal.

The measurements of interest were isotopic content, canister dose rates, and canister weights. Since the measurements would become part of the characterization information being provided to NTS, the measurements were obtained using documented procedures and calibrated equipment. The result of the measurements would also support the shipping cask selection and design of the shielded overpack, facility handling equipment, and burial vault.

### Video Inspection

Since the majority of the storage wells holding the canisters had been closed for several years, a video camera was lowered into each of the storage wells to inspect the condition of the wells and canisters. The video signal was viewed remotely since the dose rate at the top of the storage well exceeded 0.5 Sv/hr (50 rem/hr) in some instances. Of specific interest was whether the canister attachment points were accessible (i.e., not blocked by loose debris) and the integrity of the canister attachment points and lanyards met basic criteria for serviceability. Access to all of the canisters was found to be acceptable. The condition of the lifting features for all of the canisters was also found to be acceptable with the exception of one canister with a broken lanyard.

### Radiological Measurement Process

The specific goal of the radiological measurements was to obtain a dose rate profile over the length of the canister and collect qualitative gamma spectroscopy information for isotopic confirmation and relative abundance correlation. To support the radiological measurements, BJC designed and fabricated shielded equipment to augment the existing facility handling equipment. One important piece of equipment was the doughnut-shaped "interface plate" that housed a high-range dose rate probe and included a narrow channel that was aimed at an external gamma spectroscopy unit. A collator and additional supplementary shielding was used with the gamma spectroscopy unit to limit interference from other radiological material stored in the vicinity. The dose rate and gamma spectroscopy data were collected simultaneously by moving the canister through the interface plate at discreet increments of approximately 5 centimeters (2 inches) over the entire length to obtain a dose rate profile. The dose rate measurements were obtained between 15 and 30 centimeters (6 and 12 inches) from the canister surface depending on the canister diameter. Since the operation was performed vertically, a remote-reading dynamometer was used to obtain accurate weights for each of the canisters.

## Measurement Results

The gamma spectroscopy measurements confirmed the presence of the anticipated high- energy gamma emitting isotopes. The primary gamma isotopes observed were Co-60, Eu-152, and Eu-154. The relative isotopic abundance in the canister waste with multiple isotopes was, in general, consistent with the waste documentation radionuclide distribution. As anticipated, the energy spectrum for the Sr-90 RTG source canisters was a continuum and the data was useful only to support the expectation of bremsstrahlung radiation. However, the gamma spectroscopy task did identify a few canisters with Cs-137 waste that was not recorded on the waste documentation. Further process knowledge review for these canisters is being pursued to assure adequate documentation for disposal.

The dose rate profile measurements indicated that, for the majority of the canisters, the dose rate varied along the length of the canister in an approximately bell curve distribution centered around the mid-point of the waste within the canister. The process knowledge for these canisters indicated the waste items were long homogenous items (e.g., activated rods). There were also a few canisters with dose rate distributions that could be described as uneven peaks or skewed toward the top or bottom of the canister. The process knowledge for these canisters indicated the waste was a collection of small source terms (e.g., sources). BJC interpreted these results to mean that the high dose rate regions corresponded to pockets of higher activity items within the canister.

For several of the canisters, the peak dose rate was much greater than the historical disposal paperwork indicated. The majority of the peak dose rate measurements for the canisters were between 10 and 100 Sv/hr (i.e., between 1,000 and 10,000 rem/hr). The canister with the highest dose rate exceeded the high range probe upper limit of 200 Sv/hr (20,000 rem/hr). An estimated peak dose rate for that canister was determined to be 250 Sv/hr (25,000 rem/hr) by using indirect dose rate measurements obtained through 20 centimeters (8 inches) of lead shielding. Table II summarizes the peak measurements for nineteen of the twenty canisters. The dose rate profile information for the canister with the broken lanyard will be measured in the spring of 2005.

**Table II. Peak Canister Dose Rate Measurements**

| Canister | 0.01 – 1.0 [Sv/hr] | 1.0 - 10 (Sv/hr) | 10 - 100 (Sv/hr) | 100 – 200 (Sv/hr) | >200 (Sv/hr) |
|---|---|---|---|---|---|
| Type 1 | | | | 1 | 1 |
| Type 2 | 1 | 2 | 3 | | |
| Type 3 | | 3 | 5 | 2 | |
| Type 4 | | | 1 | | |

### Canister Characterization

The gamma spectroscopy measurements confirmed the type and relative abundance of the gamma emitting isotopes in the canisters. Process knowledge (including ORIGEN models) allowed scaling factors to be established for the pure beta and low-energy gamma emitting isotopes in the activated metal waste. The isotopic distribution and dose rate profile information were used as input for MicroShield© models to correlate the measured dose rate with the projected isotopic content.

The shielding models were designed around a “disk on edge” geometry where the disk thickness was dependent on the distance from the high range probe to adjust for angular contribution. An arbitrary total activity in the appropriate isotopic distribution (e.g., 1 TBq total of 30% Eu-152 and 70% Eu-154) was used in the models and iteratively increased until the projected dose rate from the model matched the measured dose rate from the canister dose rate profile. A summation of the radioactivity for each disk model resulted in a total activity for each canister. A final qualitative check of the model was performed by distributing the total canister activity evenly over the waste region and projecting a median dose rate. The median dose rate was compared to the dose rate profile in order to assess if the projected dose rate was reasonable given the actual measurements. In general, there was very good agreement for the canisters with bell-shaped dose rate profile distributions. The canisters with the highly-skewed dose rate profile distributions were evaluated by comparing the relative area under the two corresponding curves for agreement. Overall, the modeling generated reasonable values for the activity in the canisters.

## CANISTER OVERPACKING, SHIPMENT AND BURIAL AT THE NEVADA TEST SITE

The design of the canister overpack and burial vault as well as selection of the shipping cask was an iterative process. The key parameter tying the overpack, burial vault, and shipping cask together was the dose rate of the waste. As a starting position, an external dose rate goal for the overpack was determined with the BJC waste operations and radiation control program staff in Oak Ridge. After the upper handling limits were determined, BJC met with NTS staff to discuss the shipment of the overpacked waste with the proposed dose rates in a shielded Type B shipping cask. The proposed maximum overpack dose rates were:

- Top - 2 mSv/hr (i.e., 200 mrem/hr)
- Side - 0.2 Sv/hr (i.e., 20 rem/hr)
- Bottom - 5 mSv/hr (i.e., 500 mrem/hr)

BJC also proposed to provide NTS with shielded “burial vaults” to load the overpacks into upon arrival at NTS. The external dose rate goal for the burial vaults was “contact handled” (i.e., <2 mSv/hr or <200 mrem/hr). NTS agreed in concept with the approach provided that BJC would supply any necessary materials, equipment, or specific training (e.g., cask handling).

The disposal of the Sr-90 RTG source canisters may result in different dose rate goals than for the other canisters. Additional consideration for decay heat and higher packaging criteria for waste with greater than 750 PE-g may result in a significantly different external dose rate for the RTG source canisters.

## Shipping Cask Selection

Several Type B shipping casks were evaluated for use in shipping the canisters to NTS. There are several casks certified for the waste type and isotopic content of the waste in the canisters. However, an evaluation of the external dose rate for the cask accident scenario using the unshielded waste resulted in the elimination of several casks as shipping options and reduced the viability of shipping multiple canisters in one cask shipment. It was determined through shielding models that the worst case canisters would need in excess of 15 centimeters (6 inches) of lead-equivalent shielding on the cask to be compliant with the cask safety analysis documentation. Many of the canisters could be shipped with less than 10 centimeters (4 inches) of lead-equivalent shielding on the cask.

A key design parameter for the canister overpack was the shipping cask internal cavity dimensions and weight capacity. The cavity dimensions and weight capacity had to be large enough to accommodate the shielded overpack size and weight. To reach the external overpack dose rate goals, several inches of lead-equivalent shielding would need to be provided by the overpack. Shielding models were used to determine the maximum outer diameter and height of the overpack to reach the design dose rate goals. The result of the models indicated that, for any canister, a diameter of 53 centimeters (21 inches) and a height of 132 centimeters (52 inches) with lid-closure and lift features included would provide adequate space. For the highest dose rate canisters, the shielding requirements could require the overpack to weigh in excess of 2,900 kilograms (6,400 pounds). However, many of the moderate and lower dose rate canisters could be packaged in an overpack that weighs less than 2,000 kilograms (4,400 pounds).

Another constraint considered during the cask selection process was related to the locations where the cask loading and unloading would occur. The waste sites in both Oak Ridge and at NTS were outdoor field locations. Shipping casks that were designed for transport in a horizontal orientation, and then removed from the transport trailer and placed on a hard surface during loading or unloading, were deemed undesirable for this project. The better arrangement was to use top-loading shipping casks that would remain on the transport trailer during loading and unloading.

Finally, the project cost and schedule impacts associated with cask shipments was evaluated. A cost sensitivity assessment indicated that the number of cask shipments and daily rental cost for different types of shipping casks had a large influence on the overall project cost. When cask availability and onsite facility operations were considered, BJC determined that larger casks that could hold two canisters at a time were not as cost effective overall as less expensive smaller casks that could ship only one canister.

The result of the shipping cask selection process pointed toward the use of the ChemNuclear CNS 1-13G and CNS 1-13C for all the canisters except the Sr-90 RTG sources. Both casks have the same inner cavity diameter of 67 centimeters (26.5 inches) and height of 137 centimeters (54 inches). The cask handling procedures for both are similar but the CNS 1-13G has an additional overpack to secure. Both casks can be devoted to the Oak Ridge project for the duration of the shipments and the rental cost per time period was less than the costs for several other casks. The CNS 1-13G provides 15.7 centimeters (6.2 inches) of lead-equivalent shielding with the option to use a 5 centimeter (2 inch) thick shielded liner to provide additional shielding. The CNS 1-13G will be used to ship the higher dose rate canisters. The CNS 1-13C provides 14.5

centimeters (5.7 inches) of lead-equivalent shielding and a weight limitation of 2,268 kilograms (5,000 pounds). The CNS 1-13C will be used to ship the lower dose rate canisters.

BJC is evaluating the shipment of the two Sr-90 RTG source canisters in Type B spent nuclear fuel shipping casks. Supplemental safety analysis and Certificate of Compliance modification would be necessary to use the spent nuclear fuel shipping casks for shipment of the Sr-90 RTG sources. One cask being evaluated is the NLI-1 spent nuclear fuel cask. Since the NLI-1 cask certification will expire in 2008 without any opportunity of renewal by the NRC, BJC is considering the feasibility of purchasing the cask for a one-time shipment and disposal of the Sr-90 RTG sources at NTS. If the purchase and disposal of the NLI-1 or another spent nuclear fuel cask is not feasible, BJC will likely request an exception to the NTS safety basis requirements for a one-time shipment.

### Canister Overpack

The design of the canister overpack was optimized around the:

- CNS 1-13G and 1-13C inner cavity limitations,
- Dose rate goals,
- Dimensions for canister Types 1 though 4
- Ease of canister loading and closure to reduce exposure,
- Compatibility with the facility where the canisters are loaded into the overpacks, and
- Standardization of design to reduce fabrication cost and schedule, allow a standard design of the burial vault, and limit the amount of training and practice required for use in a remote-handled environment.

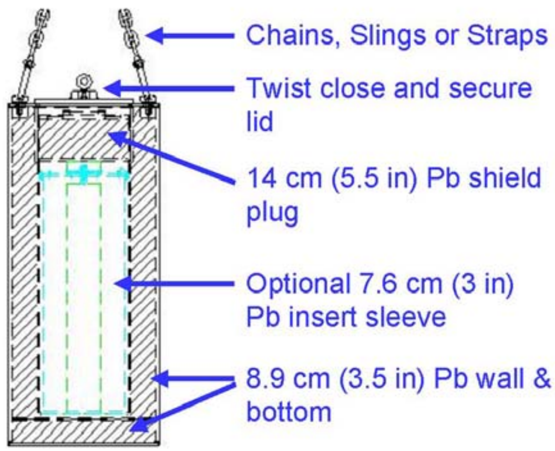


**Fig. 2. Canister Overpack**

After several iterations, a design was completed that met the overall goals (Figure2). The design accommodates all four canister types and includes an optional lead insert shield sleeve to add more shielding for the smaller diameter and higher dose rate canisters. The internal cavity of the overpack is 32 centimeters (12.5 inches) in diameter and 89 centimeters (35 inches) high. The design includes a 14 centimeter (5.5 inch) thick shield plug to reduce the dose rate from the top of the canister to less than 0.2 mSv/hr (200 mrem/hr) for most of the canisters. The lid is designed for quick closure and securing by twisting into place and tightening two captured acorn nuts. The lift attachments are two hoist rings that can be used for chains, slings, or straps. The net weight of the overpack without the shield sleeve is approximately 2,130 kilograms (4,700 pounds) and with the shield sleeve the weight is approximately 2,812 kilograms (6,200 pounds). The external diameter of the overpack is 53 centimeters (21 inches) and the height is 132 centimeters (52 inches). The estimated cost for the design and fabrication of 20 overpacks is $70,000.

**Burial Vault**

BJC has access to several 18 centimeter (7 inch) thick concrete vaults that will be modified by adding two concrete cavities to accommodate overpacks for burial at NTS (see Figures 3 and 4). The cavity diameter in the burial vault is 61 centimeters (24 inches). The burial vaults are constructed of reinforced concrete with lift points and fork tine channels. As modified, the burial vault will weigh over 13,600 kilograms (15 tons). The external dimensions of the shield boxes are 1.85 meters (73 inches) high, 1.7 meters (67 inches) deep, and 2.4 meters (94 inches) long.

The burial vaults will provide a minimum of 40 centimeters (16 inches) of concrete shielding between the overpack and the external sides of the burial vault. The bottom and top of the burial vault will provide 18 centimeters (7 inches) of concrete shielding. When loaded with the overpacks, NTS will be able to move the burial vaults with the same controls they would use for any contact-handled waste stream. BJC will provide 10 burial vaults to NTS for the Oak Ridge legacy canister waste. The estimated cost for the design and fabrication of 10 burial vaults is $45,000.

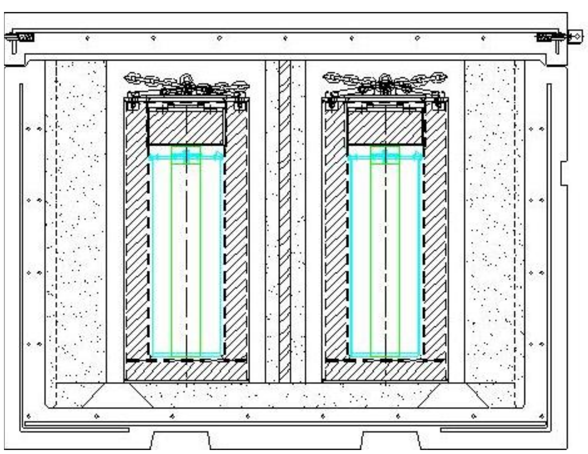

**Fig. 3. Burial Vault Diagram**

**Fig. 3. Photo of Burial Vault**

## OTHER REMOTE HANDLED WASTE

The disposal strategy proposed in this paper is being considered for other remote handled waste streams in Oak Ridge. Several hot cells at ORNL have debris and sources that exhibit high dose rates. At some point those materials will be packaged as waste. The waste could be packaged into steel cans with sizes up to the cavity of the overpack. After the waste is packaged into the cans, the cans would be loaded into the shield overpack inside the hot cell or remote-handled area. If the waste had very high dose rates, the waste could be packaged into smaller diameter cans and the shield insert sleeve could be used in the overpack. The waste could also be staged onsite in a burial vault if the waste was not ready for shipment directly to NTS (e.g., awaiting profile approval, characterization results, etc.), or until the shipping cask arrived.

Transportation safety analysis work is being planned to use the burial vault and overpack combination as an onsite transport package. BJC plans to repackage other stored waste that is not currently in approved shipping containers into steel cans that are compatible with the overpack design. After the steel cans are filled, the cans will be loaded into the overpacks and then the burial vault. The loaded burial vault will be transported onsite to a waste storage location and stage for future shipment to NTS.

## CONCLUSION

The remote handled LLW work being pioneered by BJC and Bechtel Nevada will result in an approved strategy for disposal of high dose rate LLW at NTS. The packaging, shipment, and disposal strategy is simple and flexible. Continued use of this strategy is anticipated for much of the high dose rate waste from Oak Ridge. Other DOE sites that need to dispose of LLW with high dose rates at NTS are invited to obtain information from DOE-ORO on the equipment and process being used.

**FOOTNOTES**

[a] This work is being performed by Bechtel Jacobs Company LLC under Contract DE-AC05-98OR22700 with the United States Department of Energy.

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