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Unclassified TPBAR Releases, Including Tritium

TTQP-1-091, Revision 14

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TRITIUM TECHNOLOGY PROGRAM

UNCLASSIFIED TPBAR RELEASES, INCLUDING TRITIUM

TTQP-1-091

Revision 14

Effective Date: 07/24/12

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Revision 14

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1.0 INTRODUCTION

This document provides a listing of unclassified tritium release values that should be assumed for unclassified analysis. Much of the information is brought forth from the related documents listed in Section 5.0 to provide a single-source listing of unclassified release values. This information has been updated based on current design analysis and available experimental data.

2.0 SUMMARY OF UNCLASSIFIED RELEASES, INCLUDING TRITIUM

All tritium-producing burnable absorber rod (TPBAR) analyses presented here assume that a maximum of 1.2 grams of tritium per TPBAR will be generated during an 18-month operating cycle (Lopez and Love, 2006). Tables 1, 2, and 3 provide a summary of the information provided in this section.

Table 1. Summary of Unclassified Tritium Release Assumptions for Non-Transportation Scenarios

In-Reactor Permeation (at ~600 F)	In-Reactor Release from Defective TPBARs	Spent Fuel Pool Accident Releases (<200ºF)	Tritium Releases from TPBARs in Storage Canisters (<200ºF)
Less than 0.53 mCi per TPBAR per hour	Released as it is generated	The Tennessee Valley Authority take-action limit of 60 microcuries per ml of spent fuel pool water will not be exceeded following the simultaneous breach of up to 24 TPBARs. The best estimate total tritium release in this event is less than 25% of the total TPBAR tritium inventory. The release rate will be < 3% (of initial inventory) per hour. The instantaneous release of tritium from breached TPBARs (as gas within the released gas from the TPBARs) will not exceed 0.001 Ci/TPBAR. The concentration of lithium and aluminum in the spent fuel pool following a 24-TPBAR breach will not exceed 400 ppb and 50 ppb, respectively.	Tritium partial pressure within storage canisters containing LTA TPBARs and sections will not exceed 25 torr. Tritium release from extracted TPBARs will not exceed 1% of the declared tritium residual.

Table 2. Summary of Unclassified Tritium Release Assumptions for Cask Transportation Scenarios

Intact TPBARs			Event-Failed TPBARs				TPBARs Pre-Failed In-Reactor	
Ambient to 200 ºF	>200ºF to 650ºF	>650ºF to 1050ºF	Ambient to 200°F	>200°F to 650ºF	>650°F to 1050°F	>1050°F	Ambient to 200°F	>200°F
<0.05 mCi per hour for 300 or less TPBARs	<0.60 mCi per hour	<0.5 Ci per TPBAR per hour	<0.1 Ci per TPBAR per hour	<55 Ci total per TPBAR	<100% of inventory	100% of inventory	<0.1 Ci per TPBAR per hour	up to 100% of inventory

Table 3. Unclassified Helium Release Assumption for Cask Transportation Scenarios

TPBAR Condition	TPBAR Condition	Helium Release to Cask
Intact	Intact	No release
Event-Failed	Event-Failed	0.42 moles per TPBAR (following shutdown and 90-day cooling period), plus the decay-generated moles of He-3 at time t (years) following the cooldown, calculated as: He-3(moles) = (0.4-0.0055)*{1 – exp[-(ln2)*t/12.32]}

2.1 Intact TPBAR In-reactor Tritium Permeation

The in-reactor tritium permeation rate deduced from RCS tritium activity for the group of 240 Mark 9.2 (FLG) design TPBARs in Watts Bar Cycle 10, averaged over 513 EFPDs, was 3.8 ± 0.8 Ci/TPBAR/year (95% confidence interval) (Shaver and Niehus, 2011). The 95% upper bound of 3.8 + 0.8 = 4.6 Ci/TPBAR/year is recommended as the basis for assessing the tritium release from intact TPBARs. This translates to < 0.53 mCi/TPBAR/hour.

2.2 In-reactor Tritium Release from a Failed TPBAR

This scenario involves a TPBAR that may have a fabrication defect or may be damaged prior to insertion into the reactor for irradiation. In this case, 100 percent of the tritium generated in the TPBAR is assumed to be released to the reactor coolant as it is generated (Lanning, 1996).

2.3 TPBAR Releases from Spent Fuel Pool Accidents

2.3.1 Spent Fuel Pool Tritium Concentration Limit

It has been determined that following the simultaneous breach of 24 TPBARs, the Tennessee Valley Authority take-action limit for tritium concentration in the spent fuel pool water will not be exceeded. The concentration limit is 60 microcuries per milliliter. The best estimate of total tritium release in this event is less than 25% of the TPBAR inventory. The release will not be instantaneous, but will occur at a steady rate over a time period substantially greater than 8 hours. The rate will thus be less than 3% (of initial inventory) per hour (Lanning, 2001).

2.3.2 Instantaneous Tritium Release per TPBAR

The instantaneous release of tritium from breached TPBARs in the spent fuel pool (as gas within the released gas from the TPBARs) will not exceed 0.001 Ci/TPBAR (Schmitt, 2012).

2.3.3 Lithium and Aluminum Release

In the event of a 24-TPBAR breach in the spent fuel, the following concentration limits for lithium and aluminum will not be exceeded (Migliore, 2001):

- 400 ppb lithium
- 50 ppb aluminum.

2.4 Tritium Releases from TPBARs within Storage Canisters (<200°F)

The upper-bounding tritium partial pressure within storage canisters containing lead test assembly (LTA) TPBARs or sections is not expected to exceed 20 torr under nominal storage conditions (~86ºF) (Thornhill, 2002). The bounding pressure for maximum temperatures (<200ºF) is estimated by increasing this figure by the ratio of absolute temperatures, to 25 torr.

Tritium release from extracted TPBARs in storage will not exceed 1% of the declared post-extraction residual tritium (Clemmer et al. 1984; and Johnson et al. 1976).

In both cases, the form of the released tritium will be tritiated water vapor or condensate (HTO).

2.5 TPBAR Transportation Cask Event Releases

All of the release rates reported below are for releases from the TPBARs into the transportation cask, not from the transportation cask into the environment; the evaluation of tritium permeation (release) from the shipping cask to the environment is beyond the scope of this review.

2.5.1 Intact TPBARs

2.5.1.1 For TPBAR temperatures ranging from ambient to less than 200ºF, and for casks containing 300 or less TPBARs, the tritium release would be less than 0.05 mCi per hour. The tritium would be released from the TPBARs in the form of molecular tritium gas (i.e., T_2 or HT) (Schmitt, 2012).

2.5.1.2 For TPBAR temperatures ranging from 200ºF to 650ºF, the average tritium release would be less than 0.60 mCi per TPBAR per hour based on the upper-bound in-reactor release rate of 4.6 Ci/TPBAR/year. The tritium would be released from the TPBARs in the form of tritium gas (Schmitt, 2012).

2.5.1.3 For TPBAR temperatures ranging from 650ºF up to 1050ºF (565ºC), the tritium release should be considered to be less than 0.5 Ci per TPBAR per hour. Again, the tritium would be released from the TPBARs in the form of tritium gas (Schmitt, 2012).

2.5.1.4 At temperatures above 1050°F, the TPBARs are assumed to have burst, releasing 100% of the tritium inventory (Schmitt, 2012).

2.5.1.5 Helium release from intact TPBARs is negligible.

2.5.2 Event-failed TPBARs

This section applies to rods breached either 1) in the dry condition (after cask loading) or 2) in water (e.g., spent fuel pool drop) prior to cask loading, but which were dried after cask loading (Schmitt, 2012).

2.5.2.1 For TPBAR temperatures ranging from ambient to 200ºF, the tritium release from a TPBAR whose cladding fails mechanically (e.g., due to impact forces) should be considered to be less than 0.1 Ci per TPBAR per hour (Schmitt, 2012).

2.5.2.2 For TPBAR temperatures ranging from 200°F to 650°F, the total tritium release from a TPBAR whose cladding fails mechanically (e.g., due to impact forces) should be considered to be less than 55 Ci per TPBAR (Schmitt, 2012).

2.5.2.3 For TPBAR temperatures ranging from 650°F to 1050ºF, the tritium release should be considered to be up to 100% of the TPBAR tritium inventory (Schmitt, 2012).

2.5.2.4 For TPBAR temperatures in excess of 1050ºF, it should be assumed that 100 percent of the tritium inventory of the TPBAR would be instantaneously released (Schmitt, 2012).

2.5.2.5 The helium inventory per TPBAR following shutdown and a 90-day cooling period is calculated to be 0.42 moles (total of He-4 from fill gas plus tritium production, plus residual He-3 and decay-generated He-3) [Pagh and Starner, 2007].

The additional He-3 moles per TPBAR generated by tritium decay at any time "t" (years) following the 90-day cooldown can be calculated as:

He-3(moles) = (0.4-0.0055)*{1 – exp[-(ln2)*t/12.32]}.

It is recommended that 100% of all He-3 and He-4 be assumed to be released from event-failed TPBARs. This assumption may be significantly conservative for decay-generated He-3, since it is largely retained within the solid internal components of the TPBAR. However, a specific postirradiation temperature history for the TPBAR components would be required to calculate specific release fractions.

2.5.3 Pre-failed TPBARs

This section applies to rods that have pre-existing cladding breaches (in-reactor) prior to cask loading (Schmitt, 2012).

2.5.3.1 Casks used for transportation of TPBARs are assumed to contain up to 300 rods, two of which can be pre-failed (NAC-LWT SAR, 2008). For pre-failed TPBARs at temperatures ranging from ambient to less than 200°F, the tritium release for event-failed TPBARs – 0.1Ci per TPBAR per hour – applies (Schmitt, 2012).

2.5.3.2 Without further definition of the timing and nature of the failure and the subsequent operational and cask environmental conditions, it is conservative to assume that 100% of the pre-failed TPBAR inventory is released to the cask during transport when temperatures exceed 200°F (Schmitt, 2012).

3.0 FLAMMABLE GAS SOURCES

Because transportation accident temperatures are limited to 402°F, flammable gas generation for temperatures greater than ~400°F are not considered here.

Releases from event-failed rods (i.e., 55 Ci/TPBAR) will result in the release of 0.30 moles of T_2O and HTO from the 298 event-failed rods. The pre-failed TPBARs are assumed to be waterlogged, and for the purposes of estimating tritium release, the potential flammable hydrogen (H_2) gas formation from these rods is calculated assuming 100% release of the potential 7.75 moles of water per TPBAR. This results in a total of up to 15.8 moles of water (H2O, T2O, and HTO) that can be released to the cask.

The conversion of this water to hydrogen gas is based upon temperature dependent oxidation rates from reaction with hot steel surfaces. This results in the generation and release of 0.18 moles of flammable gas per year at temperatures up to 200°F and release of 0.72 moles of flammable gas per year at temperatures up to 400°F.

These bounding estimates for moisture release and flammable gas formation are summarized in Table 4 (Schmitt, 2012).

Table 4. Summary of Unclassified Bounding Flammable Gas Formation and Moisture Release for Cask Transportation Scenarios

Flammable Gas Formation [1]			
Intact TPBARs		**Event-Failed and Pre-Failed TPBARs**	
Ambient to 200°F	>200°F to 400°F	Ambient to 200°F	>200°F to 400°F
Negligible	Negligible	<0.18 moles per year	<0.72 moles per year
Moisture Release from TPBARs [2]			
Intact TPBARs		**Event-failed TPBARs**	**Pre-failed TPBARs**
Negligible		0.30 moles (for 298 TPBARs)	15.5 moles (for 2 TPBARs)

[1] Moles refer to moles H_2 equivalent
[2] Moles refer to moles H_2O equivalent

4.0 SHIPMENT OF TPBAR SEGMENTS AND FINES

Shipment of sectioned TPBARs plus cutting fines is planned. Such shipments will be bounded in content by up to 55 equivalent TPBAR lengths (NAC-LWT SAR, 2008), with tritium content of the TPBARs less than the design limit of 1.2 grams tritium per TPBAR. The segments are expected to retain their internal components largely intact; however, impact loads during shipment could result in an undetermined extent of pellet cracking and further fragmentation of pellet pieces. Conservatively, it is assumed that 100% of the tritium in the pellets is released during shipment. This bounding assumption regarding tritium release from pellets is judged to include any in-shipment release of the residual tritium in the cutting fines.

The same declarations made in Section 3.0 above for event-failed rods apply to the shipment of TPBAR segments regarding the expected form of the released tritium and the conversion to flammable species. That is, the expected forms of the released tritium are T_2O and HTO and the conversion to flammable species (T_2 and HT) will result in the release of 0.055 moles of flammable gas from the 55 equivalent TPBAR lengths (0.30 moles*55/298), given cask temperatures less than 400ºF.

Table 5 indicates the bounding quantities of released tritium and flammable gas generation for shipment of TPBAR segments as described above.

Table 5. Summary of Unclassified Bounding Tritium Release and Flammable Gas Formation for Cask Shipment of TPBAR Segments and Cutting Fines (up to 55 Equivalent TPBARs)

Tritium Releases		**Flammable Gas Generation** (moles refer to moles H_2 equivalent)	
Ambient to 200°F	>200°F to 400°F	Ambient to 200°F	>200°F to 400°F
100% of pellet inventory	100% of pellet inventory	Negligible	< 0.055 moles

5.0 RELATED DOCUMENTS

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