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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Watts Bar Nuclear Plant Unit 1
Facility Operating License No. NPF-90
NRC Docket No. 50-390

Subject: **Watts Bar Nuclear Plant, Unit 1 Tritium Production Program, Updated Plans for Cycle 13 Operation and Updated Evaluation of the Radiological Impacts of Tritium Permeation into the Reactor Coolant System**

References:

1. Letter from TVA to NRC, "Watts Bar Nuclear Plant - Request for Additional Information (RAI) Regarding Radiological Impact (TAC No. MB1884)," dated May 23, 2002 (ADAMS Accession No. ML021490139)

2. Letter from NRC to TVA, "Watts Bar Nuclear Plant, Unit 1 - Issuance of Amendment to Irradiate Up to 2304 Tritium-Producing Burnable Absorber Rods in the Reactor Core (TAC No. MB1884)," dated September 23, 2002 (ADAMS Accession No. ML022540925)

3. Letter from NRC to TVA, "Watts Bar Nuclear Plant, Unit 1 - Issuance of an Amendment Regarding Revision of Boron Requirements for Cold Leg Accumulators and Refueling Water Storage Tank (TAC No. MB9480)," dated October 8, 2003 (ADAMS Accession No. ML032880062)

4. Letter from TVA to NRC, "Watts Bar Nuclear Plant (WBN) Unit 1 - Tritium Production Program - Program Enhancements," dated April 27, 2004 (ADAMS Accession No. ML041200683)

5. Letter from TVA to NRC, "Watts Bar Nuclear Plant (WBN) Unit 1 - Tritium Production Program - Unit 1 Cycle 6 Operating Experience," dated March 22, 2005 (ADAMS Accession No. ML050870454)

6. Letter from TVA to NRC, "Watts Bar Nuclear Plant (WBN) Unit 1 - Technical Specification Change 07-01, Revision of Number of Tritium Producing Burnable Absorber Rods (TPBARs) in the Reactor Core," dated April 25, 2007 (ADAMS Accession No. ML071210604)

7. Letter from NRC to TVA, "Watts Bar Nuclear Plant, Unit 1 - Issuance of Amendment Regarding the Maximum Number of Tritium Producing Burnable Assembly Rods in the Reactor Core (TAC No. MD5430)," dated January 18, 2008 (ADAMS Accession No. ML073520546)

8. Letter from TVA to NRC, "Watts Bar Nuclear Plant (WBN) Unit 1 - Technical Specifications Change - 'Revision of Boron Requirements for Cold Leg Accumulators and Refueling Water Storage Tank,'" dated August 1, 2008 (ADAMS Accession No. ML08210093)

9. Letter from TVA to NRC, "Watts Bar Nuclear Plant (WBN) Unit 1 - Revised Technical Specifications Change WBN-TS-08-04 – Revision to the Maximum Number of TPBARs that Can Be Irradiated in the Reactor Core Per Cycle (TAC No. MD9396)," dated December 31, 2008 (ADAMS Accession No. ML090090044)

10. Letter from NRC to TVA, "Watts Bar Nuclear Plant, Unit 1 -Issuance of Amendment Regarding the Maximum Number of Tritium Producing Burnable Assembly Rods in the Reactor Core (TAC No. MD9396)," dated May 4, 2009 (ADAMS Accession No. ML090920506)

11. Letter from NRC to TVA, "Summary of January 23, 2013 Pre-Submittal Meeting with Tennessee Valley Authority on a Proposed License Amendment Request," dated February 21, 2013 (ADAMS Accession No. ML13044A477)

12. Letter from TVA to NRC, "Notification of the Number of Tritium Producing Burnable Absorber Rods for the Operating Cycle 13 Reactor Core," dated April 8, 2014 (ADAMS Accession No. ML14100A356)

The purpose of this letter is to provide updated information regarding the Tennessee Valley Authority (TVA) program to irradiate Tritium Producing Burnable Absorber Rods (TPBARs) at Watts Bar Nuclear Plant (WBN), Unit 1. Specifically, TVA is providing an updated evaluation of the radiological environmental impacts associated with the irradiation of TPBARs in the WBN, Unit 1 core, including an updated evaluation of the impacts of permeation of tritium from TPBARs into the Reactor Coolant System (RCS).

Planned Irradiation of TPBARs during WBN, Unit 1 Cycle 13

By letter dated September 23, 2002 (Reference 2), the NRC issued License Amendment 40 to Facility Operating License No. NPF-90 for WBN, Unit 1. Under License Amendment 40, the NRC authorized TVA to irradiate up to 2,304 TPBARs in the WBN, Unit 1 reactor core each fuel cycle. Subsequently, by letter dated October 8, 2003 (Reference 3), the NRC issued License Amendment 48 to the WBN, Unit 1 Facility Operating License revising the number of TPBARS authorized to be irradiated in each core from 2,304 to 240. The number of authorized TPBARs was again revised by License Amendment 67, which was issued by the NRC on January 18, 2008 (Reference 7); authorizing TVA to irradiate up to 400 TPBARS in the WBN, Unit 1 reactor core. Finally, the number of TPBARS authorized for irradiation in the WBN, Unit 1 core was revised to its current limit of 704 by License Amendment 77, which was issued on May 4, 2009 (Reference 10).

WBN, Unit 1 is currently operating in Cycle 13. Consistent with its letter dated April 8, 2014 (Reference 12), WBN, Unit 1 is operating with 704 TPBARS, as authorized by the WBN, Unit 1 Facility Operating License.

Historical Consideration of Tritium Permeation into the RCS and Associated Radiological Environmental Impacts

A comprehensive description of the radiological impacts associated with irradiating TPBARS was provided in TVA's letter dated May 23, 2002 (Reference 1), prior to the issuance of License Amendment 40. The May 23, 2002, letter included a report entitled "Review of Radiological Considerations for Production of Tritium at Watts Bar Nuclear Plant" (the report). The report described multiple mechanisms by which tritium accumulates in the RCS of a tritium-producing core. One specific mechanism discussed was the permeation of tritium through the cladding of a TPBAR into the RCS. The report included numerous tables presenting projections of radiological exposure and dose against various NRC radiological exposure limits. The projected radiological impacts were evaluated against these guidelines and limits for multiple operating scenarios, including normal and abnormal operation as well as various accident events.

In the report, TVA stated that the total release of tritium into the RCS of 2,304 Curies (Ci) per year was based on a nominal 1.0 Ci per year permeation per TPBAR into the reactor coolant and the then proposed maximum number of 2,304 TPBARs in the reactor core. With this assumed permeation as well as consideration of the other contributors of tritium into the reactor coolant discussed in the report, TVA demonstrated that the projected radiological impacts of the proposed TPBAR operation were well within NRC environmental guidelines and dose limits

The NRC evaluated the environmental consequences of TVA's proposed irradiation of up to 2,304 TPBARs. The NRC documented its evaluation in an Environmental Assessment (EA), which was published in the Federal Register on August 26, 2002 (67 FR 54826). In the EA, the NRC referenced TVA's May 23, 2002, report. With regard to the radiological impact from tritium release to the RCS under normal plant operations with 2,304 TPBARs in the core, the staff concluded that:

> "...The additional dose rate from operating WBN with 2304 TPBARs in the reactor will not have a significant impact on TVA's ability to control worker radiation doses and keep them well within regulatory limits using the controls and practices in WBN's existing Radiation Protection Program."

In the EA, the NRC staff also addressed radiological impact from liquid effluents under normal plant operations with 2,304 TPBARs in the core. The staff concluded:

> "...The potential radiological impact on plant workers, members of the public, and the environment from operation with the TPC complies with all regulatory dose limits."

The NRC staff addressed other aspects of the radiological environmental impacts as part of the EA. In summary, the staff concluded:

> "The proposed action will not significantly increase the probability or consequences of accidents, no changes are being made in the types of effluents that may be released offsite, and there is no significant increase in occupational or public radiation exposure. Therefore, there are no significant radiological environmental impacts associated with the proposed action."

By letter dated April 27, 2004 (Reference 4), TVA informed the NRC of the results of evaluations that had been performed by Pacific Northwest National Laboratory, and of certain program enhancements that had been made regarding a refinement to the analytical model used to estimate the amount of tritium that would be released from TPBARs into the RCS. The enhancements and revised modeling were made to achieve the functional criterion of no more than 1000 Ci per 1000 TPBARs per year.

Subsequently, in a letter dated March 22, 2005 (Reference 5), TVA advised the NRC that experience during WBN, Unit 1 Cycle 6 operation showed that the functional requirement had not been met. To ensure that operation during Cycle 7 and future cycles would not exceed a total release of tritium into the RCS of 2,304 annual curies from TPBARs (i.e., the value assumed in the May 23, 2002, report and in the subsequent August 26, 2002 NRC Environmental Assessment), TVA stated that it would limit the number of TPBARs to be irradiated in any cycle such that the total tritium release into the RCS would remain below the value established with License Amendment 40 (i.e., 2,304 annual curies from TPBARs) as an interim tritium permeation functional requirement.

The issue of permeation of tritium from TPBARs into the RCS was again discussed by TVA in its request to amend the WBN, Unit 1 Facility Operating License dated April 25, 2007 (Reference 6). The April 25, 2007, License Amendment Request (LAR) proposed revising the number of TPBARs authorized to be irradiated in the WBN, Unit 1 core from 240 to 400. The specific changes to the WBN, Unit 1 Facility Operating License affected by the LAR included changes to the technical specifications associated with boron concentration in the Refueling Water Storage Tank and the Accumulators, as well as the specific designated limit on authorized number of TPBARs in the core. The LAR provided updated information on permeation of tritium into the reactor coolant, and provided information on changes to TPBAR design intended to mitigate tritium permeation into the reactor coolant. The LAR did not include changes to the technical specifications specific to the issue of tritium permeation.

The NRC approved TVA's request to revise the authorized number of TPBARs in the WBN, Unit 1 core to 400 by issuance of License Amendment 67 to the WBN, Unit 1 Facility Operating License on January 18, 2008 (Reference 7). In the Safety Evaluation associated with License Amendment 67, the NRC acknowledged that TVA was planning to use TPBARs with design changes intended to address permeation issues. The specific permeation rates or cumulative totals of tritium in the reactor coolant due to permeation were not addressed in the Safety Evaluation and did not form a part of the staff's explicit basis for approval of License Amendment 67.

With respect to permeation, in the Background section of the Safety Evaluation for License Amendment 67, the NRC staff stated:

> "Because the tritium permeation from TPBARs was found to be greater than expected in Cycle 6, TVA stated in a March 22, 2005, letter to NRC that the number of TPBARs irradiated in WBN-1 would remain at 240 until the permeation issue was understood and resolved, thus only 240 TPBARS were irradiated in Cycles 6, 7 and 8."

and

> "On the basis of post-irradiation examinations performed on Cycle 6 TPBARs, Pacific Northwest National Laboratory (PNNL), designer of the TPBARS, has proposed changes to the TPBAR design to correct the permeation issue. TPBARS with these design changes are proposed to be irradiated in the WBN-1 core during operating Cycle 9, beginning in the spring of 2008."

With regard to structural changes to the TPBARs, in the Safety Evaluation for License Amendment 67, the staff stated:

> "As previously noted, PNNL, the designer of the TPBARs, proposed changes to the TPBAR design to correct the permeation issue, and TPBARs with these design changes are proposed to be irradiated in the WBN-1 core starting with operating Cycle 9. The changes are primarily related to the design of internal components.

> In its safety evaluation for Amendment No. 40 to the WBN-1 Facility Operating License, which authorized the insertion of up to 2,304 TPBARs in the WBN-1 core, the NRC staff did not perform a detailed structural evaluation. Rather, it based its acceptance of the structural design on review of the DOE/TVA Interagency Agreement, which provides a means for imposing TVA requirements for safety-related components directly on DOE's TPBAR suppliers. This insures that TPBAR design, procurement and fabrication will be performed in accordance with a quality assurance (QA) program that complies with 10 CFR Part 50, Appendix B and NRC Regulatory Guide 1.28, "Quality Assurance Program Requirements (Design and Construction)."
>
> In its August 22, 2007, response to a staff request for additional information, the licensee stated that the controls used in the design, fabrication and procurement of the redesigned TPBARs and TPBAR components are the same as those used in the original design.
>
> Therefore, the NRC staff concludes that the changes to the structural design of the TPBARs will be made in accordance with applicable NRC regulatory procurement and QA requirements, and are acceptable."

By letter dated August 1, 2008 (Reference 8), TVA requested a revision to the WBN, Unit 1 Facility Operating License to increase the maximum number of TPBARs from 400 to 2,304. This request was superseded by letter dated December 31, 2008 (Reference 9), requesting a revision to the WBN, Unit 1 Facility Operating License to increase the maximum number of TPBARs from 400 to 704. The NRC issued License Amendment 77 to the WBN, Unit 1 Facility Operating License on May 4, 2009 (Reference 10), approving the increase in authorized TPBARs to 704. In the Safety Evaluation accompanying the License Amendment 77, the NRC staff stated, in part:

> "The NRC staff reviewed the information for Cycles 6, 7 and 8 that has shown the primary constraint on the number of TPBARs in the core is the TPBAR tritium release per year of 2304 Curies per year. The NRC staff finds that the maximum number of 704 TPBARs is bounded by the mechanical design limitations on the TPBARs as reviewed in Amendment 67."

and

> "The other limitations to the maximum number of 704 TPBARs relate to the excess reactivity contributions of the TPBARs in post-LOCA scenarios, which the NRC staff finds acceptable as evaluated in the preceding sections."

However, the specific permeation rates or cumulative totals of tritium in the reactor coolant due to permeation were not addressed in the Safety Evaluation and did not form a part of the staff's explicit basis for approval of License Amendment 77.

During a public meeting held on January 23, 2013 (Reference 11) to discuss a new proposed LAR for TPBARs, TVA informed the NRC of its intent to provide an update to the WBN, Unit 1 tritium production program operating experience letter dated March 22, 2005, removing the interim limits on tritium releases attributable to TPBARs. TVA stated that the update would include general discussion of the expected effluent releases for 704 TPBARs and would return to the normal effluent controls of 10 CFR Part 20, 10 CFR Part 50 Appendix I, and the WBN, Unit 1 Technical Specifications.

During the January 23, 2013 meeting, PNNL explained how they and TVA performed surveillance of estimated tritium permeation over the last six cycles of TPBAR irradiation for the Tritium Readiness Program. The overall permeation performance data for the last six cycles of operation was presented. The initial design goal for TPBAR tritium permeation was 1 Curie/TPBAR/year. The observed permeation was higher than the original design goal; however, no design or production flaws were identified through the careful and extensive evaluation of the performance data. PNNL noted that the tritium permeation data included three cycles of the updated TPBAR design that was described in the TVA letter dated April 25, 2007 (Reference 6). There was no appreciable difference noted for the tritium permeation from the new TPBAR design. Based on the results of the evaluations, the proposed management strategy now assumes TPBAR tritium permeation will be 5.0 Curies per TPBAR per year. Even with this permeation rate, radionuclide releases to the environment at WBN, Unit 1 can be managed to meet the NRC requirements in 10 CFR Part 20 and 10 CFR Part 50 Appendix I. During the January 23, 2013, meeting, TVA answered general questions from the NRC about the methodology for measurement and uncertainty estimation. TVA also answered clarifying questions from the NRC about how the normalized TPBAR data relates to aggregate release data and regulatory limits. NRC summarized that they understood that the actual permeation performance for the TPBARs was greater than the original performance goal. NRC asked a clarifying question about whether any NRC action would be required for the letter removing the interim limit on tritium releases attributed to TPBARs; TVA indicated that none was required.

Reevaluation of Tritium Permeation into the RCS and Associated Radiological Environmental Impacts for Cycle 13 Operation

Through the period in which TVA has been irradiating TPBARs at WBN, Unit 1, TVA has managed issues associated with predicting the permeation of tritium from TPBARs into the RCS. To date, TVA has managed the permeation issue in a manner that has maintained the annual release of tritium from TPBARs into the reactor coolant to an amount less than the 2,304 Ci per year assumed in the May 23, 2002 report. However, TVA has determined that there is a slight risk that the tritium released from the site attributed to TPBAR permeation could exceed TVA's interim limit of 2,304 Ci in calendar year 2015. To support operation through the remainder of Cycle 13, TVA has reevaluated the radiological aspects of the environmental impacts associated with the planned irradiation of 704 TPBARs.

In order to meet Department of Energy requirements for tritium supply, TVA must irradiate the full number of authorized TPBARS during Cycle 13 operation. Consequently, TVA is revising its approach to managing the radiological environmental impacts of tritium permeation into the RCS.

Enclosure 1 provides the reevaluation of the TPBAR permeation issue. The evaluation includes a review of the environmental impacts, with a particular focus on evaluating the radiological aspects associated with the irradiation of 704 TPBARs in the WBN, Unit 1 reactor core. This review incorporates the lessons learned from the previous tritium production fuel cycles at WBN, Unit 1 (i.e., Cycles 6 through 11) and addresses both the onsite and offsite potential radiological effect of tritium production. Significant differences between the updated TPBAR permeation estimates with a 704 TPBAR core and the evaluation previously provided to NRC in support of License Amendment 40 are identified and assessed for potential impact.

The updated analyses demonstrate that doses to the public from effluents and the tritium release concentrations remain well within the regulatory As Low as Reasonably Achievable (ALARA) public dose guidelines of 10 CFR Part 50 Appendix I, and well below 10 CFR Part 20 release limits. In addition, the updated analyses demonstrate that design basis accident offsite dose consequences and control room operator dose consequences remain within the limits of 10 CFR Part 100, 10 CFR Part 50.67, and 10 CFR Part 50, Appendix A, General Design Criterion 19, as appropriate. Therefore, there continues to be no significant radiological environmental effect associated with the Tritium Production Program at WBN, Unit 1. TVA will irradiate TPBARs up to the limit authorized in License Amendment 77 (i.e., 704 TPBARs) and manage plant effluent releases (including tritium releases attributed to TPBAR permeation) in accordance with the requirements of the plant Technical Specifications, 10 CFR Part 20, and 10 CFR Part 50 Appendix I.

There are no new regulatory commitments included in this submittal. Please address any questions regarding this submittal to Mr. Edward D. Schrull at (423) 751-3850.

Respectfully,

J. W. Shea
Vice President, Nuclear Licensing

Enclosure:

Review of Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant: Radiological Impacts – 704 TPBAR Core

cc: See Page 9

cc (Enclosure):

NRC Regional Administrator - Region II
NRC Senior Resident Inspector – Watts Bar Nuclear Plant, Unit 1
NRC Senior Resident Inspector – Watts Bar Nuclear Plant, Unit 2

ENCLOSURE

TENNESSEE VALLEY AUTHORITY
WATTS BAR NUCLEAR PLANT
UNIT 1

Subject: **Review of Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant: Radiological Impacts - 704 TPBAR Core**

Review of Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant: Radiological Impacts – 704 TPBAR Core

Tennessee Valley Authority

December 2014

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Background

TVA License Amendment Request 40 dated August 20, 2001, established Reactor Coolant System (RCS) tritium fixed action levels of 9 microcuries per gram (μCi/gm) and 15 μCi/gm, which were based on a cycle inventory of 2,304 Tritium Producing Burnable Absorber Rods (TPBARs) and breaker-to-breaker runs. While never exceeded, tritium production experience indicated that the action levels were insensitive to variations in the number of TPBARs and RCS water balance. TVA has established an updated TBPAR permeation performance metric.

TVA letter dated May 23, 2002, "Watts Bar Nuclear Plant - Request for Additional Information (RAI) Regarding Radiological Impact (TAC No. MB1884)," provided comparative information regarding the radiological impact of irradiating TPBARs at Watts Bar Nuclear Plant (WBN), Unit 1. The information provided, included an estimate of the influence on Occupation Radiation Exposure and an assessment of radiological effluent releases due to normal and abnormal operation. This information is being updated to reflect Tritium Production Program changes that affect these assessments.

License Amendment 40 issued on September 23, 2002, authorized WBN Unit 1 to irradiate up to a maximum of 2,304 TPBARs in WBN Unit 1. License Amendment 77 issued on May 4, 2009, modified the authorized number of TPBARs to be irradiated to a maximum of 704.

TVA Letter to NRC dated March 22, 2005, "Watts Bar Nuclear Plant (WBN) Unit 1 - Tritium Production Program - Unit 1 Cycle 6 Operating Experience," notified NRC that TVA had imposed interim administrative limits on the number of TPBARs to be loaded in the WBN Unit 1 reactor. The interim controls limited the number of TPBARs to be irradiated in any cycle such that the total tritium released into the RCS by permeation would remain below the 2,304 curie (Ci) value evaluated for License Amendment 40. TVA has maintained the interim administrative limits while higher than expected tritium permeation was investigated.

TVA Letter to NRC dated April 25, 2007, "Watts Bar Nuclear Plant (WBN) Unit 1 - Technical Specification Change 07-01, Revision of Number of Tritium Producing Burnable Absorber Rods (TPBARs) in the Reactor Core," included an update on the tritium permeation investigation, including a discussion of the post irradiation examination (PIE) and the Mark 9.2 TPBAR design changes. Based on the PIE and review of the mechanisms associated with tritium transport within the TPBAR, several design changes were made to the TPBARs inserted in Cycle 9. The changes were expected to decrease the tritium permeation and achieve the original tritium permeation goal of less than one Ci per TPBAR per year. TVA also stated that the effectiveness of the TPBAR design changes would be determined through the monitoring of RCS tritium levels throughout Cycle 9 operation.

TVA Letter to NRC dated December 31, 2008, "Watts Bar Nuclear Plant (WBN) Unit 1 - Revised Technical Specifications Change WBN-TS-08-04 – Revision to the Maximum Number of TPBARs that Can Be Irradiated in the Reactor Core Per Cycle (TAC No. MD9396)," included an update on the TPBAR tritium release rate through Cycle 8, which showed consistent performance with that observed in Cycle 7.

Environmental Radiological Impact Considerations – 704 TPBAR Core

TVA conducted this updated review of the environmental impacts with a particular focus on evaluating the radiological aspects associated with the irradiation of TPBARs at WBN Unit 1 for a 704 TPBAR tritium production core (TPC). This review utilizes the updated conservative TPBAR annual release (permeation) rates of 5 tritium Ci/TPBAR/year for the Realistic Basis (i.e., effluent dose calculations) and 10 tritium Ci/TPBAR/year for the Design Basis[1] (i.e., station occupational exposure and radwaste system capability review). In addition, this review incorporates the experiences and lessons from the previous tritium production fuel cycles at WBN Unit 1 (Cycles 6 through 12). This review addresses both the onsite and offsite potential radiological impacts of tritium production.

Updated plant-specific evaluations were performed for WBN Unit 1 using the equations and values given in the WBN Updated Final Safety Analysis Report (FSAR) and Offsite Dose Calculation Manual (ODCM). The review includes the identification of any significant differences between the updated TPBAR permeation estimates with a 704 TPBAR core and the WBN Unit 1 License Amendment 40 associated with the TPBARs and an assessment for potential impacts. The noted differences are discussed in each section of this review. When the WBN License Amendment 40 values remain bounding, they are so indicated.

CONCLUSION

Updated program controls provide further refinement to the application of the TPBARs permeation performance metric. The permeation performance metric refinements will facilitate the monitoring of TPBAR cycle-to-cycle performance that will allow TVA and Department of Energy (DOE) to monitor TPBAR permeation performance as a metric for tracking, trending, and evaluating effectiveness of future design changes and TPBAR performance.

The updated analyses demonstrate that doses to the public from effluents and the tritium release concentrations will remain well within the regulatory As Low as Reasonably Achievable (ALARA) public dose guidelines of 10 CFR Part 50 Appendix I and well below ODCM limits and 10 CFR Part 20 release limits. With respect to Occupational Radiation Exposure, the revised estimated annual exposure remains a well within the 149 rem assessment[2] total. Therefore, there continues to be no significant radiological environmental impacts associated with the Tritium Production Program at WBN Unit 1.

The radiological consequences of the pre-accident failed TPBAR design-basis accidents and all design-basis accident doses assuming the failure of TPBARs in the TPBAR core remain within the limits of 10 CFR Part 100 and 10 CFR 50.67 for offsite dose consequences, and the limits of General Design Criteria (GDC) 19 and 10 CFR 50.67 for control room operator dose consequences.

Environmental Impacts of the Proposed Irradiations

WBN Unit 1 Operational Experience with Tritium Production Cores

Following TVA's confirmation of the higher tritium levels (as described in the March 22, 2005 letter), a number of actions were initiated to determine if the increase was due to greater than predicted permeation or some other factor. At the request of TVA, Pacific Northwest National Laboratory (PNNL) performed a failure modes and effects analyses (FMEA) on the TPBARs, considering plausible failure modes to examine whether the failure of any component in the TPBAR could have resulted in tritium levels similar to what was observed. That initial evaluation concluded that the most probable cause for increased tritium in the RCS was a greater than predicted amount of tritium permeating through the cladding due to an alternative mechanism not considered previously.

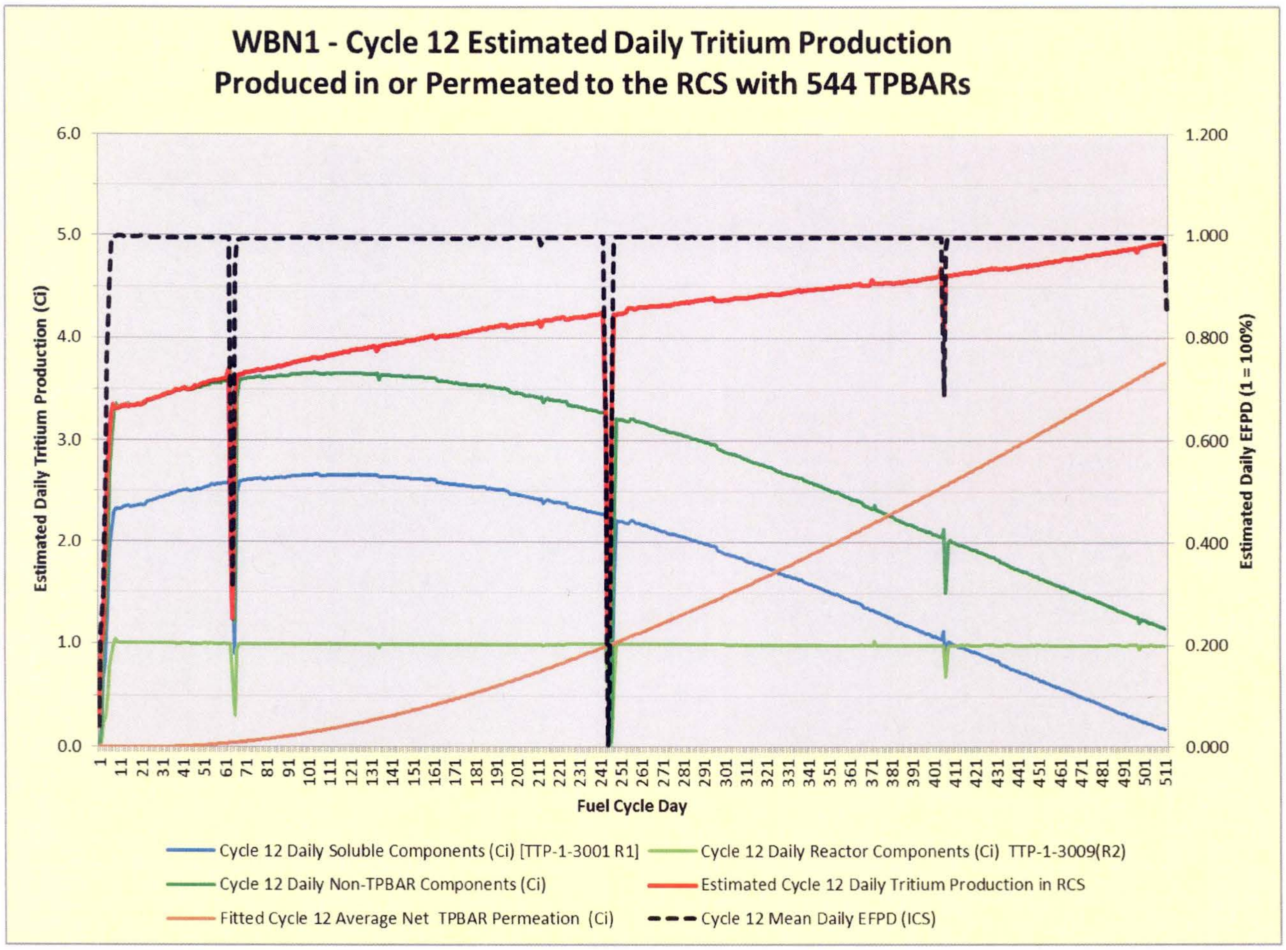
Also evaluated, but ruled as low probability events were a fabrication-induced problem or an error in the past predictive model. TVA visually examined the Cycle 6 TPBARs and to see if there are any visual indications of problems. None were found during this examination. TVA has also requested that DOE perform PIE on a sample of Cycle 6 TPBARs to compare with the lead test assembly PIE results. TVA participated in the review of the PIE results.

As described in the April 25, 2007 letter, the original TPBAR design was refined to a full-length getter design, known as the Mark 9.2 TPBAR. The Mark 9.2 design incorporated internal and external component design enhancements. This new TPBAR design has been used at WBN Unit 1 starting in Cycle 9. These design changes were selected to address issues identified in the PIE. The expectation was that the design changes would mitigate the features that caused the tritium permeation in Cycle 6 to exceed the functional criterion associated with the production TPBAR design. The actual effectiveness of the changes was to be determined through the monitoring of RCS tritium levels throughout Cycle 9 operation. In fact, the permeation performance of the Mark 9.2 TPBAR design has not been significantly different from the original TPBAR design. Consequently, PNNL and TVA have concluded that the original theoretical calculations for tritium permeation were optimistic. Actual performance has demonstrated consistent but higher tritium permeation than the original functional performance target of 1,000 Ci/1,000 TPBARs/year.

TPBAR Tritium Permeation

When reviewing station annual tritium effluents, it is important to recognize that plants such as WBN Unit 1 operate with 18-month fuel cycles which tend to generate more non-TPBAR tritium early in the core cycle, owing to higher initial boron concentrations and/or burnable poisons and integral fuel burnable absorber rods that are required for reactivity control and more TPBAR generated tritium later in core life as the tritium inventory within a TPBAR increases from zero curies at the beginning of the cycle to an average of about 9,200 curies at cycle's end. Figure 1 provides estimated Cycle 12 daily RCS tritium production/permeation rates for WBN Unit 1 with 544 TPBARs. The production by the soluble sources (i.e., boron, and lithium) decrease as the RCS is diluted to compensate for fuel burn up (with peak RCS boron 1,615 parts per million (ppm), end-of-cycle RCS boron 62 ppm). Reactor component tritium production sources consist of fuel rods, control rods, secondary source rods, and wet annular burnable absorber (WABAs). Reactor component tritium production tends to remain relatively flat (with a slight increase) for the cycle. The tritium is produced within the components and permeates through the cladding into the RCS. The TPBAR source term is a function of the number of installed TPBARs and is also related to their physical core location and core power history (e.g., neutron flux and burnup). Estimated TPBAR permeation continues to increase throughout the fuel cycle, with a constant power level. The overall combined tritium producing sources demonstrate increasing daily tritium releases to the RCS. Because of operational constraints and the time required to process RCS discharges for the non-tritium radioactive components, station tritium effluent releases may occur subsequent to the year of production and tritium release to the RCS.

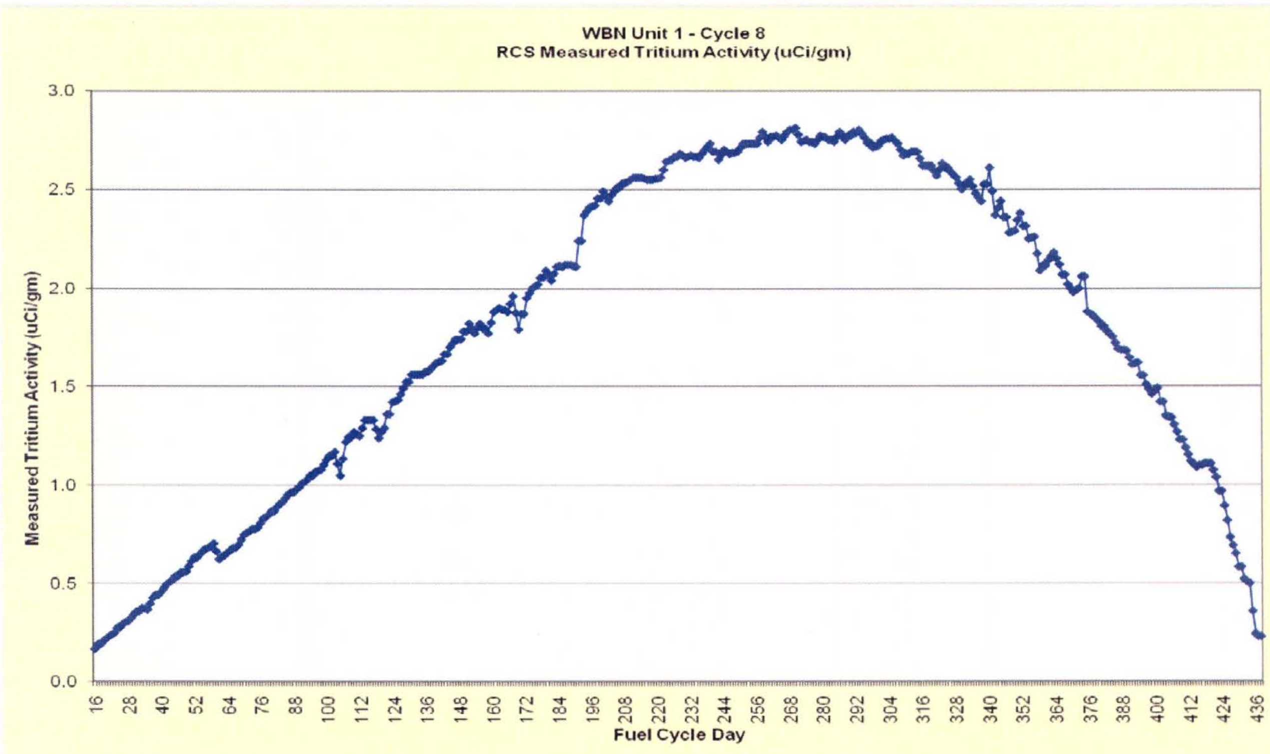
Figure 1: Estimated Daily Tritium Releases to RCS with 544 TPBARs



A typical RCS tritium concentration pattern for breaker–to-breaker runs using WBN Unit 1 Cycle 8, is shown below in Figure 2 as an example. WBN Unit 1 non-tritium production

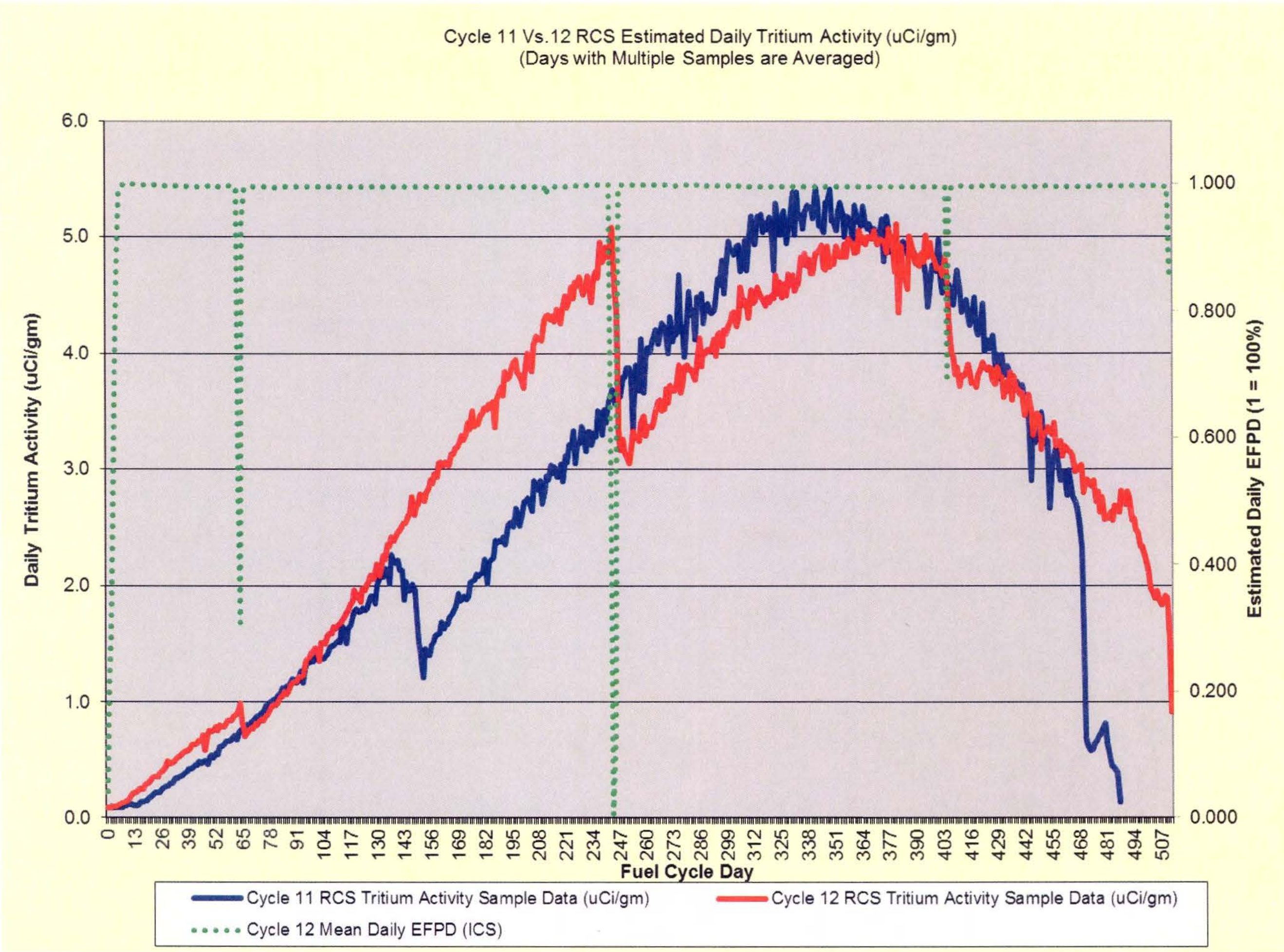
Cycle 3 demonstrated a similar pattern. Cycles with breaker–to-breaker runs tend to demonstrate the highest peak RCS tritium concentrations.

Figure 2: RCS tritium concentrations (breaker–to-breaker run) from WBN Unit 1 Cycle 8 240 TPBARs)



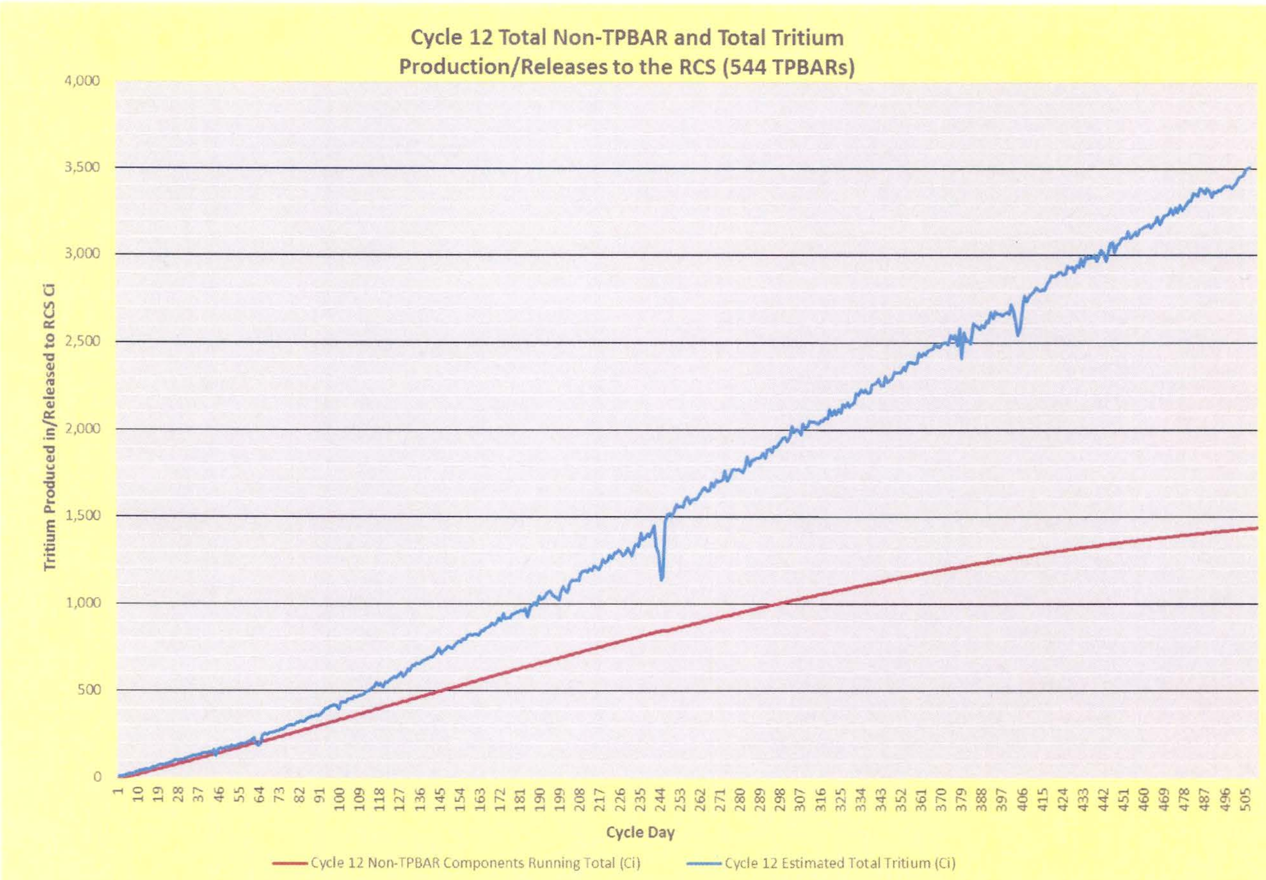
WBN latest complete Cycles, 11 and 12 were not breaker–to-breaker runs. The cycles experienced down powers and shutdowns which resulted in large dilutions, and subsequent RCS tritium reduction. A comparison of the daily RCS tritium activity for Cycles 11 (544 TPBARs) and 12 (544 TPBARs) in Figure 3 shows the variability introduced and impact of down powers and outages on RCS tritium activity.

Figure 3: Comparison of the Daily RCS Tritium Activity for Cycles 11 and 12



The TPBARs are designed with a stainless steel cladding and an aluminized internal coating. The tritium is produced by neutron irradiation of lithium aluminate pellets contained within the cladding and is gettered (collected and retained) by annular zirconium sleeves (getters) around the pellets. The aluminized coating and stainless steel cladding act as a barrier to tritium release. TPBARs are designed and fabricated to retain as much tritium as possible within the TPBAR. Since the majority of TPBAR produced tritium is chemically bonded within the TPBAR, only a small percentage of the produced tritium is available in a form that could permeate through the TPBAR cladding. As with other tritium producing components (e.g., fuel rods, control rods, secondary neutron source rods) some of this free tritium inventory in the TPBARs will permeate the cladding material and be released to the primary coolant. The design goal for this permeation process is to keep the tritium permeation as low as reasonably achievable. TPBAR permeation is nonlinear with respect to the core's effective full power days. A typical TPBAR's tritium inventory begins at zero at the start of the irradiation cycle and ends with about 9,200 Ci of tritium at the end of the irradiation cycle. TPBAR tritium permeation increases with the maximum permeation rates towards the end of the cycle. Figure 4 shows this effect for the Cycle 12 estimated tritium production.

Figure 4: Cycle 12 Estimated Total Non-TPBAR and Total Tritium Production/Releases to RCS



Monitoring TPBAR Estimated Permeation Performance

When taking measurements of RCS tritium levels, it is not possible to differentiate between tritium from TPBARs and tritium from other core components and RCS sources; therefore, the tritium attributed to TPBARs is determined by subtracting the expected tritium value established by measurements taken in cycles without TPBARs from the total tritium measured in the RCS with TPBARs.

The cumulative TPBAR tritium release at any point in the cycle is calculated as the difference of two larger quantities as described below:

(1) The total (calculated) cumulative tritium to date, T_{Total}, including that which is currently in RCS (daily measurement) plus the estimated sum of the tritium removed from the RCS to date via letdown to compensate for water/boric acid injections. This total includes the tritium released from the TPBARs plus tritium from non-TPBAR sources in the RCS.

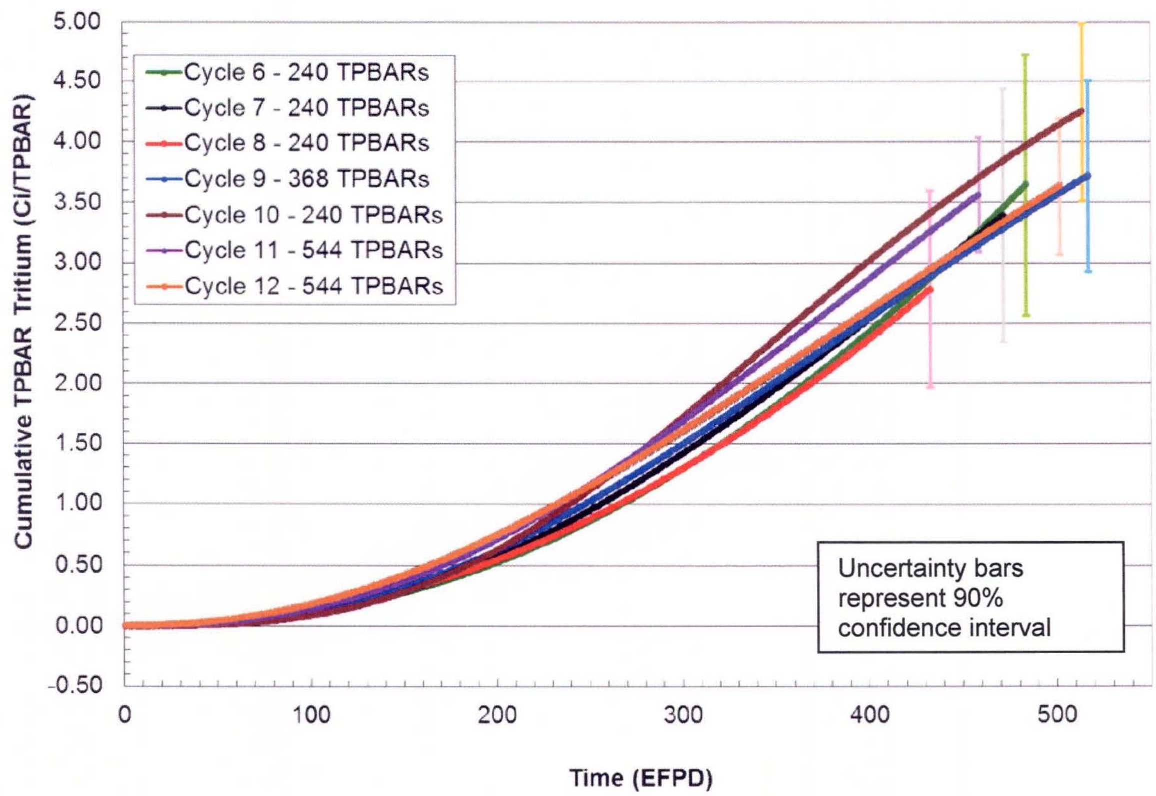
$$T_{TPBAR}(t) = T_{Total}(t) - T_{non\text{-}TPBAR}(t)$$

(2) The projected cumulative tritium that would have accrued to date, in the absence of TPBARs, $T_{non\text{-}TPBAR}$, from sources including production from soluble boron and lithium, and permeation into the RCS from fuel rods, burnable absorber rods, secondary source rods, and control rods, all of which produce tritium in their internal components.

$$T_{non\text{-}TPBAR}(t) = T_{Soluble\ Boron}(t) + T_{Lithium}(t) + T_{Fuel\ Rods}(t) + T_{Burnable\ Absorbers}(t) + T_{Control\ Rods}(t) + T_{Secondary\ Source\ Rods}(t)$$

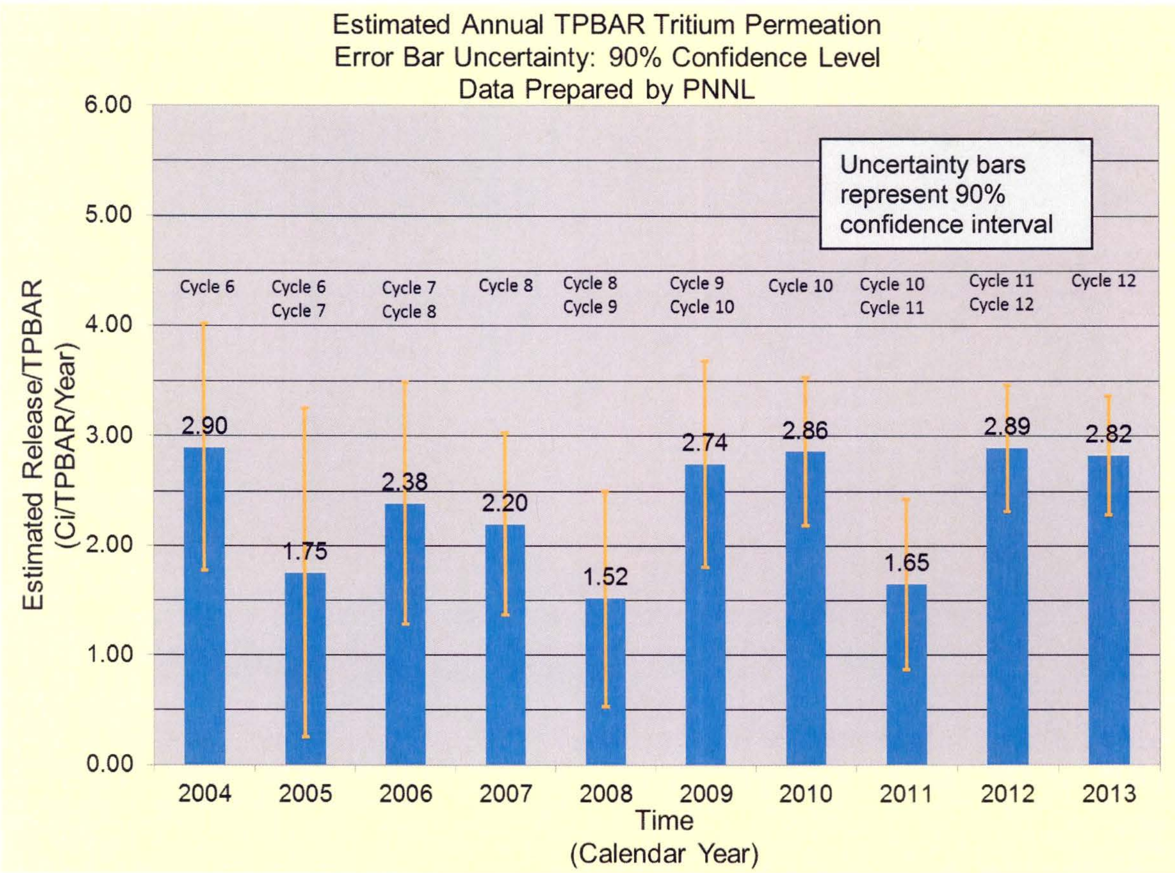
There are uncertainties in both the measurements and the determination of the amount of tritium generated from non-TPBAR sources. This results in an uncertainty in the amount of tritium attributable to TPBARs. The estimated cumulative tritium permeation per TPBAR as a function of effective full power days (EFPD) for WBN Unit 1 Tritium Production Cycles 6 through 12 are shown on Figure 5.

Figure 5: Estimated TPBAR Permeation for WBN Mk 9.2 Cycles 9 through 12



When the TPBAR permeation estimates are presented in a calendar year format (as shown in Figure 6), corresponding to the NRC monitoring and reporting requirements, the annualized per TPBAR permeation have consistently remained less than 3 Ci/year. With the approximate 18 month fuel cycles, portions of two fuel cycles will occur periodically in the same calendar years.

Figure 6: Estimated Annual TPBAR Permeation for WBN Cycles 6 through 12



Based on actual performance data, TVA has determined that the updated conservative TPBAR annual release (permeation) rates of 5 tritium Ci/TPBAR/year for the Realistic Basis (effluent dose calculations) and 10 tritium Ci/TPBAR/year for the Design Basis (station occupational exposure and radwaste system capability review) should be used for regulatory evaluations. The realistic permeation rate of 5 Ci/TPBAR/year is acceptable because it bounds the observed permeation rate. The design basis permeation rate of 10 Ci/TPBAR/year provides an additional factor of 2 margin and is therefore reasonable, but conservative and bounding.

Tritium Source Terms

Radwaste System Design Basis Tritium Source Terms

The quantity of tritium produced and the Radwaste System Design Basis production/release in the RCS for the WBN Unit 1 reactor may be found in FSAR Table 11A-1. These values are presented for an entire fuel cycle. The Radwaste System

Design Basis activity levels are considered in the estimation of Occupational Radiation Exposure, process capacity design of plant radwaste systems and plant shielding evaluations. The annual Radwaste System Design Basis for a non-TPC is summarized in Table 1.

Table 1: Non-TPC Tritium Production/Radwaste System Design Basis Values (Annual per UFSAR Table 11A-1)

Tritium Source	Total Produced (Ci/year)	Design Release to RCS (Ci/year)
Indirect/reactor component	14,057	1,462
Direct/Soluble	427	427
Total	14,484	1,889

Notes: Power level = 3565 Megawatt (thermal)

Release fraction from fuel = 10 percent Design, 2 percent Expected

Release fraction from burnable poison rods = 10 percent Design, 2 percent Expected

Operating time = 495 days

RCS Lithium concentration = 2.2 ppm

Initial RCS boron concentration = 1100 ppm.

The annual Radwaste System Design Basis tritium production/release with 704 TPBARs is summarized in Table 2.

Table 2: TPC Tritium Production/Radwaste System Design Basis Values (Per UFSAR Table 11A-1)

Tritium Source	Total Produced (Ci/year)	Design Release to RCS (Ci/year)
Non-TPC Tritium	14,484	1,889
TPBARs (704 with 10 Curies/TPBAR/Year permeation)	4,317,632	7,040
Total	4,332,116	8,929

Notes: At the end of the operating cycle, the maximum available tritium in a single TPBAR is calculated to be about 11,600 Ci (or 7,733 Ci/year).

The average TPBAR will contain about 9,200 Ci (or 6,133 Ci/year) of tritium at the end of the operating cycle.

Realistic Source Terms

The NRC's method for determining source terms for calculating releases of radioactive material in liquid and gaseous effluents is provided in NUREG–0017 Revision 1[3]. The calculated realistic average annual tritium value from NUREG-0017 Revision 1 for WBN Unit 1 is 1,392 Ci. The NRC tritium value with the addition of the 3,520 Ci (from 704 TPBARs with 5 Ci/year permeation) for a total average annual 4,912 tritium Ci from the TPBARs was used by TVA to demonstrate continued compliance with the offsite ALARA dose objectives of 10 CFR Part 50 Appendix I.

Tritium Impacts on Station Normal Operation

Site-specific data collected during extended non-TPC operating cycles (WBN Unit 1 Cycle 3 and Sequoyah Nuclear Plant (SQN) Unit 1 Cycle 10, breaker-to-breaker non-TPC cycles) have provided useful data to estimate the impact from tritium production on station radiological conditions. The RCS maximum tritium levels noted during the extended operating cycles were ≈ 2.5 μCi/gm with a cycle RCS tritium mean of ≈ 1.0 μCi/gm. The TVA experienced end of cycle (pre-flood up) RCS tritium values have typically been in the 0.1 - 0.3 μCi/gm range for both WBN Unit 1 and SQN Unit 1. The post-flood up tritium values have typically been in the mid 10^{-2} μCi/gm range. The extended cycle tritium peak RCS tritium values of ≈ 2.5 μCi/gm have resulted in containment peak tritium Derived Air Concentration (DAC)-fractions of <0.15 for both WBN Unit 1 and SQN Unit 1 with a containment average DAC-fraction of about 0.08.

Because of weepage through valve stems and pump shaft seals, some coolant escapes into the containment and the auxiliary buildings. A portion of the RCS leakage flashes to steam/evaporates, thus contributing to the tritiated water vapor source term, and a fraction remains as liquid, becoming part of the liquid source term. The relative amount of leakage entering the gaseous and liquid phases is dependent upon the temperature and pressure at the point where the leakage occurs. 10 percent (i.e., flashing and Spent Fuel Pool (SFP) evaporative losses) is the assumed gaseous effluent fraction for dose impact modeling (from NUREG-0017), whereas WBN Unit 1 effluent history indicates an average of ≈ 5 percent. As tritiated water vapor is not removed by filtration or ion exchange it will be released as gaseous effluent to the environment. A breaker-to-breaker run will potentially produce the maximum RCS tritium concentration. Cycles 11 and 12, with 544 TPBARs, were estimated to have a maximum at just less than 7.0 µCi/gm. With 704 TPBARs and 5 Ci/TPBAR/year permeation, the estimated maximum Realistic Basis RCS tritium concentration is estimated to be 10.8 µCi/gm with a mean tritium concentration estimated to be 5.1 µCi/gm[4].

There is a strong correlation between the RCS tritium concentration and the containment airborne tritium concentration (e.g., mean 1 µCi/gm tritium/RCS yields ≈ 0.08 tritium DAC in containment). The containment tritium DAC values are a function of the RCS tritium activity, the transfer of tritium from the RCS to the containment atmosphere, and the turnover/dilution of the containment atmosphere through periodic and continuous containment venting and purging. The SFP tritium source term is driven by the SFP tritium concentration and pool temperature.

The projected tritium release to the RCS with a TPC containing 704 TPBARs releasing tritium at the design maximum rate (from Table 2) will result in about a factor of ten increase over the non-TPC tritium production rate, that is,

Ratio = (TPC) 8,929 Ci/year / (Nominal Core) 870 Ci/year = 10.3.

The TPC will not change the normal operations of the plant, e.g. no extra dilution, no recycle of primary coolant, and/or other changes that would impact coolant tritium concentrations, and thus the concentration of all other isotopes except tritium will remain the same. It has been calculated that with no modifications to TVA's current boron-control feed and bleed methodologies (i.e., 366,000 gallon cycle letdown), the design basis RCS maximum tritium values will approximate 16.7 µCi/gm with a cycle mean of ≈ 10.2 µCi/gm. These values would indicate an estimated containment peak tritium DAC-fraction of ≈ 1.34 and an average containment tritium DAC-fraction of about 0.82. The design basis estimated containment average tritium DAC-fraction equates to an effective dose rate of about 2 millirem (mrem)/hour.

As previously discussed, the primary radiological significance of exposure to tritium is in the form of internal exposure and a potential hazard arises when personnel are exposed to equipment that has been wetted with tritiated liquids. Therefore, the design features of the plant that address contamination and airborne radioactivity control (e.g., drain and ventilation systems) are potentially challenged. TVA has concluded there will be minimal impact on estimated annual Total Effective Dose Equivalent (TEDE) values. TVA, using the site-specific data collected during recent extended operating cycles, has evaluated the additional deep-dose equivalent to select station personnel during TPBAR consolidation and the additional committed effective dose equivalent from possible increased tritium airborne activity in containment.

TVA's current estimate of the TPBAR cycle work scope includes pre-cycle preparation activities, post cycle removal and handling activities, TPBAR consolidation (including equipment setup and disassembly) and shipping activities, and the processing, packaging, and shipping of the irradiated components for an estimated total of 1 mrem/TPBAR. License Amendment 40 estimated the incremental annual station dose (for 2,304 TPBARs) to be 3.2 rem per year.

TVA estimates that when using Radwaste System Design Basis Tritium values for the 704 TPBAR core, this additional TEDE is about 0.5 rem per year for TPBAR handling and consolidation activities[5] (0.7 rem per TPC cycle) and 100 tritium DAC-hr/μCi/gm RCS Tritium (average internal exposure for 1 μCi/gm average RCS tritium cycles) = 100 * 10.2 μCi/gm mean RCS tritium = 1,020 DAC-hr.* 2.5 mrem/DAC-hr. = 2.55 rem per year for the additional committed effective dose equivalent from possible increased tritium airborne activity in containment. This estimated total additional 3.1 rem per year is an increase of ≈7.8 percent of the current WBN station average annual dose of 40 rem. WBN's current 3 year collective TEDE per reactor years 2010 – 2012 is 39.998 rem[6]. WBN is a top quartile Occupation Radiation Exposure performer. An additional annual average 3.1 tritium rem would raise the TEDE total to 43.1 rem, a value that remains well within the 149 rem assessment[7] total.

Real Time Performance Monitoring

To monitor TPBAR performance, TVA has established performance metrics with two tritium action levels. These action levels are cycle specific and are based on the net estimated TPBAR tritium, which is defined as the difference between the total calculated tritium released to the RCS (i.e., current RCS inventory plus removed via letdown) from all sources minus the estimated tritium released to the RCS from the traditional non-TPBAR sources (i.e., boron, lithium, fuel rods, control rods, secondary source rods, WABAs, etc.).

Action Level 1 is triggered when the net cumulative estimated TPBAR tritium exceeds 1.5 the TPC estimated value. Action Level 2 is triggered when the net cumulative estimated TPBAR tritium exceeds triple the TPC estimated value. The Action Level 1 value of 1.5 is approximately the 95 percent confidence level of the total uncertainty in the net estimated TPBAR tritium value. That is, if exceeded there is a 5 percent probability that the estimated value is consistent with expected TPBAR permeation performance. The TPC estimated value is at a specific time in the cycle dependent calculated value. The tritium attributed to TPBARs is determined by subtracting the expected tritium value established by measurements taken in cycles without TPBARs from the total tritium estimated in the RCS with TPBARs, the estimated value is established prior to each cycle and is based on the number of TPBARs to be irradiated during the cycle and observed previous TPBAR permeation performance. For a specific fuel cycle EFPD, the Action Level Trigger follows:

$$AL_{Trigger} = \text{(Total RCS Inventory – non-TPBAR Sources) / TPBAR Core Estimated Value}$$

The use of the cycle specific TPC estimated value as the permeation performance metric compensates for RCS water balance (water makeup and letdown) and the reactor power history for the cycle. The lower action level requires more frequent tritium system sampling to monitor, verify, and trend the tritium levels. In the unlikely event that the higher action level is exceeded, TVA will take further action to minimize the onsite and offsite radiological impacts of abnormal RCS tritium levels. These actions may include, but not be limited to, procedural and administrative measures that will serve to:

- ensure that the core is operated consistent with design objectives
- act as a trigger for increased data monitoring, tracking and trending
- provide a catalyst to prompt appropriate state, federal, contractual, and regulatory notifications
- initiate appropriate recovery and restoration actions
- aid in the development of appropriate actions for minimizing the impact of unexpected tritium production increases on:
  - worker dose
  - dose to members of the public
  - the potential uncontrolled release of radioactive material
  - low level waste

Specific actions and evaluations are contained within WBN Unit 1 Technical Instructions.

The License Amendment Request 40 RCS tritium fixed action levels of 9 μCi/gm and 15 μCi/gm were based on a cycle inventory of 2,304 TPBARs and breaker-to-breaker runs. They were insensitive to variations in the number of TPBARs and RCS water balance.

Tritium Impacts on Public Dose

Normal Operation

Using the current best source term estimates[8,9] for WBN Unit 1 determined using the model in NUREG-0017[10] (i.e., the PWR-GALE code), and the revised realistic TPC source terms for 704 TPBARs, the offsite radiation doses calculated for expected average releases of radionuclides in liquid and gaseous effluents during normal operation are summarized in Table 3. This table also lists the regulatory established radioactive effluent design objectives. The offsite radiation doses were calculated following Regulatory Guide (RG) 1.109[11]

Table 3: Annual Projected Impact of TPC on Effluent Dose to Maximally Exposed Members of the Public

Normal Operations	Revised TPC (for 704 TPBARS)	NRC Annual Effluent Exposure Guideline (from 10 CFR Part 50 Appendix I)
Annual Radioactive Gaseous Emissions		
Maximally Hypothetical Individual Exposure (Realistic Basis)	0.55 mrem	5 mrem
	9.49 mrem (Bone)	15 mrem
Annual Radioactive Liquid Emissions		
Maximally Hypothetical Individual Exposure (Realistic Basis)	0.41 mrem	3 mrem
	0.56 mrem (liver)	10 mrem

Note: Tritium is not the dominant contributor to any dose projection

Table 3 demonstrates that the calculated WBN Unit 1 station effluent doses remain well below the NRC acceptance criteria.

Solid Radioactive Waste

License Amendment 40 assessed the environmental impact from the solid radioactive waste associated with the production of 2,304 TPBARs. Tritium production solid radioactive waste environmental impact associated with 704 TPBARs is bounded by the License Amendment 40 impact assessment.

Spent Fuel Generation and Storage

License Amendment 40 assessed the environmental impact from the storage of additional spent fuel associated with the production of 2,304 TPBARs. The number of additional fresh fuel bundles per cycle due to tritium production was set to approximately 20. Irradiating 704 TPBARs will require approximately four additional fresh fuel bundles per cycle.

Tritium production additional spent fuel generation environmental impact associated with 704 TPBARs is bounded by the License Amendment 40 impact assessment.

Tritium Impacts on Station Accident Analysis

WBN Unit 1 License Amendment 40 assessed the station accident analyses affected by the production of 2,304 TPBARs. To appropriately account for the radiological consequences of the increased tritium in the TPC, TVA included calculated TEDE[12] and Federal Guidance Report Number 11[13] dose conversion values for thyroid in the accident analysis. TPBARs are designed to withstand the rigors associated with category I through IV events; therefore, no TPBAR failures are predicted to occur during the design-basis accidents except for the Large Break Loss of Coolant Accident (LBLOCA) or the Fuel Handling Accident (FHA).

No Accident Failed TPBARs

To account for the potential available tritium from TPC operation it was assumed that two TPBARs had failed prior to the design-basis accidents and the tritium was conservatively distributed to the affect components.[14] The evaluations considered the postulated release of all the tritium in the two pre-accident failed TPBARs.

WBNNAL3003 Revision 3, "Reactor Coolant and Secondary Side Activities in Accordance with ANSI/ANS-18.1-1984," served as the basis for the WBN Unit 1 Amendment 40 tritium accident basis activity for the non-LBLOCA and non-FHA accident analysis. The assumed RCS tritium activity **at the time of the accidents was 98.4 µCi/gm.** WBNNAL3003 Revision 5, "Reactor Coolant and Secondary Side Activities in Accordance with ANSI/ANS-18.1-1984," served as the basis for the updated evaluations of tritium accident basis activity for the non-LBLOCA and non-FHA accident dose consequence analyses. The assumed RCS tritium activity at the time of the accidents was ***124.49*** **µCi/gm, which is based on 2,500 TPBARs with an assumed permeation of 10** Ci/TPBAR/year and two failed TPBARs.

The radiological consequences of the pre-accident failed TPBAR design-basis accidents in a ***2,500*** TPBAR core remain well within a small fraction of the 10 CFR Part 100 and GDC 19 dose limits.

LBLOCA

License Amendment 40 considered 2,304 TPBARs for the LBLOCA. The radiological consequences of a LBLOCA with 704 TPBARs are bounded by the License Amendment 40 assessment.

FHA

The FHA analysis is unaffected by the authorized number of TPBARs allowed in the reactor core and remain bounding. The calculation was performed to determine the dose to control room operators following a design basis FHA. In addition, the offsite doses resulting from a design basis FHA were also calculated. Base assumptions utilized alternate source guidance from RG 1.183 (Alternate Source Term)[15]. A TPBAR-only accident was also analyzed.

The FHA is assumed to occur at 100 hours after shutdown. The other assumptions used to calculate the activity released are in accordance with RG 1.25[16] and NUREG/CR-5009[17] or RG 1.183 (Alternate Source Term/AST). It is assumed that all 24 TPBARs in a fuel assembly break. It is also assumed that **25** percent of the tritium in the spent fuel pool is released following the FHA through evaporation of the pool. There will not be 100 percent release of tritium from a TPBAR failure in a FHA because there are no high temperatures involved with the FHA. In addition, a large fraction of the spent fuel pool will not evaporate in 8 hours, since the spent fuel pool cooling system maintains the temperature below the boiling point.

The control room operator doses are below the GDC 19 limits of 5 rem gamma, 30 rem beta, 30 rem thyroid, and 10 CFR 50.67 limit of 5 rem TEDE. The radiological consequences are less than the 10 CFR Part 100 limits of 25 rem gamma, 300 rem beta, 300 rem thyroid, and 10 CFR 50.67 limit of 25 rem TEDE. The radiological consequences of a FHA are well within the 10 CFR 50.67, 10 CFR Part 100, and GDC 19 dose limits.

Therefore, all design basis accident doses assuming the failure of TPBARs are within the limits of 10 CFR Part 100 and 10 CFR 50.67 for offsite dose consequences, and the limits of GDC 19 and 10 CFR 50.67 for control room operator dose consequences.

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[1] This Design basis source term is used to assess station occupational exposure and radwaste system capability. It should not be confused with the FSAR Chapter 15 Accident Design Basis source term used for offsite dose evaluations.

[2] Watts Bar Nuclear Plant, Updated Final Safety Analysis Report (UFSAR), Section 11A.6.

[3] NUREG-0017, Revision 1, "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors"

[4] WBNNAL 3003 R5 "***Reactor Coolant and Secondary*** **Side Activities in Accordance with ANS1/ANS-18,1-1984"** August 7, 2013

[5] Operational experience, cycles 8 – 10, for all related activities (pre-work, TPBAR Handling fixture setup, Consolidation, fixture storage, production and PIE shipping, waste hub disposal, cleanup and post-work activities) averaged 0.46 mrem/TPBAR. Rounded upward to 1 mrem/TPBAR to handle contingencies.

[6] NUREG-0713 Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities, 2012, Vol. 34, U.S. Nuclear Regulatory Commission, April 2014.

[7] Watts Bar Nuclear Plant, Updated Final Safety Analysis Report (UFSAR).

[9] TVA has calculated the total annual C-14 production for WBN Unit 1 to be 11.2 Ci, 98 percent of the C-14 is gaseous, and 20 percent of the gaseous C-14 is carbon dioxide.

[10] NUREG-0017 R1 "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents From Pressurized Water Reactors" April 1985

[11] Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," Revision 1, October 1977.

[12] 10 CFR Appendix B to Part 20--Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage

[13] EPA-520/1-86-020, Federal Guidance Report No. 11 Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. Washington, D.C.

[14] Watts Bar Nuclear Plant (WBN) - Unit 1 - Revision of Boron Concentration Limits and Reactor Core Limitations for Tritium Production Cores (TPCs) - Technical Specification (TS) Change No. TVA-WBN-TS-00-015, August 20, 2001 (ADAMS Accession No. ML012390106).

[15] Regulatory Guide 1.183, **"**Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors**"**, July 2000

[16] Regulatory Guide 1.25, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors," March 1972

[17] NUREG/CR-5009, "Assessment of the Use of Extended Burnup Fuel in Light Water Power Reactors" February 1988