APPENDIX E DESCRIPTION AND REVIEW PROCEDURES FOR IRRADIATED TRITIUM-PRODUCING BURNABLE ABSORBER RODS PACKAGES

INTRODUCTION

This appendix is organized in the same manner as the chapters of this standard review plan (SRP) and pertains only to the review procedures (Section 4) of each chapter. The section numbering in this section corresponds to the pertinent section in the chapters of this SRP.

This appendix is intended to provide details on package-review guidance for the shipment of irradiated tritium-producing burnable absorber rods (TPBARs) and supplements the review procedures in the primary chapters of this SRP. Chapters of this SRP would normally be applicable to the review of any packaging used for the shipment of irradiated TPBARs. For purposes of this appendix, however, no specific packaging has been identified for the shipment of such contents. This appendix, therefore, should be considered to be a topical report, as opposed to a package-specific report.

During the irradiation process, TPBARs function in the reactor core like any other burnable poison rods, with the notable exception that TPBARs are designed to produce tritium. Thus, on the one hand, the primary purpose of this appendix is to provide guidance for the review of tritium transportation packages. On the other hand, because TPBARs function in the reactor core like any other burnable poison rods, the shipment of irradiated TPBARs can be expected to take on all the shielding considerations of a spent nuclear fuel (SNF) transportation package, without having to deal with any of the criticality concerns.

This appendix considers each of the chapters of the SRP and highlights the special considerations or attention needed for TPBARs. In sections where no significant differences exist, that particular section is omitted. Because it is already assumed that the shipment of irradiated TPBARs will be made in packages previously used for the shipment of SNF, there are many cross-references to individual chapter sections of this SRP.

1 General Information Evaluation

1.4 Review Procedures

This section considers each of the subsections of Section 1.4 (Review Procedures) of Chapter 1 and highlights the special considerations or attention needed for TPBAR transportation packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section.

See Chapter 1, Figure 1-1, of this SRP for the interrelationship between the review of the general information and the other chapter reviews.

1.4.2.3 Contents

TPBARs are similar in size and nuclear characteristics to standard, commercial pressurized-water reactor (PWR), stainless-steel-clad burnable absorber rods. The exterior of the TPBAR is a stainless-steel tube, approximately 386 centimeters [152 inches] from tip to tip at room temperature. The nominal outer diameter of the stainless-steel cladding is 0.381 inches. The internal components have been designed and selected to produce and retain tritium (PNNL, 2012).

Figure E.1-1 illustrates the concentric, cylindrical, internal components of a TPBAR. Within the stainless-steel cladding is a metal getter[1] tube that encircles a stack of annular, ceramic pellets of lithium aluminate ($LiAlO_2$). The pellets are enriched with the lithium-6 isotope. When irradiated in a PWR, the lithium-6 pellets absorb neutrons, simulating the nuclear characteristics of a burnable absorber rod, and produce tritium, a hydrogen isotope. The tritium chemically reacts with the metal getter, which captures the tritium as a metal hydride.

To meet design limitations on rod internal pressure and burnup of the lithium pellets, the amount of tritium production per TPBAR is limited to a maximum of 1.2 grams (at 9,619 curies (Ci) of tritium per gram—see Attachment A to this appendix) over the full design life of the rod (approximately 500 equivalent full-power days). The potential release rate of tritium into the reactor coolant is subject to a design limit of less than 1,000 Ci/1,000 TPBARs per year. This is achieved by the combined effects of the metal getter tube surrounding the lithium aluminate pellets and an aluminide barrier coating on the inner surface of the cladding.

TPBAR Components

TPBAR cladding is double-vacuum-melted, Type 316 stainless steel. To prevent hydrogen from diffusing inward from the coolant to the TPBAR getter and to prevent tritium from diffusing outward from the TPBAR to the reactor coolant, an aluminide coating is on the inner surface of the cladding. This coating barrier must remain effective during fabrication, handling, and in-reactor operations.

The annular ceramic pellets are composed of sintered, high-density, lithium aluminate.

[1] A colloquial term used in the tritium business, the term “getter” can be and is often used as a noun, an adjective, and a verb.

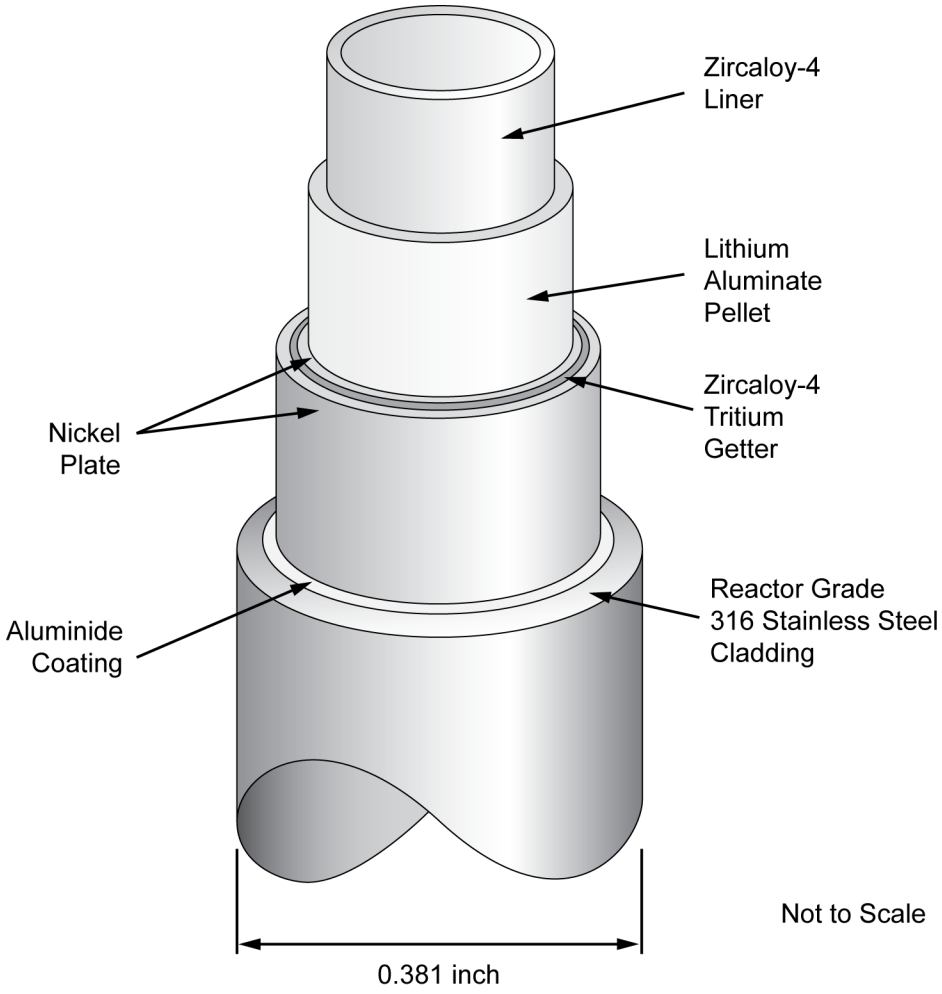

Figure E1-1 Isometric Section of a Tritium-Producing Burnable Absorber Rod

The metal getter tube located between the cladding and the lithium aluminate pellets is composed of nickel-plated Zircaloy-4. The getter absorbs the molecular tritium (T_2) generated during irradiation. Nickel plating is used on both sides of the getter to prevent oxidation of the Zircaloy-4 surfaces, which would reduce the tritium absorption rate. Consequently, this plating must remain effective during fabrication, handling, and in-reactor operations.

An unplated Zircaloy-4 tube lines the inside of the annular pellets. This component is called the "liner." Because some of the tritium produced in the pellets may be released as oxidized molecules (T_2O), the liner reduces these species to molecular tritium by reacting with the oxygen. The liner also provides mechanical support to prevent axial movement of pellet material in case any pellets crack during TPBAR handling or operation.

Axial Arrangement of the Components

Two TPBAR designs are described in this document: (i) the standard TPBAR design, in which the pellet column and getter tubes are segmented into sections called "pencils," and (ii) the full-length getter TPBAR design, in which the getter tube runs the full length of the TPBAR. An "interim option" for the full-length getter design facilitates use of existing pellet stacks and liners.

Standard TPBAR Design

The getter tube is cut and rolled over (coined) to capture the liner and pellets within an assembly called a “pencil.” A total of 11 pencil assemblies are stacked within the cladding tube of each TPBAR (see Figure E.1-2). The majority of the pencils are of standard length (approximately 12 inches). One or more of the pencils are of variable length.

To minimize the impact of power peaking in adjacent fuel rods resulting from the axial gaps between the stacked pencils, there is more than one type of TPBAR. The types are differentiated by where the variable-length pencil or pencils are loaded within the pencil stack. The loading sequence of the pencils is tracked, and each TPBAR is identified by type so that the location of each TPBAR type within a TPBAR assembly can be specified.

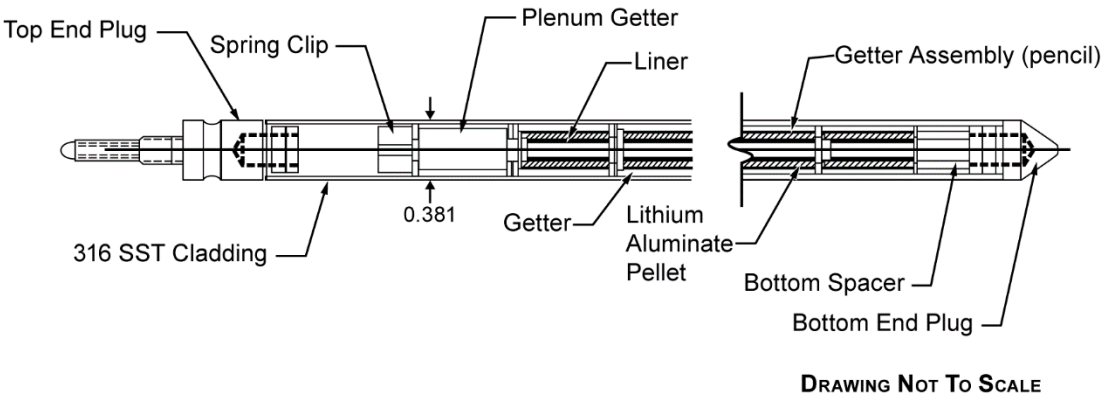

Figure E1-2 Axial Layout of TPBAR Internal Components—Standard Design

Full-Length Getter TPBAR Design

The axial arrangement of components is altered for the full-length getter TPBAR design. In this design, a single getter tube runs the full length of the TPBAR and surrounds both the pellet column and the upper and lower spacer tubes (see Figure E.1-3). The spacer tubes at the top and bottom of the pellet column are nickel-plated Zircaloy getters. The Zircaloy liner tubes and lithium aluminate pellet stacks in the full-length getter design are longer than in the standard design: typically, approximately 16 inches compared to approximately 12 inches in the standard design. However, for the interim full-length getter design option, the liner tubes and pellet stacks will be similar to (or made from) standard-design liner tubes and pellet stacks. That is, a combination of standard-length stacks (approximately 12 inches) and short-length stacks (approximately 9 inches) from the standard design will be used to make up the pellet column in the interim full-length getter design. The interim design option is employed solely for the purpose of utilizing existing inventories of components.

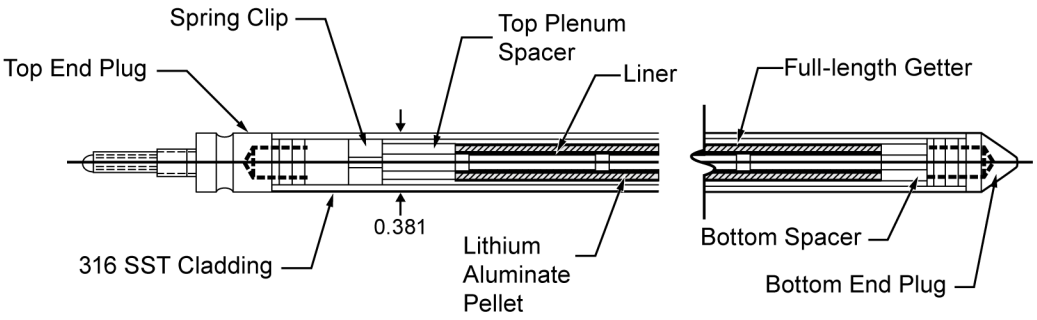

Figure E1-3 Axial Layout of TPBAR Internal Components—Full-Length Getter Design

The use of the full-length getter design eliminates the need for variable-length pencils and different TPBAR types to minimize the impact of power peaking in adjacent fuel rods resulting from axial gaps between pencils. The pellet column in the full-length getter TPBAR design is essentially continuous, and there is no power-peaking penalty from axial gaps in the absorber column.

Common TPBAR Design Features

For hermetic closure of the TPBARs, end plugs similar to those used in commercial PWR burnable absorber rods are welded to each end of the cladding tube. As is shown in Figure E.1-3 and Figure E.1-4, a gas plenum space is located above the top of the absorber column and below the top end plug. A spring clip in this plenum space holds the internals in place during pre-irradiation handling and shipping. Depending on the design, either a top plenum getter tube or a spacer tube is placed in the plenum space to getter additional tritium.

The length of the column of enriched lithium aluminate must be variable to provide optimal flexibility in reactor core design. Consequently, the column of enriched lithium aluminate pellets is approximately centered axially about the core mid-plane elevation but ranges in total length from about 126 to 132 inches. A thick-walled, nickel-plated, Zircaloy-4 spacer tube is placed between the bottom of the absorber column and the bottom end plug both to support the absorber column and to getter tritium.

A TPBAR assembly is shown in Figure E.1-4. It should be noted, however, that a typical design used in a 17×17 fuel assembly would be 24 TPBARs, rather than the eight illustrated in Figure E.1-4. Multiple fuel assembly designs can be accommodated by changes to the TPBAR lengths and end plugs.

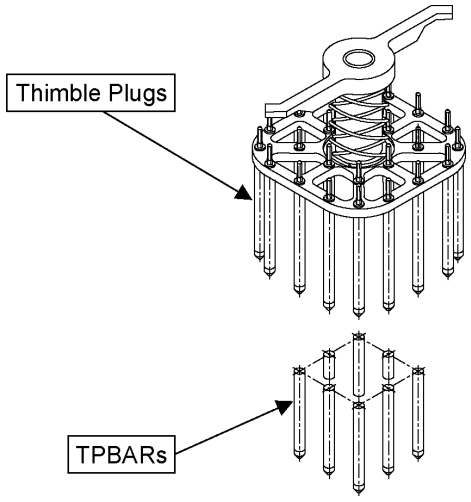

Figure E1-4 Typical TPBAR Assembly

After irradiation and removal from the reactor core, the individual TPBARs will be removed from their base plates and loaded into a consolidation canister for shipment. The consolidation canister, which is designed to hold up to 300 individual TPBARs in a closely packed formation, is then loaded into the transport package for shipment.

Under the current design, therefore, the maximum tritium contents for any given shipment becomes (300 TPBARs) × (1.2 grams of tritium/TPBAR) × (9,619 curies/gram of tritium) = 3.46×10^6 Ci, or about 3,200 A_2. Under these criteria, the package used for the shipment of irradiated TPBARs will be designated as a Category I package, in accordance with Regulatory Guide (RG) 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Case Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)."

Other radioactive contents that should be expected include activation products from the stainless-steel cladding. Although these can be expected to include a relatively large fraction of cobalt-60, the total activity contribution from cobalt-60 should be relatively small, compared to the tritium. The shielding requirements needed for the shipment of irradiated TPBARs, however, are based entirely on the activation products from the stainless steel and are not driven at all by the tritium.

No fissile material contents are associated with the shipment of irradiated TPBARs. There are, therefore, no criticality concerns.

1.6 References

Pacific Northwest National Laboratory (PNNL), Tritium Technology Program, "Description of the Tritium-Producing Burnable Absorber Rod for the Commercial Light Water Reactor," TTQP-1-015, Revision 19, February 12, 2012. (Note: The bulk of the material presented in the sections above was taken from this reference.)

Regulatory Guide 7.11, U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)," Agencywide Documents Access and Management System Accession No. ML003739413.

2 Structural Evaluation

2.4 Review Procedures

This section considers each of the subsections of Section 2.4 (Review Procedures) of this SRP and highlights the special considerations or attention needed for TPBAR transport packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section.

See Chapter 2, Figure 2-1, of this SRP for the interrelationship between the review of the structural evaluation and the other chapter reviews.

2.4.3 Lifting and Tie-Down Standards for All Packages

The lifting and tie-down devices of a TPBAR shipping package should not normally be exposed to tritium. Therefore, the evaluation of such devices should be no different for a TPBAR transport package than for other packages. However, if such devices are an integral part of the containment vessel, such as trunnions attached to the containment vessel, the reviewer should verify that the structural capacity of the trunnions will not be degraded by tritium that may have permeated through the containment vessel after multiple shipments.

2.4.5 Normal Conditions of Transport

The reviewer should verify that the structural, bolting, and seal components/materials of the packaging lid can uphold the safety performance of the package under normal conditions of transport, if the components have been exposed to and may be affected by contact with tritium.

As discussed in Section 4.4.1.1 of this appendix, elastomeric seals cannot be used for the containment of tritium. The containment seals of tritium packages are commonly made of metal O-rings or metal-to-metal, knife-edge seals. These types of seals typically require a greater compression than that needed for elastomeric seals. To provide the necessary compression, high-strength bolts are often used with a high preload. The high preload is also intended to prevent vibrational loosening of the bolted closure, which can occur during normal conditions of transport. Using a very high preload (sometimes as much as 90 percent of the proof load of the bolts) is a common practice for preventing vibrational loosening. However, because high-strength bolts are susceptible to embrittlement by tritium, the high preload may cause the bolts to fracture unexpectedly under cold conditions, if the bolts have been affected by tritium. Normally, the fracture of a single bolt should not result in the fracture of other bolts and a catastrophic failure of the containment closure. Thus, RG 7.11 and RG 7.12, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1 m) but Not Exceeding 12 Inches (0.3 m),” have not explicitly included the containment closure bolts as “fracture critical” components, whose fracture, once initiated, will continue and result in a catastrophic failure of the containment. Thus, closure bolts of most packages are exempt from the stringent fracture-toughness requirement specified in RG 7.11 and RG 7.12. However, in the case of tritium containment, with high-strength bolts and high bolt preloads, such an exemption may not be a prudent practice. Therefore, it is recommended that the fracture criteria of RG 7.11 and RG 7.12 also be used for the selection of closure bolts for TPBAR shipping packages. In addition, the bolt stress should be kept below the bolting stress limits of American Society of Mechanical Engineers

Boiler and Pressure Vessel Code (ASME B&PV Code), Section III, Subsection NB. Thus, methods other than using very high preload may be needed to prevent vibrational loosening.

As discussed in Section 7.4.3 of this appendix, the package designer is obligated to provide a reasonable and conservative estimate of the tritium environment to which each packaging component may be exposed, and a realistic assessment of the potential effects that the tritium environment can have on the properties and structural integrity of each component. As indicated in Table E.4-1 of this appendix, the amount of tritium released from damaged TPBARs can be several orders of magnitude greater than that from intact TPBARs, or from event-failed TPBARs. Thus, the tritium concentration within the containment boundary can increase significantly with an increasing number of damaged TPBARs. For normal conditions of transport, the condition that has the greatest potential to produce additional damage to the TPBARs is vibration. A vibration and fatigue evaluation of the TPBARs should be performed to determine if the natural frequencies of the TPBARs lie in the dominant frequency ranges of the transport vehicle floor. While there are no regulatory requirements that state that the contents must arrive at the destination site intact, it is important to note that the working lifetimes of the components exposed to tritium can be expected to be inversely proportional to the tritium levels to which the components are exposed.

2.4.6 Hypothetical Accident Conditions

The reviewer should verify that excessive damage of the irradiated TPBAR contents will not occur under hypothetical accident conditions, so that the safety performance of the package will not be catastrophically affected throughout the sequence of hypothetical accident condition tests.

As was noted above, the amount of tritium released from damaged TPBARs can be several orders of magnitude greater than that from intact TPBARs, or from event-failed TPBARs, and that the tritium concentration in the containment can increase significantly with an increasing number of damaged TPBARs. Under hypothetical accident conditions, the test requirement that can be expected to have the greatest potential to produce damage to the TPBARs is the 30-foot end-on drop. A buckling analysis of the TPBARs should, therefore, be performed for the 30-foot end-on drop. Under the large axial compression generated by the end-on drop, the long, slender TPBARs can buckle easily and rupture after suffering excessive deformation/strain after buckling. The buckling evaluation of TPBARs must employ realistic assumptions about the initial geometric imperfections, as well as the lateral and end constraints of the TPBARs. When the effects of geometric imperfections and constraints are properly included, it should be expected that inadequately supported TPBARs can buckle easily under relatively low impact *g* loads. The reviewer, therefore, should verify that the TPBARs will be properly supported throughout the entire sequence of hypothetical accident condition tests.

Again, as was noted above, there are no regulatory requirements that state that the contents must arrive at the destination site intact. In this case, however, the reviewer should be looking for the possibility of catastrophic failure of the containment vessel, or any of its major components, as a result of substantially increased levels of tritium into containment.

2.6 References

U.S. Nuclear Regulatory Commission, Regulatory Guide 7.11, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m),” June 1991a.

U.S. Nuclear Regulatory Commission, Regulatory Guide 7.12, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1 m) but Not Exceeding 12 Inches (0.3 m),” June 1991b.

3 Thermal Evaluation

3.4 Review Procedures

This section considers each of the subsections of Section 3.4 (Review Procedures) of this SRP and highlights the special considerations or attention needed for TPBAR transport packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section.

See Chapter 3, Figure 3-1, of this SRP for the interrelationship between the review of the thermal evaluation and the other chapter reviews.

3.4.1 Description of Thermal Design

3.4.1.3 Content Decay Heat

According to Table E3-1 (PNNL, 2004), the TPBAR heat load 30 days after removal from the reactor is estimated by the design agency to be 3.35 watts/TPBAR. Although the estimated value quickly drops to 2.31 watts/TPBAR at a 90-day time interval, for purposes of conservatism, the 30-day value should be used for all thermal analyses, throughout.

This is also consistent with the information presented in Section 2.10.6 of NRC 2002, which states the following:

> TVA [has] also evaluated the heat production from a fully loaded consolidation canister and its potential effect on the spent fuel racks. The potential heat generation within the consolidation canister is small enough that it can be safely stored in the existing fuel racks. An irradiated absorber rod will only produce about 3 watts of heat 30 days after reactor shutdown. This is equivalent to a maximum heat load of 900 watts/canister, assuming a fully loaded canister contains a maximum of 300 absorber rods. This heat load is small given that adequate circulation is provided through the open topped canister and through the drainage/cooling holes on the sides and bottom of the canisters. Therefore, the staff concludes that this configuration will provide adequate natural circulation.

Since the typical heat load for a SNF transport package is normally on the order of a few to several tens of kilowatts, the total heat load on a typical TPBAR transport package should be relatively small. In the case of a TPBAR transport package, however, the total heat load is not particularly important. What is more important is the equilibrium temperature of the consolidated bundle of TPBARS within the containment vessel, since temperature will be the primary driving force for the expected tritium losses from the TPBARs into containment.

Preliminary analyses suggest that the equilibrium temperature should be on the order of ~400 degrees Fahrenheit (°F) (see the related discussions in Sections 3.4.5.2, 4.4.3, and 7.4.3 below).

Table E3-1 Decay Heat in a TPBAR (Watts/TPBAR)

Nuclide	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
^{3}H[a]	3.90E-01	3.89E-01	3.85E-01	3.80E-01	3.69E-01	2.95E-01	2.23E-01
^{32}P	1.04E-02	3.42E-03	1.87E-04	2.38E-06	3.06E-10	5.86E-12	5.83E-12
^{51}Cr	2.07E-01	1.17E-01	2.60E-02	2.74E-03	2.66E-05	3.57E-21	5.10E-41
^{54}Mn	2.09E-01	1.98E-01	1.73E-01	1.42E-01	9.42E-02	3.69E-03	6.42E-05
^{55}Fe	7.28E-03	7.15E-03	6.85E-03	6.41E-03	5.60E-03	1.93E-03	5.08E-04
^{59}Fe	1.54E-01	1.08E-01	4.28E-02	1.07E-02	6.16E-04	1.04E-13	6.30E-26
^{58}Co	1.61E+00	1.29E+00	7.14E-01	2.96E-01	4.82E-02	2.94E-08	5.03E-16
^{60}Co	5.55E-01	5.50E-01	5.39E-01	5.21E-01	4.88E-01	2.88E-01	1.49E-01
^{63}Ni	2.30E-03	2.30E-03	2.30E-03	2.30E-03	2.29E-03	2.22E-03	2.14E-03
^{76}As	7.74E-03	3.76E-09	1.28E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{95}Zr	3.33E-01	2.60E-01	1.36E-01	5.11E-02	6.87E-03	9.18E-10	2.35E-18
^{95}Nb	3.32E-01	3.12E-01	2.13E-01	9.53E-02	1.41E-02	1.93E-09	4.93E-18
^{99}Mo	5.40E-02	1.64E-04	4.44E-11	6.24E-21	0.00E+00	0.00E+00	0.00E+00
^{117m}Sn	1.52E-02	4.88E-03	2.50E-04	2.91E-06	3.03E-10	0.00E+00	0.00E+00
^{119m}Sn	4.35E-03	4.08E-03	3.44E-03	2.67E-03	1.58E-03	2.53E-05	1.45E-07
^{125}Sn	1.46E-02	2.79E-03	3.73E-05	5.77E-08	9.47E-14	0.00E+00	0.00E+00
^{125}Sb	5.23E-03	5.20E-03	5.00E-03	4.70E-03	4.14E-03	1.52E-03	4.35E-04
^{182}Ta	9.55E-02	8.31E-02	5.79E-02	3.36E-02	1.10E-02	1.65E-06	3.42E-11
^{183}Ta	1.61E-01	7.08E-03	2.03E-06	9.91E-12	1.15E-22	0.00E+00	0.00E+00
Total	4.19E+00	3.35E+00	2.31E+00	1.55E+00	1.05E+00	5.92E-01	3.75E-01

[a] The ORIGEN2 values for H-3 are not reported. The values given for H-3 are based on a maximum of 1.2 g of tritium per TPBAR at discharge, as specified in Lopez 2003. There is 0.325 W per gram of tritium, and the half-life of tritium is 12.33 years. The value of 1.2 g at discharge is decayed appropriately for the various decay times. Source: PNNL, 2004.

3.4.5 Thermal Evaluation under Normal Conditions of Transport

3.4.5.2 Maximum Normal Operating Pressure

For TPBAR transport packages, the maximum normal operating pressure (MNOP) at the estimated temperature of about 400 °F should be in the range of 1 to 2 atmospheres, plus any additional pressure generated due to tritium in-leakage/permeation. It should be noted, however, that, based on the information presented in Section 4.4.3.1 below, tritium in-leakage/permeation is only expected to range between 7.6×10^{-6} and 5.2×10^{-3} moles of tritium per year, for intact TPBARs (see Table E.4-1). As such, the additional pressure generated due to tritium in-leakage/permeation would likely be a second-order correction.

The requirement that tritium (as hydrogen) makes up less than 5 percent of the gas for flammability regulations is also satisfied because, as is shown above, the contribution of tritium (as hydrogen) as a flammable gas can be expected to be small. In addition, it should also be noted that any tritium that escapes from intact TPBARs will be rapidly converted to tritiated

water vapor (HTO).[2] As tritiated water vapor, the available tritium (i.e., as HTO) is already oxidized and, therefore, is no longer flammable. As yet a third layer of conservatism, the reviewer should verify that, as part of the loading process, the package will be vacuum dried and backfilled with an inert gas, in accordance with the generic procedures outlined in the Pacific Northwest National Laboratory (PNNL) document, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel" (Knoll and Gilbert, 1987). This should be verified as part of the operating procedures review.

For those situations where the tritium released into containment might be substantially greater than that described above, such as the total failure of one (or more) TPBARs, with the loss of up to 100 percent of inventory per TPBAR, the reviewer should verify that the tritium concentration in any void volume of the containment will be less than 5 percent, by volume, over the standard shipping time of 1 year.

One additional factor that must be considered is a possible change in the thermal properties of the backfill gas. As a first approximation, it should be assumed that the thermal properties of tritium are virtually identical to those of hydrogen. Likewise, it should also be assumed that the thermal properties of HTO are virtually identical to those of normal water vapor (H_2O). As long as the tritium losses into containment are small, such as those described above (i.e., between 7.6×10^{-6} and 5.2×10^{-3} moles of tritium per year), changes to the thermal properties of the backfill gas would likely be negligible. As the estimated tritium losses into containment get larger, such as those described below in Section 4.4.3 (i.e., on the order of ~0.2 moles of tritium, or more), the reviewer should verify that the applicant has provided the appropriate calculations (1) using the assumption of 100 percent tritium (as hydrogen) gas and (2) using the assumption of 100 percent HTO. The worst-case situation can then be determined, and verified, by the reviewer.

3.4.6 Thermal Evaluation under Hypothetical Accident Conditions

3.4.6.3 Maximum Temperatures and Pressures

As an absolute, worst-case condition, the reviewer should assume that all TPBARs fail, with the loss of up to 100 percent of the total tritium inventory. This would be equivalent to a total loss of ~3.46×10^{6} Ci, or ~60 moles of tritium.

As a first approximation, the estimated temperature of the TPBARs and the surrounding gas should be about 400 °F.

As for possible changes to the thermal properties of the backfill gas, the reviewer should again verify that the applicant has provided the appropriate calculations (i) using the assumption of 100-percent tritium (as hydrogen) gas, and (ii) using the assumption of 100-percent HTO. The worst-case situation can then be determined, and verified, by the reviewer.

3.6 References

[2] Chemically, the term "HTO" is used to describe tritiated water vapor (see Attachment A to this appendix). While that may be more favorable from a transportation perspective, it is not nearly as favorable from a health and safety perspective because HTO is, by far, more hazardous than tritium gas (i.e., HT or T_2). (See Attachment B to this appendix.)

Knoll, R.W., and E.R. Gilbert, “Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel,” PNL-6365, Pacific Northwest National Laboratory, Richland, Washington, November 1987.

Lopez, A., Jr., 2003, “Production TPBAR Design Inputs for Watts Bar (U),” PNNL-TTQP-1-702, Rev. 9., Pacific Northwest National Laboratory, Richland, Washington.

Pacific Northwest National Laboratory (PNNL), Tritium Technology Program, “Unclassified Bounding Source Term, Radionuclide Concentrations, Decay Heat, and Dose Rates for the Production TPBAR,” TTQP-1-111, Revision 4, September 16, 2004.

U.S. Nuclear Regulatory Commission, “Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Amendment No. 40 to Facility Operating License No. NPF-90 Tennessee Valley Authority Watts Bar Nuclear Plant, Unit I Docket No. 50-390,” September 23, 2002. (See, in particular, Section 2.10.6.) Note: This particular document was included as Enclosure 2 of a letter from L.M. Padovan (NRC) to J.A. Scalice (TVA), September 23, 2002, Subject: Watts Bar Nuclear Plant, Unit 1-Issuance of Amendment to Irradiate up to 2,304 Tritium-Producing Burnable Absorber Rods in the Reactor Core (TAC NO. MB 1884), ADAMS Accession No. ML022540925.

4 Containment Evaluation

4.4 Review Procedures

This section considers each of the subsections of Section 4.4 (Review Procedures) of Chapter 4 of this SRP and highlights the special considerations or attention needed for TPBAR transport packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section.

See Chapter 4, Figure 4-1, of this SRP for the interrelationship between the review of the containment evaluation and the other chapter reviews.

4.4.1 Description of the Containment System

4.4.1.1 Containment Boundary

Materials of Construction

For high-purity tritium containment systems, high-pressure tritium containment systems, and systems where the internal surfaces will be exposed to such environments, 300-series stainless steels are preferred over virtually all other materials. It should also be noted that, for welded assemblies, it is advisable to use only the low-carbon grades (e.g., 304L, 316L) to reduce susceptibility to intergranular corrosion or intergranular-stress-corrosion cracking.

For the shipment of irradiated TPBARs, however, where the internal surfaces of the containment vessel are not expected to see high-purity or high-pressure-tritium environments, the use of other types of stainless steels is acceptable as long as (i) the material in question has the appropriate structural properties, (ii) the material in question is an accepted ASME B&PV Code, Section III material, and (iii) additional inspection requirements are imposed, as part of the maintenance program requirements, to guard against long-term problems such as

intergranular corrosion or intergranular-stress-corrosion cracking (see also the related discussions in Sections 7.4.3, below).

Welds

Special precautions should be taken to control and qualify weld materials, weld processes, welding procedures, and welders, as appropriate, for the material selected for the containment vessel body and lid. Additional precautions should also be taken to note that the appropriate followup procedures have been added to long-term maintenance requirements for the packaging, again, to guard against long-term problems such as intergranular corrosion or intergranular-stress-corrosion cracking. (See Table 2 of Monroe and Sears 1984 for a summary of welding criteria that is based on the requirements of the ASME Boiler and Pressure Vessel Code. See also Section 9.4.2.3, below.)

Seals

The generic rule of thumb for any tritium-handling system is that elastomeric seals[3] are not acceptable for use in any part of the containment boundary. This includes (i) the use of elastomeric seals between the containment vessel body and lid, (ii) the use of elastomeric seals for any valve stem tip/valve seat combinations that might be part of the containment boundary, such as vent- and drain-port valves, and (iii) the use of elastomeric seals between the containment vessel body and the vent- and drain-port covers, when the vent- and drain-port covers are part of the containment boundary. The primary reason for this general prohibition on the use of elastomeric seals can be traced, in part, to permeation issues and, in part, to the requirements of American National Standards Institute (ANSI) N14.5 (INMM, 2014):

> Permeation is the passage of a fluid through a solid barrier...by adsorption-diffusion-desorption processes. It should not be considered as leakage or a release unless the fluid itself is hazardous or radioactive. If this is the case, the container boundary must reduce the permeation to an acceptable level.

Since the permeation rate of tritium through most elastomers is about two orders of magnitude higher than that allowed by regulatory limits, the use of elastomeric seals cannot be allowed (see the additional information presented in Attachment A, Sections A.7 and A.8, to this appendix).

The use of elastomers and elastomeric seals is also discouraged for valve stem tip/valve seat combinations in those situations where the vent- and drain-port valves might become part of the containment boundary and in any situation where the surface of the elastomer might be wetted with tritium. In this case, however, the general prohibition stems from the chemical and physical properties of tritium, and from the tendency of tritium to form undesirable chemical byproducts, which can lead to the long-term degradation of the containment boundary (see Sections A.7 and A.8).

[3] For purposes of this document, the term “elastomeric seal” pertains equally to organic, elastomeric, halogenated hydrocarbon, thermoplastic resin, and thermosetting resin types of seals. See Attachment A to this appendix.

The preferred methods for sealing systems that are designed to contain tritium are through the use of all-welded construction. When the use of all-welded construction is not realistic, such as the containment boundary seal areas for transportation packages with bolted closures, the use of metal seals and/or metallic O-rings is recommended.

4.4.2 General Considerations

4.4.2.2 Type B Packages

Type B packages must satisfy the quantified release rates in Title 10 of the *Code of Federal Regulations* (10 CFR) 71.51, "Additional Requirements for Type B Packages." As noted in Regulatory Guide 7.4, "Leakage Tests on Packages for Shipment of Radioactive Material," an acceptable method for satisfying these requirements is provided in ANSI N14.5. Additional information for the determination of containment criteria is discussed below and in NUREG/CR-6487, "Containment Analysis for Type B Packages Used to Transport Various Contents," issued November 1996.

4.4.2.3 Combustible-Gas Generation

As is noted above in Section 3.4.5.2, the bulk of the gases released from irradiated TPBARs under normal conditions of transport will be released as HTO,[4] or tritiated water vapor. As tritiated water vapor, the available tritium (i.e., as HTO) is already oxidized and, therefore, is no longer flammable. An additional layer of conservatism is added, and the reviewer should verify that, as part of the loading process, the package will be vacuum dried and backfilled with an inert gas, in accordance with the generic procedures outlined in the PNNL document, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel" (Knoll and Gilbert, 1987). For normal conditions of transport, therefore, with no unexpected TPBAR failures (see below), there should be no possibility for the formation of a combustible-gas mixture inside the containment boundary.

For those situations where the tritium released into containment might be substantially greater than that described above, such as the total failure of one (or more) TPBARs, with the loss of up to 100 percent of inventory per TPBAR, the reviewer should verify that the tritium concentration in any void volume of the containment will be less than 5 percent, by volume, over the standard shipping time of 1 year.

Under hypothetical accident conditions, the situation can change, in that the tritium concentrations, as T_2 or HT, could be relatively high. In this case, however, a monitoring technique is discussed briefly in Section 8.4.1.2 of this appendix that can be used to determine the actual tritium concentration inside containment, which, on an as-needed basis, can also be used to determine potential flammability levels of the gases inside containment.

4.4.3 Containment under Normal Conditions of Transport

[4] Chemically, the term "HTO" is used to describe tritiated water vapor (see Attachment A to this appendix). While that may be more favorable from a transportation perspective, it is not nearly as favorable from a health and safety perspective, because HTO is, by far, more hazardous than tritium gas (i.e., HT or T_2) (see Attachment B to this appendix).

4.4.3.1 Type B Transportation Packages

Release calculations for a package intended for shipment of content containing tritium would be dependent on the source term associated with tritium and the dispersible radioactive solids that might be entrained with the tritium. Verify that the applicant's analysis justifies release fractions and source terms for both sources. The determination of the source term for the available radioactive solids may refer, with appropriate justification, to the information provided by PNNL, who is the design agency for TBPARs (PNNL, 2004a). Although a separate supporting document (PNNL, 2004b) provided some estimates for potential tritium release rates, as discussed below, there are a number of reasons why these estimates are not appropriate for containment release calculations. Unless release fractions and source terms can be justified, packages for shipment of tritium should be designed to meet the ANSI N14.5 definition of "leaktight." The adoption of the leaktight criterion eliminates the applicant's need to perform release calculations.

Information Related to Tritium Releases Described in PNNL 2004a, 2004b

References PNNL 2004a and PNNL 2004b provide some estimates for potential release rates associated with TPBARs; information presented in Table E.4-1 was adapted from PNNL 2004b. A review of these estimates suggests that it would be difficult, if not impossible, to determine an actual source term to be used for the determination of an allowable release rate for a package to be used for the shipment of TPBARs. A review of the information in the PNNL documents is worthwhile, however, because the estimates provided can be used to determine the condition of the TPBARs after they have been consolidated [5] and after they have been loaded into the containment vessel. (Note: The release estimates cited below in Table E.4-1 are the actual design criteria for both (i) the standard TPBAR design, and (ii) the full-length TPBAR design, respectively; see Section 1.4.2.3 of this appendix.)

TPBAR Containment System Design Criteria, Intact TPBARs

Under the broader heading of normal conditions of transport, the design agency's estimate of <0.05 millicuries per hour (mCi/hr) for 1,200 or fewer TPBARs (shown in the first column of Table E.4-1) is actually not appropriate for use as a source term for the releasable tritium, because the temperature estimates for the TPBARs in a consolidated bundle of up to 300 TPBARs should be more on the order of ~400 °F (see Section 3.4.1 of this appendix). This information points out an operational fact that there *will* be permeation losses from the TPBARs, under normal conditions of transport, and that these permeation losses *will* be going directly into containment.

The estimate provided by the design agency of <0.05 mCi/hr for the consolidated contents (i.e., up to 300 TPBARs) further equates to ~8.40 mCi/week and, for MNOP determination timeframes, ~437 mCi/yr, or ~7.6×10^{-6} moles of tritium gas per year. At the permeation rate cited in this case, all the tritium would rapidly be converted to HTO as soon as it is released, and combustible-gas generation issues will not be an issue (see Section 3.4.5.2, above, and Sections A.5 and A.6, below).

[5] Additional information on "consolidation" and the "pre-shipment "and "post-shipment" measurements is provided in Sections 8.4.1.2 and 8.4.1.3 of this appendix.

Table E4-1 Summary of Tritium Release Assumptions for Transportation Scenarios

Intact TPBARs (Normal Conditions of Transport)		Event-Failed TPBARs (Hypothetical Accident Conditions)		TPBARs Pre-Failed In-Reactor	
<200 °F	200 °F to 650 °F	Ambient to <200 °F	200 °F to 650 °F	Ambient to <200 °F	>200 °F
<0.05 mCi per hour for 1,200 or fewer TPBARs	<0.12 mCi per TPBAR per hour (based on average TPBAR in the core)	<0.1 Ci per TPBAR per hour, not to exceed 1% of the pellet tritium inventory	<55 Ci total per TPBAR	<0.1 Ci per TPBAR per hour	Up to 100% of inventory

Source: PNNL, 2004b.

The design agency's estimate of <0.12 millicuries per TPBAR per hour (mCi/(TPBAR-hr)) in the second column of Table E.4-1 is not really appropriate either, because it is a simple data-reduction value for the reactor in-core estimated permeation releases. The design agency has stated that, for intact TPBARs, "The in-reactor design tritium release rate for TPBARs is less than 1,000 Ci per 1,000 rods per year. The in-reactor design tritium release rate should be used on a core-averaged basis. This release rate should not be applied as a limit for individual TPBARs" (PNNL, 2004b). Additional supporting documentation added further clarification:

> The TPBARs were designed such that permeation through the cladding would be less than 1.0 Ci/TPBAR/year. For the production design, this value is reported as "less than 1000 Ci/1000 TPBAR/year." While the value of the permeation is not changed..., the new units of reporting emphasize that the release is based on the core average. Thus, while an individual TPBAR may release more than 1 Ci/year, the total release for 1,000 TPBARs will be less than 1,000 Ci/year. [WEC, 2001]

Although a value of <0.12 mCi/(TPBAR-hr) may not be useful as a source term for transportation purposes, it does serve a useful operational purpose, because, like the estimate provided for the first column of Table E.4-1, it does provide a second data point toward the determination of possible tritium permeation losses into containment.

As has already been noted, a value of <0.12 mCi/(TPBAR-hr) translates to ~20.2 mCi/(TPBAR·week) and, for MNOP purposes, to ~1 Ci/(TPBAR-yr). For consolidated shipments of up to 300 TPBARs, this further translates to ~300 curies per year (Ci/yr), or ~5.2×10^{-3} moles of tritium gas per year, going into containment. Again, at the permeation rate cited in this case, all the tritium would rapidly be converted to HTO—see Section 3.4.4.2 and Attachment A to this appendix—as soon as it was released, so combustible-gas generation should not be an issue.

TPBAR Containment System Design Criteria, TPBARs Pre-Failed In-Reactor[6]

For those situations where the tritium released into containment might be substantially greater than that described in either of the situations noted above, such as the total failure of one (or more) TPBARs, two different scenarios are listed in Table E.4-1 under the heading "TPBARs Pre-Failed In-Reactor": (i) where the temperature estimate is ambient to <200 °F, and (ii) where the temperature estimate is >200 °F. Both situations should be considered under the broader heading of normal conditions of transport. However, because the estimated equilibrium temperature of the TPBARs under normal conditions of transport is expected to be closer to 400 °F, the >200 °F scenario is both bounding, and more realistic, and the ambient to <200 °F scenario need not be considered any further.

Under the far-right column in Table E.4-1, the potential loss of up to 100 percent of the inventory per TPBAR represents an addition to the source term that should be used for estimating the total tritium losses into containment for normal conditions of transport. As a bounding value, this represents an additional loss of 1.2 grams, 11,543 Ci, or ~0.20 moles of tritium gas, per TPBAR, going into containment. Since the possibility that some of the losses may not be fully converted to HTO cannot be ruled out in this case, it should; therefore, be assumed that some of the losses from the TPBAR will be as T_2 and/or HT. The reviewer, therefore, should verify that the combustible-gas (i.e., the tritium) concentration in any void volume of the containment will be less than 5 percent, by volume, over the standard MNOP shipping time of 1 year. Such an assessment should include the possibility that one, or more, TPBARs might fail in this manner, for any given shipment.

4.4.4 Containment Under Hypothetical Accident Conditions

4.4.4.1 Type B Transportation Packages

For hypothetical accident conditions, verify that the applicant's containment criterion is based on being leaktight, as defined by ANSI N14.5, or is based on a bounding-release calculation, which would include the assumption of a total tritium loss, along with the assumption of the aerosol losses from the activation products. Review and verify that the applicant has justified all assumptions and calculations for the source term. Verify that the structural and thermal sections of the application show that there will be no unexpected deformation in the area around the containment seals as a result of the hypothetical accident condition testing requirements, and that the hypothetical accident condition temperature requirements will not compromise containment boundary seals.

TPBAR Containment System Design Criteria, Event-Failed TPBARs[7]

---

6 By definition, the term "pre-failed in-reactor" is intended to address the possibility of a TPBAR weld failure that occurs just before the TPBARs are unloaded from the reactor core. A normal conditions-of-transport situation, this scenario further assumes that the TPBAR in question becomes waterlogged prior to being consolidated with the other TPBARs, and prior to being loaded into the transport package. Between the chemical reactions that would be expected to occur between the water and the internal components of the TPBAR, and the expected increase in temperature, the TPBARs in question would be expected to lose up to 100 percent of their inventory (PNNL, 2004b).

7 By definition, the term "event-failed TPBARs" is intended to address the performance of the TPBARs subjected to the conditions during, and after, the hypothetical accident conditions.

Two different scenarios are listed in Table E.4-1 under the heading of "Event-Failed TPBARs": (i) where the temperature estimate is ambient to <200 °F, and (ii) where the temperature estimate is >200 °F. Both situations should be considered under the broader heading of hypothetical accident conditions. However, because the estimated equilibrium temperature of the TPBARs under hypothetical accident conditions is expected to be at least 400 °F, the >200 °F scenario is both bounding and more realistic, and the ambient to <200 °F scenario need not be considered any further.

The design agency's estimate of <55 Ci/TPBAR, in the second column under the heading of "Event-Failed TPBARs," leads to a total estimated loss of up to 16,500 Ci, or ~0.28 moles of tritium gas, going directly into containment, for consolidated shipments of up to 300 TPBARs.

To calculate the releasable source term for tritium under hypothetical accident conditions, therefore, three different tritium components would have to be considered: (i) the total amount of tritium that had previously been determined above, under normal conditions of transport (see Section 4.4.3.1, for intact TPBARs), (ii) the total amount of tritium that had previously been determined above, again, under normal conditions of transport (see Section 4.4.3.1, for the pre-failed in-reactor release scenario), and (iii) the total amount of tritium that has just been determined above for hypothetical accident conditions. Should an applicant choose to provide a release calculation rather than design and test the containment boundary to a leaktight criterion, the reviewer should verify that the releasable source term for tritium under hypothetical accident conditions includes all three components. As noted in Section 4.4.3.1, the values provided in Table E.4-1 may not be appropriate for determining the releases at normal conditions of transport.

4.4.5 Leakage Rate Tests for Type B Packages

The packaging used for the shipment of irradiated TPBARs is assumed to be an existing, modified, or newly designed spent fuel transportation package. Therefore, there would not be any fundamental difference from the requirements, and the methodology, used for the fabrication leakage tests for spent fuel packagings. The same cannot be said for packagings used for the shipment of irradiated TPBARs with respect to the maintenance, periodic, and pre-shipment leakage tests, because once a package has been used for the shipment of irradiated TPBARs, the internal surfaces of the package will have been contaminated with tritium. Thus, the procedures used for the maintenance, periodic, and pre-shipment leakage tests will have additional considerations because once the internal surfaces of the package have been contaminated with tritium, it can only be assumed that the internal surfaces will always be contaminated with tritium for the package's time in service. Additional precautions will, therefore, have to be built into the procedures used for the maintenance, periodic, and pre-shipment leakage tests. Further discussion of leakage tests of packages with tritium content is found in Sections 4.4.3.1 and 4.4.4.1 of this appendix, which mentions a leaktight acceptance criterion (as defined by ANSI-N14.5) and closed-loop measurements (described in Appendix E, Section 8.4.1.2). Likewise, for post-hypothetical accident conditions situations, should they become necessary, the closed-loop measurement technique described in Section 8.4.1.2 also becomes more important, as this is the only way to determine the amount of tritium "at risk," prior to opening the containment vessel.

4.6 References

Monroe, R.E., H.H. Woo, and R.G. Sears, Lawrence Livermore National Laboratory, "Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials," NUREG/CR-3019, U.S. Nuclear Regulatory Commission, March 1984.

Institute for Nuclear Materials Management (INMM), American National Standard for Radioactive Materials Leakage–Tests on Packages for Shipment, ANSI N14.5-2014, New York, NY, 2014.

U.S. Nuclear Regulatory Commission (NRC), "Containment Analysis for Type B Packages Used to Transport Various Contents," NUREG/CR-6487, U.S. Government Printing Office, Washington, DC, November 1996.

Knoll, R.W., and E.R. Gilbert, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel," PNL-6365, Pacific Northwest National Laboratory, Richland, Washington, November 1987.

Pacific Northwest National Laboratory, Tritium Technology Program, "Unclassified Bounding Source Term, Radionuclide Concentrations, Decay Heat, and Dose Rates for the Production TPBAR," TTQP-1-111, Revision 4, September 16, 2004a.

Pacific Northwest National Laboratory, Tritium Technology Program, "Unclassified TPBAR Releases, Including Tritium," TTQP-1-091, Revision 9, May 19, 2004b.

U.S. Nuclear Regulatory Commission, "Leakage Tests on Packages for Shipment of Radioactive Material," Regulatory Guide 7.4, Washington, DC.

Westinghouse Electric Company, LLC, "Implementation and Utilization of Tritium-Producing Burnable Absorber Rods (TPBARs) in Watts Bar Unit I," NDP-00-0344, Revision 1, July 2001. (See, in particular, Section 3.5, "TPBAR Performance.")

5 Shielding Review

5.4 Review Procedures

The shielding evaluation in Section 5.4 of Chapter 5 of this SRP applies to the review of any packaging used for the shipment of irradiated TPBARs. Because TPBARs function in the reactor core like any other burnable poison rods, the shipment of irradiated TPBARs can be expected to take on appropriate shielding considerations of irradiated nonfuel hardware in spent fuel transport packages, as described in Chapter 5 of this SRP.

This section considers each of the subsections of Section 4 (Review Procedures) and highlights special considerations or attention needed for irradiated TPBAR transportation packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section, and the review should be conducted using the procedures described in Chapter 5 of this SRP.

See Chapter 5, Figure 5-1, of this SRP for the interrelationship between the review of the shielding evaluation and the other chapter reviews.

5.4.2 Radioactive Materials and Source Terms

5.4.2.2 Gamma Sources

In general, the review of the gamma source for irradiated TPBARs should follow the guidance provided in Chapter 5 of this SRP. Similar to most other nonfuel hardware (e.g., reactor control components), the gamma source will consist entirely of photons from activated hardware. Because tritium is a low-energy beta emitter, tritium will not contribute to the gamma source term and radiation-exposure rates.[8]

Verify the applicant has determined the estimated maximum gamma source strength and spectrum by an appropriate method (e.g., standard computer codes or hand calculations). Since TPBARs are like other nonfuel hardware that is irradiated with fuel in a reactor core, the method will typically be a depletion code. Review the key parameters described in the application for the applicant's calculation method.

The gamma source term may be calculated using computer codes such as ORIGEN-S (RSICC, 2004).[9] As with any calculations using such codes, the reviewer should follow the guidance provided in Chapter 5 of this SRP to verify that the input parameters the applicant used in the analysis are applicable to the contents described in the application. As stated in Chapter 5, the input parameters to be reviewed include the following:

- types of reactor fuel used in irradiation, burnup and high burnup fuels, enrichment, and cooling time after irradiation

- initial composition and mass of the hardware of irradiated TPBARs, including impurities, such as cobalt-59, resulting in activation products, which are major contributors to dose rates

- spatial and energy variation of the neutron flux during irradiation of TPBARs

The design agency for the TPBARs (PNNL) performed unclassified bounding estimates of radionuclide concentrations and the photon source term for irradiated production TPBARs. Those estimates are reproduced below in Table E.5-1 (PNNL, 2004) and Table E.5-2 (NRC, 2002). According to PNNL 2004, these results bound the irradiation of production TPBARs in any anticipated host reactor. The calculations considered all components of the TPBARs and bound all TPBAR designs, including the full-length getter design. Note that the tritium concentrations in Table E.5-1 are not the results calculated by ORIGEN2 (RSICC, 2002),[10] but rather correspond to the functional requirement of 1.2 grams of tritium (maximum), per TPBAR, corrected for the specified decay times.

---

[8] For purposes of completeness, it should be noted that a continuous spectrum of bremsstrahlung radiation, up to the maximum tritium beta energy of 18.6 kilo electron volts (keV), will be produced as the beta particles are slowed down in the TPBARs. However, for spent fuel packages used for the shipment of TPBARs, only photons exceeding approximately 400 keV will contribute significantly to external radiation levels, so the bremsstrahlung radiation from tritium beta particles may be neglected.

[9] The discussion in Chapter 5 regarding use of codes that are the developer or vendor no longer support, such as ORIGEN 2, also applies to the review for TPBARs.

[10] As noted in a preceding footnote, for calculations in a TPBAR package application, the discussion in Chapter 5 regarding use of codes the developer or vendor no longer support, such as ORIGEN 2, applies.

Table E5-1 Maximum Radionuclide Concentrations in a TPBAR (Ci/TPBAR)							
Nuclide	**7 Days**	**30 Days**	**90 Days**	**180 Days**	**1 Year**	**5 Years**	**10 Years**
^{3}H	1.16E+04	1.15E+04	1.14E+04	1.13E+04	1.10E+04	8.76E+03	6.61E+03
^{14}C	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03
^{24}Na	1.98E-02	1.65E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{32}P	1.03E+00	3.38E-01	1.84E-02	2.35E-04	3.02E-08	5.78E-10	5.75E-10
^{35}S	1.37E-02	1.15E-02	7.15E-03	3.52E-03	8.18E-04	8.22E-09	4.65E-15
^{37}Ar	3.79E-01	2.40E-01	7.32E-02	1.23E-02	3.15E-04	8.74E-17	1.76E-32
^{39}Ar	9.49E-03	9.49E-03	9.48E-03	9.48E-03	9.46E-03	9.37E-03	9.25E-03
^{42}K	2.18E-04	8.34E-12	8.31E-12	8.27E-12	8.18E-12	7.52E-12	6.77E-12
^{41}Ca	7.51E-05	7.51E-05	7.51E-05	7.51E-05	7.51E-05	7.51E-05	7.51E-05
^{45}Ca	3.13E-01	2.84E-01	2.20E-01	1.50E-01	6.82E-02	1.37E-04	5.78E-08
^{47}Ca	1.57E-04	4.66E-06	4.86E-10	5.17E-16	2.62E-28	0.00E+00	0.00E+00
^{46}Sc	8.20E-03	6.78E-03	4.13E-03	1.96E-03	4.24E-04	2.39E-09	6.57E-16
^{47}Sc	5.68E-04	1.76E-05	1.86E-09	1.98E-15	1.00E-27	0.00E+00	0.00E+00
^{51}Cr	9.67E+02	5.44E+02	1.21E+02	1.28E+01	1.24E-01	1.66E-17	2.38E-37
^{54}Mn	4.19E+01	3.98E+01	3.48E+01	2.85E+01	1.89E+01	7.41E-01	1.29E-02
^{55}Fe	2.15E+02	2.12E+02	2.03E+02	1.90E+02	1.66E+02	5.71E+01	1.51E+01
^{59}Fe	1.98E+01	1.39E+01	5.52E+00	1.38E+00	7.96E-02	1.34E-11	8.14E-24
^{58}Co	2.69E+02	2.15E+02	1.19E+02	4.95E+01	8.06E+00	4.92E-06	8.41E-14
^{60}Co	3.60E+01	3.57E+01	3.49E+01	3.38E+01	3.16E+01	1.87E+01	9.68E+00
^{59}Ni	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01	1.68E-01
^{63}Ni	2.29E+01	2.29E+01	2.28E+01	2.28E+01	2.27E+01	2.20E+01	2.12E+01
^{66}Ni	1.52E-04	1.38E-07	1.59E-15	1.97E-27	0.00E+00	0.00E+00	0.00E+00
^{64}Cu	1.27E-03	1.04E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{66}Cu	1.52E-04	1.38E-07	1.59E-15	1.97E-27	0.00E+00	0.00E+00	0.00E+00
^{65}Zn	4.13E-03	3.87E-03	3.26E-03	2.52E-03	1.49E-03	2.34E-05	1.31E-07
^{76}As	8.74E-01	4.25E-07	1.44E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{75}Se	8.88E-01	7.77E-01	5.49E-01	3.26E-01	1.12E-01	2.38E-05	6.13E-10
^{82}Br	1.14E-03	2.25E-08	1.18E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{89}Sr	7.51E-02	5.48E-02	2.40E-02	6.99E-03	5.49E-04	1.07E-12	1.39E-23
^{89m}Y	5.48E-04	4.18E-06	1.24E-11	6.39E-20	0.00E+00	0.00E+00	0.00E+00
^{90}Y	5.14E-01	1.30E-03	1.38E-06	1.37E-06	1.36E-06	1.23E-06	1.09E-06
^{91}Y	1.92E-01	1.46E-01	7.19E-02	2.47E-02	2.76E-03	8.38E-11	3.36E-20
^{89}Zr	5.49E-04	4.18E-06	1.25E-11	6.40E-20	5.60E-37	0.00E+00	0.00E+00
^{93}Zr	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04	1.13E-04
^{95}Zr	6.57E+01	5.12E+01	2.67E+01	1.01E+01	1.36E+00	1.81E-07	4.63E-16
^{97}Zr	1.12E-01	1.65E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{92}Nb	3.04E-01	6.34E-02	1.06E-03	2.28E-06	7.41E-12	0.00E+00	0.00E+00
^{93m}Nb	3.68E-06	4.02E-06	4.87E-06	6.15E-06	8.73E-06	2.69E-05	4.49E-05
^{94}Nb	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04
^{95}Nb	6.93E+01	6.50E+01	4.45E+01	1.99E+01	2.94E+00	4.02E-07	1.03E-15
^{95m}Nb	4.80E-01	3.80E-01	1.98E-01	7.48E-02	1.01E-02	1.34E-09	3.44E-18
^{96}Nb	1.20E-03	9.19E-11	2.51E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{97}Nb	1.13E-01	1.78E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{97m}Nb	1.06E-01	1.57E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table E5-1 Maximum Radionuclide Concentrations in a TPBAR (Ci/TPBAR) (cont.)							
Nuclide	**7 Days**	**30 Days**	**90 Days**	**180 Days**	**1 Year**	**5 Years**	**10 Years**
^{93}Mo	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.04E-03	1.04E-03
^{99}Mo	1.68E+01	5.11E-02	1.38E-08	1.94E-18	0.00E+00	0.00E+00	0.00E+00
^{99}Tc	4.35E-05	4.36E-05	4.36E-05	4.36E-05	4.36E-05	4.36E-05	4.36E-05
^{103}Ru	3.21E-03	2.14E-03	7.41E-04	1.52E-04	5.76E-06	3.67E-17	3.71E-31
^{115}Cd	2.91E-04	2.27E-07	1.78E-15	1.23E-27	0.00E+00	0.00E+00	0.00E+00
^{115m}Cd	1.84E-04	1.28E-04	5.05E-05	1.25E-05	7.00E-07	9.62E-17	4.52E-29
^{113m}In	1.31E+00	1.14E+00	7.94E-01	4.62E-01	1.51E-01	2.28E-05	3.83E-10
^{114}In	1.26E-01	9.13E-02	3.94E-02	1.12E-02	8.36E-04	1.10E-12	8.64E-24
^{114m}In	1.32E-01	9.54E-02	4.12E-02	1.17E-02	8.73E-04	1.15E-12	9.03E-24
^{113}Sn	1.31E+00	1.14E+00	7.93E-01	4.61E-01	1.51E-01	2.28E-05	3.82E-10
^{117m}Sn	8.21E+00	2.63E+00	1.35E-01	1.57E-03	1.64E-07	0.00E+00	0.00E+00
^{119m}Sn	8.42E+00	7.89E+00	6.66E+00	5.16E+00	3.06E+00	4.90E-02	2.80E-04
^{121}Sn	7.39E-02	4.66E-08	3.12E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{121m}Sn	5.54E-04	5.53E-04	5.52E-04	5.50E-04	5.46E-04	5.17E-04	4.82E-04
^{123}Sn	4.78E-01	4.22E-01	3.06E-01	1.89E-01	6.99E-02	2.75E-05	1.52E-09
^{125}Sn	2.20E+00	4.21E-01	5.63E-03	8.71E-06	1.43E-11	0.00E+00	0.00E+00
^{122}Sb	1.10E-01	2.99E-04	6.12E-11	5.66E-21	0.00E+00	0.00E+00	0.00E+00
^{124}Sb	1.86E-02	1.43E-02	7.16E-03	2.54E-03	3.01E-04	1.49E-11	1.10E-20
^{125}Sb	1.67E+00	1.66E+00	1.60E+00	1.50E+00	1.32E+00	4.87E-01	1.39E-01
^{126}Sb	5.64E-02	1.56E-02	5.45E-04	3.55E-06	1.13E-10	0.00E+00	0.00E+00
^{123m}Te	3.02E-03	2.65E-03	1.87E-03	1.11E-03	3.80E-04	8.02E-08	2.05E-12
^{125m}Te	3.26E-01	3.40E-01	3.58E-01	3.56E-01	3.22E-01	1.19E-01	3.40E-02
^{131}Cs	5.10E-02	2.34E-02	1.17E-03	7.33E-06	1.50E-10	0.00E+00	0.00E+00
^{131}Ba	3.68E-02	9.53E-03	2.81E-04	1.43E-06	2.69E-11	0.00E+00	0.00E+00
^{133}Ba	7.43E-04	7.40E-04	7.32E-04	7.20E-04	6.97E-04	5.38E-04	3.90E-04
^{133m}Ba	3.65E-05	1.95E-09	1.39E-20	2.26E-37	0.00E+00	0.00E+00	0.00E+00
^{135m}Ba	2.77E-04	4.49E-10	3.51E-25	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{140}La	3.92E-04	1.86E-07	6.07E-09	4.62E-11	2.02E-15	0.00E+00	0.00E+00
^{177}Lu	2.13E-03	1.99E-04	1.57E-06	7.79E-07	3.40E-07	4.95E-10	1.40E-13
^{175}Hf	3.25E-02	2.59E-02	1.43E-02	5.86E-03	9.37E-04	4.88E-10	6.84E-18
^{181}Hf	8.82E-01	6.06E-01	2.27E-01	5.22E-02	2.52E-03	1.07E-13	1.15E-26
^{182}Ta	1.07E+01	9.33E+00	6.50E+00	3.78E+00	1.24E+00	1.85E-04	3.84E-09
^{183}Ta	2.54E+01	1.12E+00	3.21E-04	1.56E-09	1.82E-20	0.00E+00	0.00E+00
^{181}W	5.88E-03	5.16E-03	3.66E-03	2.19E-03	7.58E-04	1.78E-07	5.17E-12
^{185}W	2.09E-01	1.69E-01	9.69E-02	4.22E-02	7.64E-03	1.06E-08	5.09E-16
^{187}W	2.68E-02	2.99E-09	2.18E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{188}W	1.65E-02	1.31E-02	7.22E-03	2.94E-03	4.62E-04	2.12E-10	2.54E-18
^{186}Re	3.18E-02	4.66E-04	7.70E-09	5.16E-16	8.85E-31	0.00E+00	0.00E+00
^{188}Re	1.79E-02	1.33E-02	7.29E-03	2.97E-03	4.67E-04	2.15E-10	2.57E-18
^{191}Os	4.87E-05	1.73E-05	1.16E-06	2.03E-08	4.86E-12	0.00E+00	0.00E+00
Totals	1.34E+04	1.28E+04	1.21E+04	1.17E+04	1.12E+04	8.86E+03	6.66E+03

Source: PNNL, 2004.

Table E5-2 Maximum Photon Source Term in a TPBAR (Photons/(TPBAR·s))

Energy (MeV)	7 Days	30 Days	90 Days	180 Days	1 Year	5 Years	10 Years
1 .00E-02	7.73E+12	5.07E+12	2.33E+12	1.14E+12	6.01E+11	3.17E+11	2.28E+11
2.50E-02	6.71E+11	4.15E+11	2.59E+11	1.76E+11	1.03E+11	1.95E+10	7.02E+09
3.75E-02	1.80E+11	1.08E+11	6.65E+10	3.72E+10	1.85E+10	6.83E+09	2.84E+09
5.75E-02	5.80E+11	4.44E+11	2.90E+11	1.60E+11	5.27E+10	4.20E+09	2.15E+09
8.50E-02	1.52E+11	9.81E+10	5.86E+10	2.93E+10	9.11E+09	1.66E+09	8.49E+08
1.25E-01	2.24E+11	1.41E+11	8.80E+10	4.66E+10	1.45E+10	7.08E+08	3.45E+08
2.25E-01	4.52E+11	2.38E+11	1.20E+11	6.46E+10	2.15E+10	1.30E+09	4.20E+08
3.75E-01	3.06E+12	1.73E+12	4.10E+11	6.55E+10	1.94E+10	6.57E+09	1.90E+09
5.75E-01	2.75E+12	2.17E+12	1.21E+12	5.16E+11	1.02E+11	8.36E+09	2.39E+09
8.50E-01	1.56E+13	1.29E+13	7.83E+12	3.77E+12	1.11E+12	2.70E+10	5.28E+08
1.25E+00	3.05E+12	2.96E+12	2.81E+12	2.63E+12	2.38E+12	1.38E+12	7.16E+11
1.75E+00	5.01E+10	3.96E+10	2.20E+10	9.10E+09	1.48E+09	9.09E+02	5.52E+00
2.25E+00	2.12E+09	3.75E+08	3.27E+07	1.84E+07	1.30E+07	7.33E+06	3.80E+06
2.75E+00	7.48E+08	6.48E+04	5.30E+04	4.48E+04	3.88E+04	2.27E+04	1.18E+04
3.50E+00	5.05E+05	1.88E+00	6.13E-02	4.70E-04	3.16E-06	2.87E-06	2.58E-06
5.00E+00	5.21E+03	5.25E-08	6.64E-09	4.23E-09	1.67E-09	1.11E-12	1.93E-15
7.00E+00	6.37E-10	5.81E-10	4.31E-10	2.75E-10	1.09E-10	7.23E-14	1.25E-16
9.50E+00	4.03E-11	3.68E-11	2.72E-11	1.74E-11	6.87E-12	4.57E-15	7.93E-18
Totals	3.45E+13	2.63E+13	1.55E+13	8.65E+12	4.44E+12	1.78E+12	9.63E+11

Source: Adapted from NRC, 2002.

The photon source terms shown in Table E.5-2 above are given as functions of energy group and decay time (i.e., time since the end of irradiation). Earlier decay times correspond to larger photon source terms; therefore, the photon source term will be conservative if the decay time of the photon source term used in the shielding evaluation is less than the decay time of the TPBARs to be shipped. Because the decay time assumed in the shielding evaluation becomes a condition of approval in the certificate of compliance, the applicant should ensure that the assumed decay time accommodates their required shipping requirements.

According to the information presented in NRC 2002, a decay time of 30 days should be sufficiently conservative for the photon source term in the shielding evaluation, based on the following:

> About 30 days after the refueling is complete, plant operators would begin to remove the remaining irradiated TPBAR assemblies from the spent fuel assemblies, disassemble all of the irradiated TPBARs for consolidation, and place them into consolidation canisters. The time to start consolidating the TPBARs is not limited by any safety issues (e.g., decay heat), but rather is based on scheduling. The 30-day estimate corresponds to when the licensee expects to be finished with all outage-related activities, and can begin consolidation efforts.

5.4.2.3 Neutron Source

This section of the review guidance is not applicable for shipments of irradiated TPBARs, as the TPBARs do not contain fissile materials and do not produce neutrons.

5.4.4 Shielding Evaluation

There should be no significant differences in the methods used to calculate package dose rates or to evaluate the analyses from those methods described in Chapter 5 of this SRP. The one exception is that a minimum cooling time of 30 days should be imposed, in the certificate of compliance, on the shipment of irradiated TPBARs, as is noted in PNNL 2004 and NRC 2002, and the applicant's shielding analyses should use the source term for that cooling time.

5.6 References

Radiation Safety Information Computational Center (RSICC), "SCALE 5: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers," Code Package CCC-725, Oak Ridge National Laboratory, June 2004.

Radiation Safety Information Computational Center (RSICC), "ORIGEN2 V2.2: Isotope Generation and Depletion Code Matrix Exponential Method," Code Package CCC-371, Oak Ridge National Laboratory, June 2002.

Pacific Northwest National Laboratory, Tritium Technology Program, "Unclassified Bounding Source Term, Radionuclide Concentrations, Decay Heat, and Dose Rates for the Production of TPBAR," TTQP-1-111, Revision 4, September 16, 2004.

U.S. Nuclear Regulatory Commission, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Amendment No. 40 to Facility Operating License No. NPF-90 Tennessee Valley Authority Watts Bar Nuclear Plant, Unit 1 Docket No. 50-390," September 23, 2002. (See, in particular, Section 2.1.1.) Note: This document was included as Enclosure 2 of a letter from L.M. Padovan (NRC), to J.A. Scalice (TVA), dated September 23, 2002, Subject: Watts Bar Nuclear Plant, Unit I Issuance of Amendment to Irradiate up to 2,304 Tritium-Producing Burnable Absorber Rods in the Reactor Core (TAC NO. MB1884), ADAMS Accession No. ML022540925.

6 Criticality Review

6.4.2 Contents

No fissile material contents are associated with the shipment of irradiated TPBARs. There are, therefore, no criticality concerns.

7 Materials Evaluation

7.4 Review Procedures

This section considers each of the subsections of Section 7.4 (Review Procedures) of Chapter 7 of this SRP and highlights the special considerations or attention needed for TPBAR transportation packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section.

See Chapter 7, Figure 7-1, of this SRP for the interrelationship between the review of the materials evaluation and the other chapter reviews.

7.4.2 Weld Design and Inspection

The reviewer should verify that the effects of tritium, as hydrogen, and helium from the decay of tritium, on the fabrication procedures and examination requirements of the containment system have been appropriately considered, assuming that tritium will be released from the irradiated TPBARs.

Components or materials that have been previously exposed to tritium may need special repair procedures and/or post-repair examinations.

Special precautions should be taken to control and qualify weld materials, weld processes, weld procedures, and welders, as appropriate, for the materials selected for the containment body and lid. Additional precautions should also be taken to note that the appropriate followup procedures have been added to long-term maintenance requirements for the packaging, again, to guard against long-term problems such as intergranular corrosion or intergranular-stress-corrosion cracking. See Table 2 of Monroe and Sears 1984 for a summary of welding criteria that are based on the requirements of the ASME B&PV Code.

7.4.3 Mechanical Properties

Verify that the effects of tritium, as hydrogen and as helium from the decay of tritium,[1] on the mechanical properties of the structural, bolting, and seal materials have been appropriately taken into consideration, given the assumption that tritium will be released from the TPBARs (see below; see also Section 4.4.3).

For containment and other components or materials that may be exposed to tritium, the compatibility of the materials with tritium must be evaluated. Tritium can adversely affect the structural integrity of a material directly or indirectly through a third material. An example of a direct effect is the embrittlement (decrease of ductility or elongation, increase of yield strength) of a material by tritium dissolved or diffused into the material. High-strength steels are especially susceptible to this embrittlement effect. An example of indirect effect is described in Attachment A to this appendix. One experiment showed that tritium leached fluorides out of Teflon™ shavings, which subsequently caused stress-corrosion cracking of 316 stainless steel, at high pressures. It is also worth noting that such effects can be highly dependent on both temperature and pressure and are usually greater at higher temperatures and pressures. Temperature and pressure effects notwithstanding, however, it must also be noted that such effects can be exacerbated greatly in the presence of moisture.

Unfortunately, data concerning tritium effects on transport packages are rather limited. The package designer is, therefore, obligated to provide a reasonable and conservative estimate of the tritium environment to which each packaging component may be exposed and a realistic assessment of the potential effects that the tritium environment can have on the properties and structural integrity of each component. The materials reviewer can then determine the significance of the tritium effects to the safety performance of the package. Among all

[1] As tritium is an isotope of hydrogen, exposure to tritium can be expected to lead to potential hydrogen embrittlement problems for materials that would normally be susceptible to hydrogen embrittlement. The solubility of tritium, however, can also lead to a phenomenon known as “helium embrittlement,” a phenomenon that occurs when tritium finds its way into the material and decays to helium-3. The helium produced by decay gradually migrates to the grain boundaries of the material in question, leading to localized pressure buildups as a result of the growth of helium bubbles at the grain boundaries. From a materials perspective, therefore, “the effects of tritium, as hydrogen and as helium from the decay of tritium,” are referred to as two different phenomena, and both phenomena must be considered separately. (See also Section A.7 in Attachment A to this appendix.)

packaging components, those that reside inside, or in close proximity to, the containment boundary have a high risk of tritium effects. Therefore, the relation between the tritium contents and the materials of containment shells, welds, closure bolts, seals, etc., should be thoroughly investigated and understood.

For high-purity tritium containment systems, high-pressure tritium containment systems, and systems where the internal surfaces will be exposed to such environments, 300-series stainless steels are preferred over all other steels. It should also be noted that, for welded assemblies, it is advisable to use only the low-carbon grade (e.g., 304L, 316L) to reduce the potential for intergranular corrosion or intergranular-stress-corrosion cracking.

For the shipment of irradiated TPBARs, however, where the internal surfaces of the containment vessel are not expected to see high-purity or high-pressure tritium environments, the use of other types of stainless steel is acceptable, (i) as long as the material in question has the appropriate structural properties, (ii) as long as the material in question is an accepted ASME B&PV Code, Section III material, and (iii) as long as additional inspection requirements are imposed, as part of the maintenance program requirements, to guard against long-term problems, such as intergranular corrosion or intergranular-stress-corrosion cracking. Additional consideration could also be given to limiting the number of times any given package could be used for the shipment of TPBARs. At this point in time, however, no data exist to support such a requirement, and the only way to get these data is through the additional measurements described in Section 8.4.1.2, and the additional inspection requirements noted in Section 9.4.2.3 of this appendix. These additional inspection requirements will be needed for all containment components and materials that are reused for multiple TPBAR shipments.

While it may not be possible to predict the actual amount of tritium that may be released into the containment vessel for any given shipment, the information presented in Section 4.4.3 shows that the design criteria for intact TPBARs is <0.12 mCi/(TPBAR-hr), at temperatures between 200 °F and 650 °F. In addition, the information presented in Section 3.4.1.3 of this appendix shows that the equilibrium temperature for TPBARs during shipment should be about 400 °F. From this, it can be seen that, at a minimum, it should be expected that ~300 Ci of tritium will be released into the containment vessel on an annual basis, as a result of normal permeation losses from intact TPBARs. It should also be expected that some number (one or two) of TPBARs pre-failed in-reactor [2] could be included in each shipment, for an additional estimate of up to 11.5×10^3 Ci/TPBAR (see Section 4.4.3 of this appendix). At a minimum, therefore, it should be assumed that something on the order of 500 Ci of tritium will be released into the containment vessel, on an annual basis, for any given shipment. This does not include the additional assumption of the total failure of one or more TPBARs, with the loss of up to 100 percent of inventory per TPBAR. (See Table E.4-1 and Section 4.4.3.1 of this appendix, respectively.) Using an equilibrium temperature of 400 °F, the materials reviewer can begin to make an estimate of the potential effects that a tritium environment can have on the material properties and the structural integrity of each of the containment vessel components. Caution should be exercised, however, because, as was noted above, no actual data exist to support such a conclusion, and the only way to get the actual data is through the additional measurements described in Section 8.4.1.2 and the additional inspection requirements noted in Section 9.4.2.3.

[2] For a more complete description of TPBARs pre-failed in-reactor, see the discussion in Section 4.4.3.1.

Verify information concerning the accumulation of tritium effects on the materials. Previous exposures to tritium can also affect the repair quality of the affected component. It should be expected that repeated tritium exposures will change the weldability of steels and, thus, the quality of any weld repairs.

7.4.9 Content Reactions

An overview of a variety of reactions that tritium can have with various materials is provided in Attachment A to this appendix. All potential reactions, not limited to those affecting only structural properties, should be evaluated, and their possible effects on the safety performance of the package should be assessed. The reviewer should verify that these reactions with tritium, as hydrogen, and helium from the decay of tritium, and their effects on the structural, bolting, and seal materials have been appropriately considered.

The reviewer should also verify that the materials that constitute the TPBARs (e.g., lithium aluminate, Zircaloy-4) will not have any deleterious chemical, galvanic, or other reactions with the containment vessel materials if the TPBARs are damaged during transportation and storage periods. Because the transport package is to be loaded under water, and because vacuum-drying processes are to be used prior to shipment (see Section 8.4.1.2), the presence of moisture should be included in all such considerations.

7.4.10 Radiation Effects

The reviewer should verify that the damaging effects of radiation from the expected tritium releases from the TPBARs on the structural, bolting, and seal materials have been appropriately considered. Similar to other radioactive materials, tritium can cause degradation or disintegration of plastic materials through radiolysis reactions (see Attachment A to this appendix). However, because of its excellent ability to penetrate materials, tritium can be far more insidious than other radioactive materials. The common practice, as described in Section 4.4.1.1 and in Attachment A, of avoiding the use of elastomeric seals for tritium transport packages is a direct result of such considerations.

7.6 References

Monroe, R.E., H.H. Woo, and R.G. Sears, Lawrence Livermore National Laboratory, "Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials," NUREG/CR-3019, U.S. Nuclear Regulatory Commission, March 1984.

8 Operating Procedures Evaluation

8.4 Review Procedures

This section considers each of the subsections of Section 8.4 (Review Procedures) of Chapter 8 and highlights the special considerations or attention needed for TPBAR transportation packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section.

See Chapter 8, Figure 8-1, of this SRP for the interrelationship between the review of the operating procedures and the other chapter reviews.

8.4.1 Package Loading

The reviewer should verify that, prior to the start of any work with irradiated TPBARs, provisions are in place for the real-time monitoring of tritium in air. The reviewer should also verify that additional provisions are in place for the sampling of tritium in water, particularly the water in the spent fuel pool and the water in the package during the vacuum-drying process. The reviewer should then verify that provisions are in place for the followup sampling of tritium contamination levels in the vacuum pump oils that will become contaminated as part of the vacuum-drying processes used after loading. Finally, the reviewer should verify that provisions are in place for the measurement of basic tritium surface-contamination levels. (Note that most of these provisions will be very different from those normally encountered in typical reactor operations environments (see Attachment B to this appendix).

Also, because there is the very real possibility that workers could be exposed to tritium levels that are not normally associated with reactor work, the reviewer should verify that the operating procedures clearly state that all personnel involved with TPBAR loading operations will be on a tritium bioassay program, in accordance with Regulatory Guide 8.32, "Criteria for Establishing a Tritium Bioassay Program."

8.4.1.1 Preparation for Loading

The reviewer should verify that the special controls and precautions noted above are included (i.e., having appropriate tritium monitoring and sampling capabilities in place prior to beginning preparation for loading). The reviewer should also verify that additional procedures are in place to deal specifically with the determination of residual tritium outgassing and contamination in any package that has previously been used for TPBAR transport and that appropriate precautions are in place to notify the user that tritium releases are possible when opening an "empty" package and, possibly, during other package operations.

The reviewer should further verify that no elastomeric seals are used in any part of the containment boundary.[3]

8.4.1.2 Loading of Contents

The transport package for irradiated TPBARs will be loaded under water. Also, the package will be vacuum dried and backfilled with an inert gas, in accordance with the generic procedures outlined in the PNNL document, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel" (Knoll and Gilbert, 1987). However, because the procedures in that document do not address tritium-specific issues, the reviewer should verify that the appropriate tritium health physics considerations outlined below are included.

Contaminated Water Issues

It should be assumed from the outset that the water from the spent fuel pool and the cask-loading pit will be contaminated with tritium, possibly up to several tens of microcuries per milliliter (WEC, 2001). As such, there should be a cautionary note in the procedures stating, in effect, that contact with water from the spent-fuel pool and/or the cask-loading pit should be avoided to the maximum extent possible. Should a worker be splashed with water from either the spent-fuel pool or the cask-loading pit, the contaminated water should be washed off with

[3] For purposes of this document, the term "elastomeric seal" pertains equally to organic, elastomeric, halogenated hydrocarbon, thermoplastic resin, and/or thermosetting resin types of seals. See Section 4.4.1.1; see also Attachment A to this appendix.

clean water immediately. This will help minimize the potential dose to the worker (see Attachment B to this appendix).

It should also be noted that, because the water in the package will have come from the spent-fuel pool/cask-loading pit, the water in the package will also be tritium contaminated. However, it should not necessarily be expected that the contamination levels in the package water will be the same as that in the spent-fuel pool/cask-loading pit. The tritium contamination levels in the package will be dependent on the physical condition of the TPBARs (i.e., intact TPBARs vs. event-failed TPBARs) and the total permeation loss rate from the consolidated batch.[4] Since the volume of the water in the package is much smaller than the volume of water in the spent-fuel pool/cask-loading pit, the tritium contamination levels in the package water could easily be substantially higher than the tritium contamination levels in the spent-fuel pool/cask-loading pit. As a consequence, therefore, the same precautions that applied above with respect to splashing with water from the spent-fuel pool/cask-loading pit apply equally to the case of splashing with drainage water from the package (i.e., should a worker be splashed with package-drainage water, the contaminated water should be washed off with clean water immediately).

To better understand the potential hazards from splashing with water from the spent-fuel pool, the cask-loading pit, and/or the package-drainage water, it is recommended that samples be taken, early and often, throughout the package-draining process. Such samples can be analyzed, through the use of liquid-scintillation counting, to determine the relative hazard potential at any point in time.

Contaminated Vapor Issues

Once the bulk of the water has been removed from the package interior, the process of vacuum drying can begin. Here, too, additional precautions must be taken, because the exhaust gases and vapors from the vacuum-drying equipment will be tritium contaminated. As an immediate consequence, the procedures used must include provisions for the proper venting of the exhaust gases, so that they will not be vented directly into the room or into the breathing zone of the workers. As a followup consequence, it should also be noted that the pump oils used in the vacuum-drying system will also become contaminated with tritium, quite possibly up to several curies per liter. Since direct contact with the pump oil from the vacuum-drying system can represent an additional health physics hazard, contact with the vacuum pump oils and vapors should also be avoided.

Because the equipment used in the vacuum-drying process for irradiated TPBARs has the potential to be tritium contaminated, and because the tritium levels in some parts of the equipment can be expected to be relatively high, the equipment used for the vacuum-drying process for irradiated TPBARs should *not* be used for the vacuum drying of any other packages. Potential options should include decontamination of the equipment internals, changing of the vacuum pump oils to levels that indicate that the pump oils are no longer contaminated with tritium, and/or dedicated storage of such equipment for use only for shipments of irradiated TPBARs.

[4] See also the discussion above, on permeation loss rates, in Section 4.4.3.

Pre-Shipment TPBAR Outgassing Measurements

Once the internals of the package have been drained and dried and the package has been backfilled with an inert gas, an additional set of measurements should be made to determine the amount of tritium that might be "at risk" at any point in time during transport.[13, 5] (Note: If the applicant has shown by calculation that the containment criteria to be used are less than *leaktight,* this is also the only way to verify that the containment criteria defined in Section 4 of this appendix will not be exceeded for normal conditions of transport.)

Standard practices associated with tritium content suggest that no closed containers shall be opened without a preliminary determination of the airborne tritium levels that might be "at risk" (i.e., the amount of tritium that might be available to go into, or through, the worker's breathing zone(s) and/or the amount of tritium that might be available to be released directly to the environment). These types of measurements are typically performed with a closed-loop monitoring system that circulates air (or a preselected monitoring gas, such as dry nitrogen, helium, or argon) into and out of the enclosure in question, through a tritium monitor that has the capability of determining real-time tritium concentrations. Once the tritium concentration inside the containment vessel has been determined, the total amount of tritium "at risk" at any given time can be determined.

Once the amount of tritium "at risk" has been determined at the shipping facility prior to shipment, the receiving facility can be notified as to what they might expect upon receipt. Once the amount of tritium "at risk"" has been determined at the receiving facility, the receiving facility will be able to compare its measurements to those performed previously at the shipping facility. Armed with this kind of information, the receiving facility should have several options in place to deal with the situation, one of which should include the option of running the containment gases through a local cleanup system prior to opening the containment vessel. A second option that should also be considered is the sampling of the containment gases for the actual gas composition, and the subsequent determination of potential combustible-gas mixtures that might be encountered as part of the unloading process.

8.4.1.3 Preparation for Transport

For the most part, the procedures used for this portion of the operating procedures should be similar to those used for the shipment of any other radioactive material, including spent fuel. There are, however, a number of areas where the procedures used could be or should be quite different. Each is described below.

Pre-Shipment Radiation Surveys

For the shipment of irradiated TPBARs, the pre-shipment dose-rate measurement requirements should be virtually identical to the requirements for the shipment of other radioactive material. As was noted in Section 5.4.2.3, however, there should be no production of neutrons from irradiated TPBARs. The pre-shipment requirement for neutron-dose-rate measurements can, therefore, be eliminated for the shipment of irradiated TPBARs.

Pre-Shipment Surface Contamination Measurements

[5] See the additional discussion in Sections A.4, A.5, and A.6 in Attachment A to this appendix.

For the shipment of irradiated TPBARs, the pre-shipment surface contamination measurement requirements will have to be broken down into two distinct types: (i) routine surface contamination measurements for gross beta-gamma contamination, and (ii) routine surface contamination measurements for tritium "outgassing" (see Attachment A, Section A.6.3, to this appendix). Although the former type of measurement is routinely required for the shipment of most radioactive materials, including spent fuel, the phenomenon known as "outgassing" in the tritium business is equivalent to "cask-weeping" in the spent fuel business.

Pre-Shipment Leakage Tests

For the shipment of most radioactive materials, ANSI N14.5 specifies a pre-shipment leakage test criterion of a leakage rate that is either less than the reference air leakage rate or no detected leakage when tested to a sensitivity of 10^{-3} ref-cm^3/sec. It is not uncommon, however, when shipping tritium content to adopt a pre-shipment leakage test criterion of *leaktight,* as defined in ANSI N14.5 (see Section 4.4.3). Should an applicant choose to adopt the ANSI N14.5 *leaktight* criterion for the pre-shipment leakage test, it should be verified that the method(s) the applicant selected can be used to meet the leaktight 10^{-7} reference·cubic centimeters criterion.

Special Instructions

Under the broader heading of special instructions that should be provided to the consignee for opening the package, the following should be provided as part of the pre-shipment information:

(1) the pre-shipment results from the surface-contamination measurements for gross beta-gamma contamination

(2) the pre-shipment results from the surface-contamination measurements for tritium

(3) the tritium outgassing levels from the procedures described above in Section 8.4.1.2 of this appendix

8.4.2 Package Unloading

As was noted previously in Section 8.4.1 of this appendix, the reviewer should verify that monitoring and sampling provisions are in place for tritium in any of the forms that might be encountered (e.g., tritium in air, tritium in water, tritium in vacuum pump oils). Because the receiving facility will be the Tritium Extraction Facility, located at the U.S. Department of Energy's (DOE's) Savannah River Site, it is expected that the tritium-monitoring requirements described above will be in place, as specified. Also, because the Tritium Extraction Facility can be expected to operate along the same lines as any other DOE tritium facility, it is also expected that the personnel involved with the unloading operations will already be on a tritium bioassay program.

8.4.2.1 Receipt of Package from Carrier

The reviewer should verify that the standard radiation survey measurements are taken upon arrival of the package at the receiving facility. As noted previously, the TPBAR contents do not produce neutrons, so there should be no need for neutron measurements as part of the incoming survey.

For the surface-contamination measurements, however, the reviewer should verify that the procedures specify performance of *two* distinctly different types of surface-contamination measurements on the external surface of the package, the first being for gross, beta-gamma surface contamination, and the second being for surface contamination-measurements for tritium.

8.4.2.3 Removal of Contents

The reviewer should verify that, prior to the removal of the contents, there is a step in the procedures to determine the amount of tritium that might be "at risk," *before* the containment vessel is opened. The method should follow the techniques described above in Section 8.4.1.2, and, in this case, the user should be *required* to perform such a measurement, prior to the unloading of TPBARs. Given the variety of possibilities described above in Table E.4-1, and in Section 4.4.3, this is the only way that the actual amount of tritium "at risk" can be determined in a real-time, on-the-spot situation.

Once the amount of tritium "at risk" has been determined at the receiving facility, the receiving facility will be able to compare its measurements against those performed previously at the shipping facility. Armed with this kind of information, the receiving facility should have several options in place to deal with the situation, one of which, as was noted above, includes the option of running the containment gases through a local cleanup system, prior to opening the containment vessel. A second option that should also be available is the sampling of the containment gases for the actual gas composition, and the subsequent determination of potential combustible-gas mixtures that might be encountered as part of the unloading process.

8.4.3 Preparation of Empty Package for Transport/Storage

Whether the package is to be returned to the reactor, or whether the package is to be placed in storage, once it has been used for the transport of TPBARs, the internal surfaces of the containment vessel will have been contaminated with tritium. As a consequence, the package can no longer be considered as being *empty,* with respect to its tritium content. Therefore, before the *empty* package is moved to its next destination, the residual containment vessel gases will have to be sampled again, using the same basic measurement techniques described above in Section 8.4.1.2 of this appendix. The purpose of the measurement, in this case, however, is to establish a baseline value for the tritium outgassing rate from the internal surfaces of the containment vessel, from a supposedly *empty* package.

Similar measurements will have to be repeated again, prior to opening the package, at the next destination. The purpose of the measurements, in this case, however, is to determine the amount of tritium that might be "at risk" at the new receiving destination. If the amount of tritium that might be "at risk" is on the order of a few, to several tens, to several hundreds of curies, a receiving reactor site may have no objections to discharging that amount of tritium directly into its spent-fuel pool. If, on the other hand, the receiving site is a maintenance facility, where the package would be opened to room air, amounts of tritium on the order of a few, to several tens, to several hundreds of curies "at risk" discharged directly into the room air, and/or the breathing environment, would probably not be acceptable.

From a regulatory standpoint, it should also be noted that once a package has been used for the shipment of irradiated TPBARs, it can probably, never again, be shipped as an *empty* package. While the measurement techniques described above are sensitive enough to demonstrate that the amount of tritium "at risk" is well below an A_2 value for tritium

(i.e., 1,080 Ci), the internal surface contamination limits requirements specified in 49 CFR 173.428(d) now become the limiting factors.[6] (See also the additional discussion in Attachment B, Sections B.5.1.1.1 and B.5.1.1.3, to this appendix.)

Finally, it should be noted that, because it should be expected that residual amounts of tritium will always be present on/in the internal surfaces of the containment vessel, additional maintenance requirements will have to be added to look for signs of intergranular corrosion and intergranular-stress-corrosion cracking over time, particularly if the containment vessel is constructed of materials other than Type 304L or Type 316L stainless steels (see the additional discussion in Sections 7.4 and 4.4.1, above, and Section 9.4.2, below).

8.6 References

Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials—Leakage Tests on Packages for Shipment," ANSI N14.5-2014, New York, NY, 2014.

Knoll, R.W., and E.R. Gilbert, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel," PNL-6365, Pacific Northwest National Laboratory, Richland, Washington, November 1987.

U.S. Nuclear Regulatory Commission, Regulatory Guide 8.32, "Criteria for Establishing a Tritium Bioassay Program," U.S. Government Printing Office, July 1988.

Westinghouse Electric Company, LLC, "Implementation and Utilization of Tritium-Producing Burnable Absorber Rods (TPBARs) in Watts Bar Unit I," NDP-00-0344, Revision 1, July 2001. (See, in particular, Section 1.5.1, pp. 1-14 through 1-19, and Section 3.7.3, pp. 3-22 through 3-27.).

9 Acceptance Tests and Maintenance Program Evaluation

9.4 Review Procedures

This section considers each of the subsections of Section 9.4 (Review Procedures) of Chapter 9 of this SRP and highlights the special considerations or attention needed for TPBAR transportation packages. In subsections where no significant differences were found, that particular subsection has been omitted from this section.

See Chapter 9, Figure 9-1, of this SRP for the interrelationship between the review of the acceptance tests and maintenance program and the other chapter reviews.

9.4.1 Acceptance Tests

Because it has already been assumed that the packaging to be used for the shipment of irradiated TPBARs will be an existing, modified, or newly designed spent fuel transportation package, there should be no significant differences in the acceptance-test requirements for irradiated TPBAR packages, relative to the requirements for new spent-fuel packages, or new radioactive materials packages.

[6] See also the additional discussion in Sections 4.4.3, A.6.1, A.6.2, A.6.3, and A.6.4 in Attachment A to this appendix.

9.4.2 Maintenance Program

After the package has been used for the shipment of irradiated TPBARs, it should be assumed that the internals of the package are contaminated with tritium. Prior to opening an *empty* package, the appropriate precautions should be taken to verify that the internal walls of the containment vessel are not outgassing (see the related discussion in Sections 8.4.1.2 and 8.4.3 of this appendix, and Sections A.4, A.5, and A.6 of Attachment A to this appendix). This type of information can be particularly important to note for leakage testing purposes—to determine the amount of tritium (as HTO) that might have to be pumped through a vacuum system—and as information to be used for pre-inspection purposes, so that the workers can be appropriately notified of potential HTO outgassing problems.

9.4.2.3 Component and Materials Tests

As was noted in Section 8.4.3, above, it should be expected that the internals of the package will become contaminated with tritium any time the package is used for the shipment of irradiated TPBARs. As part of the maintenance program, therefore, special attention should be paid to potential long-term corrosion issues. At a minimum, therefore, it is recommended that an additional requirement be added to the maintenance program to require an annual inspection by a qualified corrosion metallurgist of all accessible containment surfaces, welds, heat-affected zones, and sealing surfaces for evidence of corrosive attack or residue.

It is further recommended that a record be kept of the total amount of tritium that has been released into the containment vessel for each package used. The total amount of tritium for any given shipment can be determined from the outgassing measurements mandated above in Section 8.4.1.2. Such records should be kept for the lifetime of the package.