

TRANSPORT AND DISPOSAL OF TRITIUM-PRODUCING BURNABLE ABSORBER RODS AT THE TRITIUM EXTRACTION FACILITY

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ABSTRACT

As a part of the Department of Energy Tritium Readiness Program, the Tritium Extraction Facility (TEF) at the Savannah River Site (SRS) is preparing to receive the first shipment of irradiated Tritium Producing Burnable Absorber Rods (TPBARs) from the Tennessee Valley Authority's Watts Bar Nuclear Plant. Tritium will be extracted from the TPBARs at the TEF. The spent TPBARs will be transported and disposed on site using the TEF Waste Container, designed and fabricated by Packaging Technology, Inc. This paper describes the TPBAR waste form, the TEF Waste Container to be used to store the waste, the operational sequence associated with management of the TPBAR waste form and the disposal facility at the SRS.

INTRODUCTION

Tritium Producing Burnable Absorber Rods (TPBARs) will be irradiated in a pressurized water reactor (PWR) and subsequently shipped to the Tritium Extraction Facility (TEF) for processing. In order to allow workers to safely process the irradiated TPBARs, remote handling is being planned for the TEF. Prior to shipment from the PWR facility, the TPBARs will be removed from their control assemblies, and consolidated into groups of approximately 300 into a consolidation container to facilitate handling. These consolidation containers are shipped to SRS.

At the TEF, the consolidation canisters are placed into furnace extraction baskets for processing. The TPBARs remain in this configuration throughout subsequent processing and disposal using the Waste Container. The waste container is designed in accordance with specific performance requirements regarding the shielding and containment of the TPBAR waste form. The container has been analyzed for the postulated normal and accident conditions specified by WSRC. Four extraction baskets are loaded remotely into the waste container at the TEF. The container is then

closed using the series of inner bolted and outer welded lids prior to transport to the on-site disposal facility.

TPBAR WASTE FORM

As shown in Figure 1, the TPBARs are irradiated in a pressurized water reactor at TVA's nuclear power plant. The TPBARs contain Lithium aluminate pellets, and are contained within a reactor-grade stainless steel cladding. The TPBARs are 12 feet long and 3/8-inch in diameter. The components of the TPBAR are activated as a result of neutron capture during irradiation. Irradiated TPBARs will emit a photon spectrum of multiple energies from the radioactive decay of these activation products [Ref. 1]. The radioactive decay will generate significant decay heat in the TPBAR. The primary radiation source is the irradiated stainless steel cladding which has activated Cobalt 60.

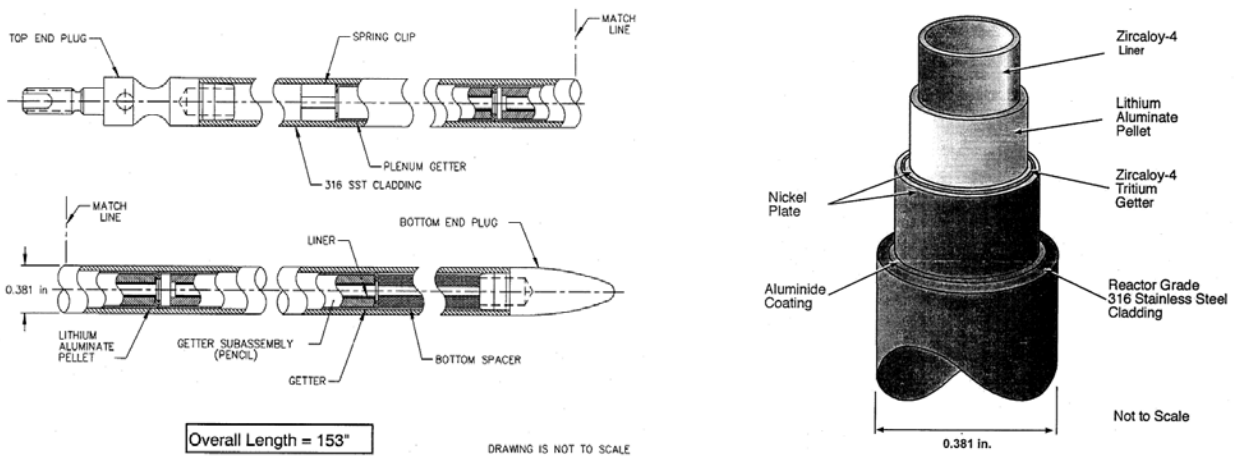


Fig. 1. TPBAR Assembly.

Prior to shipment, the irradiated TPBARs are removed from their control assemblies and consolidated into a container to facilitate handling. Up to 300 TPBARs are loaded into a consolidation container, depicted in Figure 2. The TPBARs remain in the consolidation container throughout the subsequent extraction process and is part of the waste disposal.

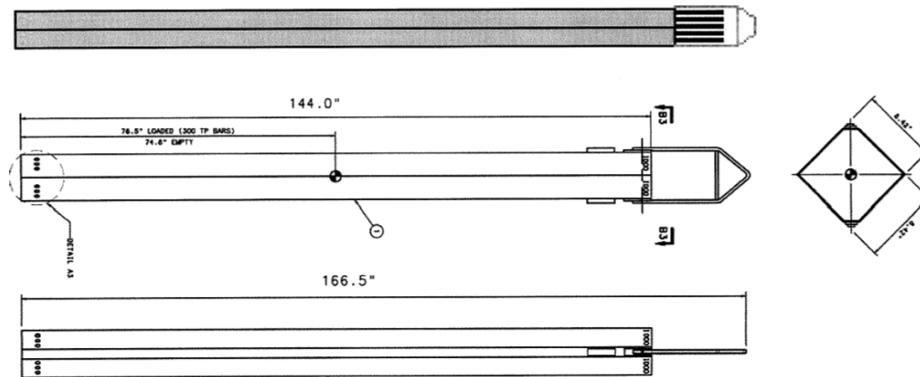


Fig. 2. Consolidation Container.

The consolidation container is delivered to the TEF and is off-loaded into a stainless steel extraction basket, shown in Figure 3. The extraction basket holds one consolidation container and is 16 feet tall and about 12 inches in diameter. During furnace extraction at the TEF, the extraction baskets become contaminated with radioactive constituents present in the TBP/AR and crud materials. After extraction, the TPBARs contain only residual amounts of tritium. Most of the other radionuclides in the extracted TPBARs will remain in the metal matrix.

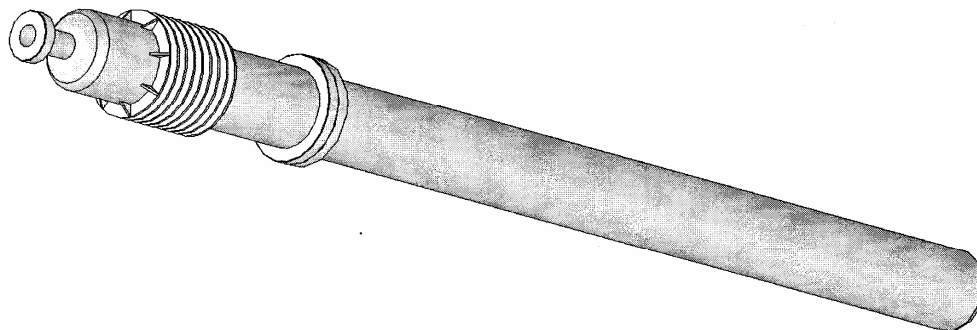


Fig. 3. Extraction Basket.

The extracted TPBARs are placed in the Way Station Module, located within the shielded storage area, where any off-gassing tritium is captured by the module stripper system. The Way Station Module has the capacity to hold six extraction baskets. When up to four extraction baskets have been processed through the TEF, the waste container will be loaded and shipped to the waste disposal facility.

Radionuclide Inventory

The radionuclide inventory contained in the TPBARs is documented in several sources. Radionuclide inventory data for an irradiated production TPBAR is contained in Reference 2. This data reflects the radionuclide inventory for the extracted TPBARs. For the purpose of calculating the non-tritium radionuclide content of the TEF waste container at the time of disposal all four TPBAR bundles are assumed to be decayed for 90 days from the time of irradiation. This assumption is quite conservative as this decay rate is based on the last TPBAR bundle being processed.

The tritium inventory was estimated separately from the other radionuclides, and is based on the assumptions from Reference 3. The tritium inventory for the TEF disposal container is calculated to be 159,600 Ci. This is based on 1200 extracted TPBARs having a tritium inventory of 133 Ci per TPBAR following an extraction. The total tritium gas available for release from the extracted TPBARs will not exceed 180,000 Ci, as documented in Reference 4. The total TPBAR radionuclide inventory, excluding tritium, is listed in Table I. This inventory represents the radionuclide content of the 1200 extracted TPBARs using the 90-day decay time for each rod.

Table I. TPBAR Radionuclide Inventory

Nuclide	Total Activity (CI)	Nuclide	Total Activity (CI)	Nuclide	Total Activity (CI)
Ar-37	8.78E+01	La-140	7.28E-06	Sc-47	5.83E-07
Ar-39	1.14E+01	Lu-177	1.88E-03	Se-75	6.59E+02
As-76	1.73E-20	Mn-54	4.18E+04	Sn-113	9.52E+02
Ba-131	3.37E-01	Mo-93	1.04E+00	Sn-117m	1.62E+02
Ba-133	8.78E-01	Mo-99	1.65E-05	Sn-119m	7.99E+03
Ba-133m	1.67E-17	Na-24	0	Sn-121	3.74E-21
Ba-135m	4.21E-22	Nb-92	1.27E+00	Sn-121m	6.62E-01
Br-82	01.42E-17	Nb-93m	5.84E-03	Sn-123	3.67E+02
C-14	1.70E+00	Nb-94	5.71E-01	Sn-125	6.76E+00
Ca-41	9.01E-02	Nb-95	5.34E+04	Sr-89	2.88E+01
Ca-45	2.64E+02	Nb-95m	2.38E+02	Ta-182	7.8E+03
Ca-47	5.83E-07	Nb-96	3.01E-26	Ta-183	3.85E-01
Cd-115	2.14E-12	Nb-97	0	Tc-99	5.23E-02
Cd-115m	6.06E-02	Nb-97m	0	Te-123m	2.24E+00
Co-58	1.43E+05	Ni-59	2.02E+02	Te-125m	4.30E+02
Co-60	4.19E+04	Ni-63	2.74E+04	W-181	4.39E+00
Cr-51	1.45E+05	Ni-66	1.91E-12	W-185	1.16E+02
Cs-131	1.40E+00	Os-191	1.39E-03	W-187	2.62E-24
Cu-64	0	P-32	2.21E+01	W-188	8.66E+00
Cu-66	1.91E-12	Re-186	9.24E-06	Y-89m	1.49E-08
Fe-55	2.44E+05	Re-188	8.75E+00	Y-90	1.66E-03
Fe-59	6.62E+03	Ru-103	8.89E-01	Y-91	8.63E+01
Hf-175	1.72E+01	S-35	8.58E+00	Zn-65	3.91E+00
Hf-181	2.72E+02	Sb-122	7.34E-08	Zr-89	1.50E-08
In-113m	9.53E+02	Sb-124	8.59E+00	Zr-93	1.36E-01
In-114	4.73E+01	Sb-125	1.9E+03	Zr-95	3.20E+04
In-114m	4.94E+01	Sb-126	6.54E-01	Zr-97	0
K-42	9.97E-09	Sc-46	4.96E+00		

The TPBAR gamma source term is for a 90-day decay time and is provided in Table II. TPBARs do not have a neutron source. As documented in Reference 5, the total gamma source term for 1200 TPBARs is 1.78×10^{16} γ/s .

Table II. Gamma Source Term per TPBAR

Energy (MeV)	γ/s
0.01	2.27E+12
0.025	2.36E+11
0.0375	6.23E+10
0.0575	2.87E+11
0.085	5.64E+10
0.125	8.68E+10
0.225	1.18E+11
0.375	4.18E+11
0.575	1.13E+12
0.85	7.37E+12
1.25	2.79E+12
1.75	2.06E+10
2.25	3.06E+07
2.75	5.15E+04
3.50	6.50E-02
5.00	6.76E-09
7.00	4.38E-10
9.50	2.77E-11
Total	1.48E+13

WASTE CONTAINER

The TEF Waste Container is required to support the mission of the Tritium Extraction Facility project. The container will be used to transport and permanently store the TPBARs inside the consolidation containers and furnace extraction baskets. The container is designed to meet SRS specifications that provide for safe handling, loading, unloading, and transport of extracted TPBARs as a non-equivalent package. The primary function of the container is to provide shielding and containment of the TPBAR contents. The design of the waste container has been optimized for handling at the TEF, with shielding thicknesses and design features optimized to meet ALARA goals.

General Performance Requirements

Design criteria for the waste container were established by WSRC in Reference 4. These criteria were established to ensure that the appropriate safety requirements for use at the site are met, while maximizing operational flexibility. A summary of pertinent criteria are as follows:

- Maximum dose rate of 200 mrem/hour (2 mSv/hour) at any point on the external surface
- Maximum dose rate of 10 mrem/hour (0.1 mSv/hour) at one meter from external surface
- Maximum dose rate of 2 mrem/hour in any normally occupied motor vehicle position
- Maximum dose limit of 60 mrem to an individual during one waste transfer operation
- Maximum surface temperature of 122°F (50°C) in shaded 100°F (38°C) ambient air

- No lead or Teflon based materials
- No external impact limiting devices
- Normal Conditions of Transport (NCT) performance requirements per 10 CFR 71
- Hypothetical Accident Conditions (HAC) performance requirements:
 - 10-foot free drop of the container onto a flat, horizontal concrete surface
 - 6-inch (15.24 cm) free drop of the container onto a 6-inch diameter bar
 - Exposure to a 30-minute, fully engulfing fire at a temperature of 600°F (316°C)
- Leak rate criteria from 10 CFR 71 for normal and accident conditions

Container Description

The purpose of the TEF Waste Container is to provide shielding and containment of the TPBAR contents throughout the loading, transport, and disposal operations at the site. The container is constructed of solid steel with a removable top closure. The container bottom and sidewalls have 13 inches (33 cm) of steel shielding. The top has 12 inches (30.5 cm) of steel shielding and is secured to the Container body with threaded fasteners. An elastomeric seal provides the interim sealing of the contents after loading operations. A final closure plate is seal welded to the container to meet the leak rate requirements for NCT and during permanent disposal. The total weight of the Container is approximately 75 tons (68,200 kg), with payload. The waste container configuration is shown in Figure 4.

The container body is constructed of normalized carbon steel (SA516 Grade 70, Fine Grain Practice), to meet the low temperature (brittle fracture) resistance criteria. Recognizing that the container is single use, carbon steel versus stainless steel versus composite using concrete for shielding was investigated. Full penetration welds on all containment boundary joints provide the required structural integrity. The inner lid is a bolt on design, typical to this type of container, which uses 28, 1-inch (2.54 cm) bolts, while the outer lid is attached via a seal weld that provides the long-term containment of the contents within the container. The exterior is coated with a two component, high solids, polyamine epoxy formulated to provide a tough, glossy, smooth, decontaminable surface to facilitate decontamination per 10 CFR 835.1002.

The trunnion lifting devices are designed in accordance with the requirements of ANSI N14.6. In addition to lifting, the lower set of trunnions is used to secure the container to the trailer and for rotating the container into the vertical at TEF.

The following sections detail the analytical evaluation of the TEF Waste Container performed to demonstrate compliance with the WSRC performance criteria. All evaluations were made by analysis; no physical testing was performed on the container.

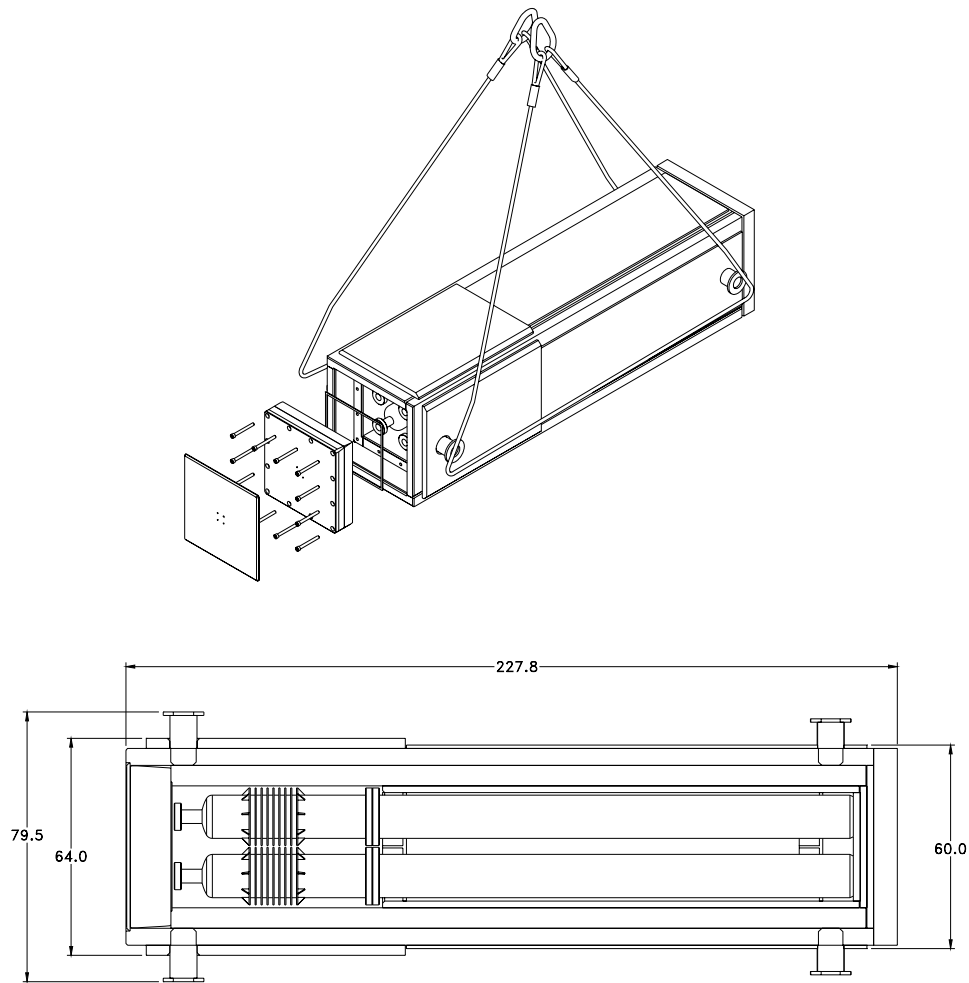


Fig. 4. TEF Waste Container.

Structural Performance

The TEF Waste Container has been evaluated for the specified NCT and HAC load conditions using hand calculations and the ANSYS finite element computer code for drop impact analyses. Both the NCT and HAC drops onto the specified concrete surface present a structural challenge for a design without impact limiters. The simple and robust design of the container allows these loads to be safely mitigated without the added operations required to install and remove an impact limiter. Impact loads were conservatively estimated by use of similitude with another heavy cask impact analysis. These impacts were applied quasi-statically to the finite element model, which calculated the stress in the members and welds of the container. The level of detail used in the finite element model allowed accurate representation of the contact conditions between the plates and slabs used to make the container. In the lid-down end drop, the lid conservatively received no support from the ground.

Allowable stresses were taken from Section III, Subsection NC of the ASME Code. All of the resulting stresses from NCT and HAC were less than the allowables. Twenty-five structural welds were evaluated in the analysis. Due to the massive nature of the container sidewalls, the 40-inch puncture drop does not result in significant stress. Therefore, the containment of radioactive materials under NCT and HAC is assured.

Thermal Performance

The waste container is analyzed for normal and accident conditions using the Sinda computer code. The thermal model of the TEF Container package represents a half-symmetry model of the package, with a symmetry planes along the package's long axis. This level of modeling is adequate to capture the temperature distributions within the package when in either the vertical or horizontal orientation. The normal conditions and initial temperatures for the hypothetical accident condition transient are calculated via a steady state analysis. These temperatures are used as input to the HAC fire transient. The thermal evaluations are performed using conservative analytical techniques to assure that all materials are maintained within their applicable minimum and maximum allowable temperature.

The steady-state thermal analysis results demonstrate that all of the components are within their respective allowable material temperatures under the evaluated normal conditions of on-site transfer and for the design decay heat loading. Additionally, the minimum material temperatures under the NCT cold condition with zero decay heat also comply with the material specifications. The analysis also demonstrates that the maximum accessible package surface temperature will be 122°F (50°C) or less when the package is in the shade and with a still air ambient temperature of 100°F (38°C), as stipulated by 10 CFR §71.43(g). A summary of temperatures calculated for NCT is listed in Table III.

Table III. Temperatures for Normal Conditions of On-Site Transfer

Component	Temperature (°F)			
	Normal Hot Transfer	Hot Transfer w/o Solar	Normal Cold Transfer	Maximum Allowable
TBAR Basket	260.8	235.9	161.3	2,700
Inner Slab	199.1	170.2	82.3	2,700
Middle Slab	175.1	142.6	47.7	2,700
Outer Slab	165.5	126.1	26.6	700 ²
Inner Lid	142.6	110.4	10.0	700 ²
Outer Lid	135.5	106.9	5.5	700 ²
Auxiliary Shielding	156.2	113.9	13.7	2,700
Outer Shielding	163.7	121.5	23.4	2,700
Inner Lid Bolts	143.2	111.1	10.8	1000
Neoprene Gasket	142.2	110.6	10.2	180
Bulk Avg. Fill Gas	198.9	171.4	85.2	N/A

The evaluation of the package performance under on-site fire accident conditions demonstrates that the TEF Container has sufficient thermal mass to limit the temperature rise in the package components to less than 250°F and result in essentially no change in the interior temperatures. All package components remain well within their associated maximum temperature limits for the fire event. Maximum temperatures for the HAC fire transient are listed in Table IV.

Table IV. Hypothetical Fire Accident Temperatures

Location	Temperature (°F)		
	Pre-fire Steady-state ¹	End Of 30 Minute Fire	Maximum Allowable
TBAR Basket	260.8	260.8	2,700
Inner Slab	199.1	199.1	2,700
Middle Slab	175.1	175.1	2,700
Outer Slab	165.5	320.0	700 ³
Inner Lid	142.6	157.3	700 ³
Outer Lid	135.5	375.4	700 ³
Auxiliary Shielding	156.2	334.0	2,700
Outer Shielding	163.7	391.4	2,700
Inner Lid Bolts	143.2	153.5	1000
Neoprene Gasket	142.2	143.3	180
Bulk Avg. Fill Gas	224.8	224.8	N/A

Shielding Performance

The performance specification for the TEF Waste Container establishes that the radiation level does not exceed 200 mrem/hr (2 mSv/hr) at any point on the external surface of the Waste Container and the radiation level at 1m does not exceed 10 mrem/hr (0.1 mSv/hr).

The procurement specification establishes that the HAC performance requirements applicable to the container are no escape of radioactive material exceeding a total amount of A₂ in 1 week, and no external radiation dose rate exceeding 1 rem/h (10 mSv/h) at 1m from the external surface of the package. The container design does not include deformable shielding or impact limiting materials. Consequently, the HAC dose rates will be similar to the NCT dose rates for the side and bottom of the container. If it is postulated that in an accident the TPBARs could slide upward to the very top of the container lid where there is less shielding, the dose rate 1 meter from the top of the lid will be 220 mrem/hr; well within the limit of 1000 mrem/hr. Dose rates calculated for the design basis source term are presented in Table V.

Table V. Maximum TEF Waste Container Dose Rates

Dose Rate Location	Dose Rate (mrem/hr)
Container Midplane Surface	13.0
1 meter from Container Midplane Surface	5.1
Upper End Surface (Radial Surface at Upper Trunnions)	0.3
Under Trailer at Support Legs (Radial Surface at Upper Trunnions at 1m)	0.3
Top Surface of Container Without Outer Lid in Vicinity of Bolts	9.6
Top Surface of Container in Vicinity of Bolts	3.5
1 foot from Top Surface of Container Without Outer Lid in Vicinity of Bolts	8.2
1 foot from Top Surface of Container in Vicinity of Bolts	2.9
1m from Top Surface	2.3
In Cab of Tractor (14 ft. from top surface of container)	0.3

ALARA Evaluation

An estimate of occupational exposures has been prepared using the dose rates calculated for the package along with the operational sequence for the TEF Waste Container. The total dose rate for each operation is the sum of the general area dose rate and the dose rate due to the waste container. In most cases the general area dose rate is assumed to be 0.05 mrem/hr, which is negligible compared to the dose rate from the container itself. The total dose for an operation is obtained by multiplying the number of workers by the dose rate and the time for the operation.

The total dose for the entire operation is conservatively estimated as 250 mrem. At a cost of \$4316 per person-rem (Reference 4), the total “cost” is \$1080. The target ALARA limit for each worker is 60 mrem. As the operation will result in a maximum worker dose of 38.5 mrem for operations/health physics personnel, this limit has been met.

OPERATIONAL SEQUENCE

Prior to loading the TEF Waste Container, the container is placed onto a trolley below the truck bay in the container decontamination area. The truck bay floor hatch shielding is put in place over the trolley, and the container is moved into containment. Transferring the Waste Container from the transportation trailer to the trolley requires five operators and will take approximately eight hours. Loading the Waste Container in the Remote Handling Area will take one operator approximately eight hours. After loading the furnace extraction baskets into the container in the remote handling area, the inner lid is remotely placed on the container, and the container is transported to the decontamination area outside containment. The container is then decontaminated as needed, the inner lids are bolted, and the outer lid is welded in place. Assembling the Waste Container requires five operators and will take approximately 30 hours to complete. The container is then placed on the heavy-haul trailer in the truck bay for transport to

the SRS Low Level Waste disposal site. Loading the Waste Container onto the Transportation trailer will require five operators and will take approximately eight hours. At the disposal site, the container will be placed into an Intermediate Level Vault (ILV) for disposal.

The Waste Container will be transferred from TEF to the E-Area Intermediate Level Vault for disposal. This on site transfer will be conducted in accordance with SRS procedures implementing the requirements of Department of Energy directives. The transfer is a total distance of 1.75 miles, and will not be in commerce. As such, the movement of the Waste Container is not required to meet DOT regulatory requirements, and is designed to meet the performance requirements for an onsite non-equivalent shipping package.

DISPOSAL FACILITY

The TEF Waste Container will be transported from the TEF to the Disposal Facility for permanent disposal. The ILV is a rectangular, sub-grade, concrete storage cell that will serve as the permanent disposal location for the loaded Waste Container. These vaults are 25 feet wide, 44.5 feet long, and 24.5 feet deep. All waste disposed at SRS is required to meet waste acceptance criteria established to ensure compliance with Federal and State regulations and agreements. The TEF Waste Container has been evaluated and shown to satisfy appropriate storage and disposal requirements.

Because the activity of the TPBARs exceeds the current performance assessment limits for the facility, a special analysis is required to allow for disposal of this waste stream at the ILV. This analysis has been completed by Savannah River National Laboratory, and accepted by the E-Area Facility Operations Committee. The extracted TPBAR waste has a potential for exceeding the Greater-Than-Class C classification for radioactive waste regulated by the Nuclear Regulatory Commission (NRC). Under NRC regulations (10 CFR 61), greater-than-class C wastes are not considered generally acceptable for near-surface disposal and thus may not be shipped to an NRC-regulated commercial site for disposal without a special petition and approval. DOE Order 435.1 does not recognize the NRC classification of Greater-Than-Class C. DOE G 435.1-1 (Table I-1.C) states that the USDOE equivalent to the NRC Greater-Than-Class C waste is to be managed as LLW.

At the ILV, requirements exist both for the physical plant, worker protection and disposal compliance. A summary of these requirements is as follows:

- The maximum, fully loaded weight limit for the waste container is 120 tons.
- The Waste Container and trailer are designed such that the container can be loaded into the ILV in a horizontal position. The hoisting and rigging design is designed such that loading the container into the ILV does not require personnel to enter the ILV.
- The exterior of the container shall be corrosion resistant.
- The Container must have less than detectable ($4E-5$ $\mu\text{Ci/cc}$) off-gassing tritium.
- The leak rate must be maintained during permanent disposal in the ILV for 125 years.

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