1101 Market Street, Chattanooga, Tennessee 37402

CNL-15-093

June 15, 2015

10 CFR 50.90

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

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

Subject: **Response to NRC Request to Supplement Application to Revise Technical Specification 4.2.1, "Fuel Assemblies" (WBN-TS-15-03) - Radiological Protection and Radiological Consequences**

Reference:

1. Letter From TVA to NRC, "Application to Revise Technical Specification 4.2.1, 'Fuel Assemblies,' (WBN-TS-15-03)," dated March 31, 2015 (ADAMS Accession No. ML15098A446)

2. Letter From NRC to TVA, "Watts Bar Nuclear Plant, Unit 1 - Supplemental Information Needed for Acceptance of Requested Licensing Action Regarding Application to Increase Tritium Producing Absorbing Rods (TAC NO. MF6050)," dated May 14, 2015 (ADAMS Accession No. ML15119A520)

3. Letter from TVA to NRC, "Response to NRC Request to Supplement Application to Revise Technical Specification 4.2.1, 'Fuel Assemblies' (WBN-TS-15-03)," dated May 27, 2015 (ADAMS Accession No. ML15147A611)

By letter dated March 31, 2015 (Reference 1), Tennessee Valley Authority (TVA) submitted a license amendment request (LAR) to revise Watts Bar Nuclear Plant (WBN), Unit 1 Technical Specification (TS) 4.2.1, "Fuel Assemblies," to increase the maximum number of Tritium Producing Burnable Absorber Rods (TPBARs) that can be irradiated per cycle from 704 to 1,792. The proposed change also revises TS 3.5.1, "Accumulators," Surveillance Requirement (SR) 3.5.1.4 and TS 3.5.4, "Refueling Water Storage Tank (RWST)," SR 3.5.4.3 to delete outdated information related to the Tritium Production Program.

By letter dated May 14, 2015, the Nuclear Regulatory Commission (NRC) requested that TVA provide additional information to supplement the LAR.

Enclosure 1 to this letter provides the requested radiation protection and radiological consequences supplemental information. Supplemental information requested in the Reference 2 letter related to human factors was submitted by TVA in the Reference 3 letter. Enclosure 2 to this letter provides a revised Review of Radiological and Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant Unit 1 - 1,792 TPBAR Core previously provided in Enclosure 2 to the Reference 1 letter. Enclosure 2 to this letter supersedes Enclosure 2 of the Reference 1 LAR in its entirety.

Consistent with the standards set forth in Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50.92(c), TVA has determined that the additional information, as provided in this letter, does not affect the no significant hazards consideration associated with the proposed application previously provided in Reference 1.

Additionally, in accordance with 10 CFR 50.91(b)(1), TVA is sending a copy of this letter and the enclosures to the Tennessee Department of Environment and Conservation.

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

I declare under penalty of perjury that the foregoing is true and correct. Executed on this 15th day of June 2015.

Respectfully,

J. W. Shea
Vice President, Nuclear Licensing

Enclosures:
1. WBN-TS-15-03 Supplemental Information
2. Review of Radiological and Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant Unit 1 – 1,792 TPBAR Core, Revision 1

Enclosures
cc (Enclosures):

NRC Regional Administrator - Region II
NRC Resident Inspector – Watts Bar Nuclear Plant
NRC Project Manager – Watts Bar Nuclear Plant
Director, Division of Radiological Health - Tennessee State Department of Environment and Conservation

ENCLOSURE 1

TENNESSEE VALLEY AUTHORITY
WATTS BAR NUCLEAR PLANT
UNIT 1

WBN-TS-15-03 Supplemental Information

Radiological Protection

Information needed by the U.S. Nuclear Regulatory Commission staff to begin its review of the Tennessee Valley Authority's (TVA, the licensee) request to increase tritium producing burnable absorber rods (TPBARs) related to radiological protection are described below.

The radiological considerations for production of tritium at Watts Bar Nuclear Plant, Unit 1 with 1,792 TPBARs irradiated per cycle, are provided in Enclosure 2 of the March 31, 2015, license amendment request (LAR), "Review of Radiological and Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant Unit 1 - 1, 792 TPBAR Core." Consistent with the NUREG-0800 Standard Review Plan, TVA uses two source terms for the evaluations (i.e., a design basis source term and a realistic source term).

1. *The design basis (DB) case assumes a maximum loading of 2,500 TPBARs in the core with a release rate of tritium (H-3) into the reactor coolant system (RCS) of 10 Ci/TPBARs/year. The design basis source term is used to evaluate the adequacy of the plant design features (e.g., radiation shielding, plant ventilation, and radwaste systems) to meet the occupational and public dose limits in 10 CFR [Title 10 of the Code of Federal Regulations] Part 20.*

2. *The realistic source term assumes a maximum loading of 1,900 TPBARs in the core with a release rate of H-3 to the RCS of 5 Ci/TPBARs/year. The realistic source term is used to demonstrate compliance with the offsite as low as reasonably achievable (ALARA) design objectives of 10 CFR Part 50, Appendix I.*

In general, the proposed revisions to the source term and the associated radiological assessment are a significant departure from those contained in the Topical Report which formed the basis for the original TPBAR license amendment. TVA needs to identify those assumptions and evaluations contained in this LAR that depart from the Topical, and provide a clear basis for the acceptability of each departure.

The evaluation provided in LAR Enclosure 2 contains several inconsistencies and omissions that must be provided as a supplement before the staff can draw any conclusions as to the acceptability of the proposed amendment request in terms of regulatory requirements and the protection of public health and safety and the environment. The information needed related to radiological protection include the following:

E2-1. Impact on Occupational Radiation Dose

LAR Enclosure 2 does not completely evaluate the impact occupational radiation doses. Based on several unsupported conversion factors (100 tritium derived air concentration (DAC)-hours per micro-Curie (µCi)/gm of RCS, and 1 µCi/gm in RCS = 0.08 DAC in containment), LAR Enclosure 2 (pages 23 and 24) calculates the expected average airborne H-3 levels in containment from operating at the DB assumptions, then calculates a corresponding minimal increase in containment dose rates and a moderate increase in annual collective occupational dose. However, as noted on page 23, 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 open processes that have been wetted with tritiated liquids." This assessment presented in Enclosure 2 does not evaluate the magnitude of this potential increased exposure pathway.

TVA needs to quantify the impact from the expected increase in RCS H-3 (resulting from operating at the DB conditions) on individual occupational radiation doses. In addition, TVA needs to provide a basis for the conversion factors used in this evaluation.

TVA Response:

The impact of increased tritium on individual occupational radiation doses was revised to provide a bounding assessment on overall station dose. License Amendment Request (LAR) Enclosure 2, Section "Tritium Impacts on Station Operation" - "Normal Operation" was revised to provide more details on how this value was determined. The conversion factors used in the previous version of the enclosure were replaced with a methodology using historical data and conservative assumptions that result in a bounding estimate. The above described changes are incorporated in Enclosure 2, pages 23 and 24 and denoted by revision bars in the right-hand page margin.

With regard to individual occupational radiation doses, prior to irradiating TPBARs in WBN, Unit 1, TVA established a radiation protection tritium control program at the WBN site. This program, documented in WBN plant procedure, Radiological Control Instruction (RCI)-137, Radiation Protection Tritium Control Program," is based on the guidance of NRC Regulatory Guide 8.32, "Criteria for Establishing a Tritium Bioassay Program," NUREG-1736, "Consolidated Guidance: 10CFR Part 20 - Standards for Protection Against Radiation," dated October 2001, Regulatory Guide 8.9, "Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program," and recommendations from the United States Department of Energy (USDOE) handbook DOE-HDBK-1079-94, "Primer on Tritium Safe Handling Practices." RCI-137 establishes actions to be taken whenever tritium levels detected in the Reactor Coolant System (RCS), Spent Fuel Pool (SFP), Chemical Volume Control System (CVCS), or any other liquid process exceed specified action levels. The action levels establish guidance for dealing with direct skin or clothing contact with a tritiated process, airborne exposure to tritium, and cumulative exposure to tritium. The RCI-137 specified actions are as follows.

Process Tritium Concentration (µCi/ml)	Total DAC-hrs	Mode of Exposure	Tritium Survey Requirements	Recommended Action
< 0.0001	N/A	direct contact	None	None
≥ 0.0001 to ≤ 0.01	N/A	direct contact	Periodic sampling of process	Prevent skin contact (e.g., gloves, rainsuits, and faceshields)
≥ 0.01	N/A	direct contact	Periodic sampling of process	Prevent skin contact. Perform random pre-job, during job, and post-job urinalysis if skin contact is possible.
≥ 0.1 to ≤ 20.0	N/A	airborne	Commence air tritium samples at RCS concentrations exceeding 0.1 µCi/ml.	Personnel protective equipment NOT required. Bioassay NOT required if no direct contact mode of exposure exists.
≥ 20.0 to ≤ 40.0	N/A *	airborne	Increased air sampling. Use real-time monitoring for personnel working in close proximity to open processes.	Consider respiratory protection, protective clothing, containments. Perform random pre-job, during job, and post-job urinalysis.
≥ 40.0 to ≤ 82.0	N/A *	airborne / direct contact	Routine tritium air sampling and real-time monitoring in all potentially affected and occupied areas. Periodic sampling of process	Consider respiratory protection, protective clothing, containments. Perform random pre-job, during job, and post-job urinalysis.
≥ 82.0	N/A	airborne / direct contact	Increase the frequencies of Air Sampling and Contamination surveys to weekly	Conduct Tritium surveys in the Auxiliary Building, Reactor Building, Service Building, Office Building Lunch room and RCS System breaches. Perform random urinalysis
H3 concentration and/or exposure time unknown, and cannot be estimated.	unknown	airborne or direct contact	Determine process concentration and commence air samples.	Implement protective actions and perform urinalysis of exposed personnel as indicated by subsequent surveys.
N/A	>40 DAC-hrs. in 7 day period or since previous bioassay in current year	airborne	Monitoring and sampling based on actual process concentrations as described above.	Perform urinalysis - all personnel exceeding limit.

*If air samples indicate ≥1 DAC-fraction (DACf) H3, all exposed personnel who wore respirators or protective clothing for protection from H3 should be sent for bioassay.

TVA's program for bioassay, documented in procedure RCDP-7, "Bioassay and Internal Dose Program," is based on Regulatory Guide 8.9. Random bioassays are performed for personnel exposed to open tritiated processes with tritium concentrations that exceed the trigger levels as outlined in the above table. Additionally, bioassays are performed for personnel who exceed the DAC-hr limit for cumulative or acute exposures to airborne tritium.

Contamination surveys are performed for activities related to the RCS, Safety Injection (SI) system, Residual Heat Removal (RHR) system, SFP, and Containment Spray (CS) system when a tritium concentration of 4 µCi/ml is exceeded. These surveys are performed using millipore or comparable smears that are dissolved in a liquid scintillation cocktail for counting.

Airborne surveys are performed when the tritium concentration in the RCS or any open liquid process system exceeds 0.1 µCi/ml. These surveys are performed using a Scintrex tritium monitor or by using the molecular sieve method. Only the molecular sieve method is used for assigning DAC-hrs or internal dose to personnel.

Section 1.5.15 in Enclosure 4 of the LAR [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)] that formed the basis for License Amendment 40 contained a discussion of the TVA monitoring capabilities; this discussion excerpted below remains applicable.

> **"Air Sampling**
> For Tritium air sampling the sampled gas (usually air) must be analyzed for tritium content (usually by liquid scintillation counting). The usual technique is to flow the sampled air through either a solid desiccant (molecular sieve, silica gel, or Drierite) or water or glycol bubblers.
>
> Another available technique for sampling HTO in room air is to use a "cold finger" or dehumidifier unit to freeze or condense the HTO out of the air. When using this methodology, to determine the tritium in air concentration, the relative humidity must be known. The typical lower limit of detection for in-station tritium air samples is 2×10^{-10} µCi/ml.
>
> **Liquid Monitoring**
> Liquids will be monitored by liquid scintillation counting. The typical lower limit of detection for in-station tritium liquid samples is 1×10^{-6} µCi/gm.
>
> TVA's liquid scintillation counters are periodically calibrated with radioactive sources, which are traceable to national standards. The counters are checked periodically with standard radioactive sources in accordance with instrument specific calibration and maintenance procedures."

Pages E2-24 and E-25 of the LAR discuss Tritium Control Values that are provided in the Topical Report to control the "undesirable radiological conditions" that can result from the buildup of H-3 in the RCS. Presumably, the basis for this control level is the potential for occupational dose since the revised value (the previous 3 µCi/gm increased to 14 µCi/gm) is based on the occupational Derived Airborne Concentration for H-3 in 10 CFR Part 20. However, the sixth paragraph on page E2-25 clearly states that the DB case (source term and assumptions) will not be able to meet this control level as revised. The estimated 29.8 µCi/gm DB case exceeds the control level by more than a factor of 2.

The licensee needs to clarify the basis for this control value, how it is applied to plant operations, and how the reposed DB is still within the Topical Report.

TVA Response:

The Department of Energy (DOE) topical report NDP-98-153, "Tritium Production Core (TPC) Topical Report," dated June 1998, and NUREG-1672, "Safety Evaluation Report Related to the Department of Energy's Topical Report on the Tritium Production Core," dated May 1999, concluded that there would be a negligible increase in the annual worker radiological exposure due to operation with TPBARs. This conclusion was based on the assumption that the reference plant would maintain the tritium primary coolant activity within the control value. However, TVA did not assume that the tritium primary coolant activity would be maintained at this control value in the LAR that formed the basis for License Amendment 40 or in this current LAR and instead determined the effect on occupational dose assuming design basis levels. Therefore, because TVA did not assume that the tritium primary coolant activity was maintained within the control value in order to meet any regulatory requirement or commitment, the section titled "Tritium Control Values (DOE, NRC, and Westinghouse Legacy Values)" was deleted from the revised LAR Enclosure 2 as well as any other discussion of the control value. The above described changes are incorporated in Enclosure 2, pages 9 and 25, and denoted by revision bars in the right-hand page margin.

E2-2. Impacts on Radioactive Waste Generation and Control

Enclosure 2, "Radwaste System Design Basis Operation" (page E2-24), does not address whether the radwaste system has sufficient capacity to effectively process the increased liquid input generated by the additional feed-and-bleed operations necessary to maintain the RCS H-3 concentrations below the tritium control level under DB conditions. The estimated DB case exceeds the control level by more than a factor of 2. TVA estimates the DB to result in H-3 concentrations of 29.8 µCi/gm then states that if H-3 concentrations exceed the 14 µCi/gm in the RCS, it will take further action to minimize the onsite and offsite radiological impacts of abnormal RCS tritium levels. Some examples of these actions include increased RCS feed and bleed operations. However, there is no indication of how effective these actions will be, nor the magnitude of the onsite and offsite radiological impacts that are expected to be attained. TVA needs to address this. In addition, "Solid Radioactive Waste" (page E2-27) does not address any increase in solid waste generated (e.g., expended ion exchange resins) from the increased liquid processing necessary to maintain RCS H-3 concentrations below the H-3 control level.

The licensee should provide this information or a basis for why no increase is expected.

<u>TVA Response:</u>

Consistent with the TVA response to Request for Supplemental Information (RSI) E2-1, TVA did not assume that the tritium primary coolant activity was maintained within the control value to meet any regulatory requirement or commitment. The design basis of the Liquid and Solid Radwaste Systems was demonstrated utilizing a design basis tritium concentration of 29.8 µCi/g. Because compliance with 10 CFR Part 20 was shown with this concentration, no additional feed and bleed operations are anticipated. LAR Enclosure 2, Section, "Solid Radioactive Waste," was also revised to clarify why no additional solid waste was evaluated with regards to resin generation. The above described changes are incorporated in Enclosure 2, pages 9, 25 and 34, and denoted by revision bars in the right-hand page margin.

E2-3. Impacts on Public Dose

Design Basis Source Term and 10 CFR Part 20 Compliance:

The fifth paragraph on page E2-24 indicates that the 14-fold increase in liquid and gaseous releases under the DB (26,889 Ci/year) continues to meet the 10 CFR Part 20 limits. No analytical evaluation results are provided to support these statements.

The licensee needs to provide an updated evaluation (similar to the corresponding safety analysis report tables) demonstrating that the increased DB effluent releases (liquid and gaseous) continue to meet 10 CFR Part 20 limits. This evaluation should include updated values for non-tritium isotopes, if the increased volume of radwaste discussed above reduces the efficiency of the radwaste processing.

TVA Response

LAR Enclosure 2 was revised to incorporate new Tables 5 through 9 to demonstrate compliance with 10 CFR Part 20, Appendix B, Table 2 limits for gaseous and liquid effluents. The existing Tables 5 and 6 were renumbered as Tables 10 and 13, respectively. Consistent with the TVA response to RSI E2-1, TVA did not assume that the tritium primary coolant activity was maintained within the control value to meet any regulatory requirement or commitment. An increased volume of radwaste is not expected and the efficiency of the radwaste system will remain unchanged. The above described changes are incorporated in Enclosure 2, pages 9 and 25 through 31, and denoted by revision bars in the right-hand page margin.

Realistic Source Term and 10 CFR Part 50 Appendix I Compliance:

Enclosure 2, "Tritium Impacts on Public Dose" (page E2-26), does not describe the impact of the H-3 on public dose. Table 5 on page E2-27 provides the results of two sets of offsite dose calculations: those performed to support License Amendment No. 40, allowing 2,304 TPBARs, and those performed to support this LAR, performed at 1,900 TPBARs. There is no explanation provided to explain why a more than 400 percent increase in H-3 releases (from 2,304 Ci/year to 9,500 Ci/year) results in a lower dose to the whole body from gaseous and significantly lower doses to the whole body and maximum organ dose from liquid emissions. The increase in maximum organ dose from gaseous effluents appears to be the result of adding Carbon-14 to the source term.

The licensee should provide an evaluation indicating the offsite dose resulting from the increased release and a rationale, including a description of any changes to the calculation input parameters and assumptions, for the unexpected results in Table 5.

TVA Response

LAR Enclosure 2 was revised to add a section that summarizes the changes in the source terms used. LAR Enclosure 2, Section. "Realistic Source Terms," was revised to provide more details on inputs and assumptions to the source term. LAR Enclosure 2, Table 10 (previously Table 5) was revised to compare offsite doses expected without TPBARs and with 1,900 TPBARs instead of providing a comparison to License Amendment 40. Table 10 shows that the dose remained the same or increased, as would be expected. This revised table provides better insight on the impact of the increase in TPBARs than the previous table. The above described changes are incorporated in Enclosure 2, pages 6 through 8, 16, and 33, and denoted by revision bars in the right-hand page margin.

Radiological Consequences

Information needed by the U.S. Nuclear Regulatory Commission (NRC) staff to begin its review of the Tennessee Valley Authority's (TVA, the licensee), license amendment request (LAR) to increase tritium producing burnable absorber rods (TPBARs) related to radiologic consequences is described below.

On page E2-29 of 33, "Radiological Consequences of Accidents," TVA describes that Watts Bar Nuclear Plant, Unit 1 License Amendment No. 40 (Agencywide Documents Access and Management System Accession No. ML022540925) assessed the station accident analyses affected by the production of 2,304 TPBARs and that the March 31, 2015, LAR for 1, 792 TPBARs is bounded by the previously NRG-approved license amendment, and that the radiological consequences remain well within a small fraction of the regulatory limits of Title 10 of the Code of Federal Regulations (10 CFR) Part 100, 10 CFR 50.67, and General Design Criterion 19. The March 31, 2015, submittal does not include sufficient information to support these statements. In addition, new insights were gained from Cycles 6 through 12. The Department of Energy topical report referred to in License Amendment No. 40 contains information on permeation rates that are now known to be inaccurate.

For the application to be acceptable, the licensee needs to provide information supporting the statements in its application. Specifically, it should provide the following:

E3-1. Provide a discussion of the technical analysis performed to determine that the current licensing basis radiological consequences for the design-basis accidents (DBAs) bound the new radiological consequences for DBAs accounting for the requested increase to 1,792 TPBARs per cycle. This technical analysis should do the following:

- *Show the current inputs and assumptions used for each design basis radiological consequence evaluation as compared to the new inputs and assumptions that reflect the insights gained from Cycles 6 through 12.*
- *Explain any differences, or if there are no differences, then it should explain why it is acceptable to remain the same considering the insights gained from Cycles 6 through 12.*

TVA Response:

LAR Enclosure 2, Section, "Radiological Consequences of Accidents," was revised to include the inputs and assumptions utilized for each design basis accident (DBA) related to the tritium source term for the current licensing basis and the new licensing basis, if changed. If the tritium source term was not affected by the insights gained from Cycles 6 through 12 (i.e., increased permeation rate), then an explanation was provided. A summary describing the various source terms was added. The above described changes are incorporated in Enclosure 2, pages 6 through 8, 35, 36 and 37, and denoted by revision bars in the right-hand page margin.

In addition, with one exception, the Main Steam Line Break and Steam Generator Tube Rupture inputs and assumptions are the same as those used to support License Amendment 91 regarding the change to the Dose Equivalent I-131 spike limit, which was approved in the NRC Safety Evaluation dated December 5, 2012 (ADAMS Accession No. ML12279A115). The only exception is the control room isolation delay time, which was increased from 40 seconds to 74 seconds to correct an error in how the delay time was determined.

E3-2. Provide the current licensing basis source term used for each design basis accident compared to the new source term that reflects the insights gained from Cycles 6 through 12.

TVA Response:

LAR Enclosure 2 Section titled "Radiological Consequences of Accidents," was revised to explicitly provide the tritium source term used in each DBA for the current licensing basis and the new licensing basis, if changed. The above described changes are incorporated in Enclosure 2, pages 6 through 8, 35, 36 and 37 and denoted by revision bars in the right-hand page margin.

E3-3. Provide the current licensing basis calculated doses compared to the new calculated doses that reflect the insights gained from Cycles 6 through 12.

TVA Response:

LAR, Enclosure 2 was revised to incorporate new Tables 11 and 12 to provide the current licensing basis calculated doses for the Loss of Coolant Accident (LOCA) and Fuel Handling Accident (FHA). In addition, Table 13 (previously Table 6) was revised to include the current licensing basis calculated values and the new calculated values. The above described changes are incorporated in Enclosure 2, pages 35, 36 and 37, and denoted by revision bars in the right-hand page margin.

ENCLOSURE 2

TENNESSEE VALLEY AUTHORITY
WATTS BAR NUCLEAR PLANT
UNIT 1

Review of Radiological and Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant Unit 1 – 1,792 TPBAR Core

Revision 1

(40 pages including cover)

Review of Radiological and Environmental Considerations for Production of Tritium at Watts Bar Nuclear Plant Unit 1 – 1,792 TPBAR Core

Revision 1

TENNESSEE VALLEY AUTHORITY

June 15, 2015

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Background

The Department of Energy (DOE) and the Tennessee Valley Authority (TVA) have agreed to cooperate in a program to produce tritium for the National Security Stockpile by irradiating Tritium Producing Burnable Absorber Rods (TPBARs) at Watts Bar Nuclear (WBN) Unit 1.

The initial environmental impacts of producing tritium at WBN Unit 1 were assessed in a Final Environmental Impact Statement (EIS) for the Production of Tritium in a Commercial Light Water Reactor (DOE/EIS - 0288, March 1999) which was prepared by DOE. TVA was a cooperating agency in the preparation of this EIS, and adopted the EIS in accordance with 40 CFR 1506.30 of the Council on Environmental Quality regulations. TVA's *Record of Decision* (ROD*) and Adoption of the Final Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor* were published in the Federal Register at 65 Federal Register 26259 (May 5, 2000). In addition to the DOE EIS and TVA's ROD, a Tritium Production Core (TPC) Topical Report (NDP-98-181, Revision 1) was prepared by DOE to address the safety and licensing issues associated with incorporating TPBARs in a pressurized water reactor (PWR). The Nuclear Regulatory Commission's (NRC) Standard Review Plan (SRP) NUREG-0800 was used as the basis for evaluating the impact of the TPBARs on a reference plant. The NRC reviewed the TPC Topical Report and issued Safety Evaluation Report (SER) NUREG-1672 to support plant-specific licensing of TPBARs in a PWR.

TVA letter dated August 20, 2001[1], addressed the interface items described in NUREG-1672, Section 5.1, and requested authorization to irradiate not more than 2,304 TPBARs in WBN Unit 1. NRC issued a Safety Evaluation (SE) approving WBN Unit 1 License Amendment 40 on September 23, 2002[2], authorizing WBN Unit 1 to irradiate up to a maximum of 2,304 TPBARs in WBN Unit 1. TVA's application for that amendment provided radiological analyses based on 2,304 Curies (Ci)/year release attributable to TPBARs, based on the TVA functional requirement of one Ci/TPBAR/year for 2,304 TPBARs. The SE recognized that for the 2,304 TPC "licensee calculations demonstrated that doses to the public from effluents and the tritium release concentrations will remain below offsite dose calculation manual (ODCM) limits and 10 CFR Part 20 release limits." The ODCM reflects the plant-specific, applicable requirements of 10 CFR Part 20 and 10 CFR Part 50, Appendix I. The NRC Environmental Assessment and Finding of No Significant Impact for the 2,304 TPC concluded that 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.*"

TVA notified NRC that TVA had imposed interim administrative limits on the number of TPBARs to be loaded in the WBN, Unit 1 reactor.[3] The interim controls limited the number of TPBARs to be irradiated in any cycle such that the total tritium released into the Reactor Coolant System (RCS) by permeation would remain below the 2,304 Ci value evaluated for WBN Unit 1 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, 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.[4] 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 for Cycle 9. The changes were expected to decrease the tritium permeation and achieve the original tritium permeation goal of less than 1.0 Ci/TPBAR/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.[5]

Radiological and Environmental Impact Considerations – 1,792 TPC[6]

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 for a 1,900 TPBAR 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[7] (i.e., station occupational exposure and radwaste system capability review).

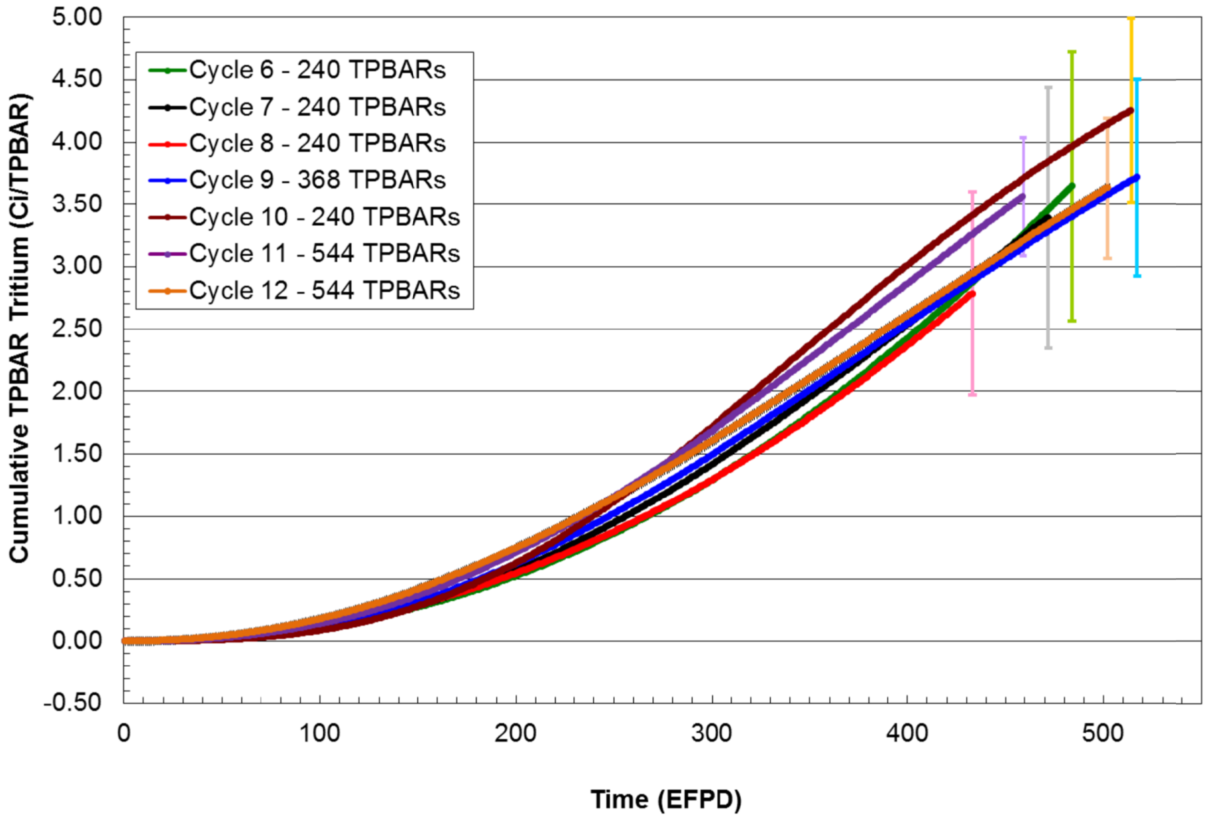
Technical justification: The realistic permeation rate of 5 Ci/TPBAR/year is acceptable because it bounds the observed permeation rate. The design basis permeation rate of 10 Ci/TPBAR/year provides an additional factor of two margin and is therefore reasonable, but conservative and bounding.

Pacific Northwest National Laboratory (PNNL)[8] has estimated the permeation and uncertainty for cycle 12 TPBARs as end of cycle release for cycle 12 was calculated to be 3.6 ± 0.6 Ci/TPBAR. The bounding annual tritium release rate for cycle 12, averaged over the last year of the cycle, was calculated to be 3.2 ± 0.6 Ci/TPBAR/year.

The estimated cumulative tritium permeation per TPBAR for WBN Unit 1 Tritium Production Cycles 6 – 12 are shown on Figure 1.

The Mark 9.2 TPBAR design[9] included significant design changes from the multi-pencil Production TPBAR design of the prior TPC Cycles. However, the average annual release rate per Mark 9.2 TPBAR (3.4 ± 0.8 Ci/TPBAR/year) is similar to that estimated for the multi-pencil Production Design TPBARs of previous WBN Unit 1 cycles.

Figure 1: Estimated TPBAR Permeation for WBN Unit 1 Cycles 6 through 12 (Uncertainty bars represent 90% confidence interval)



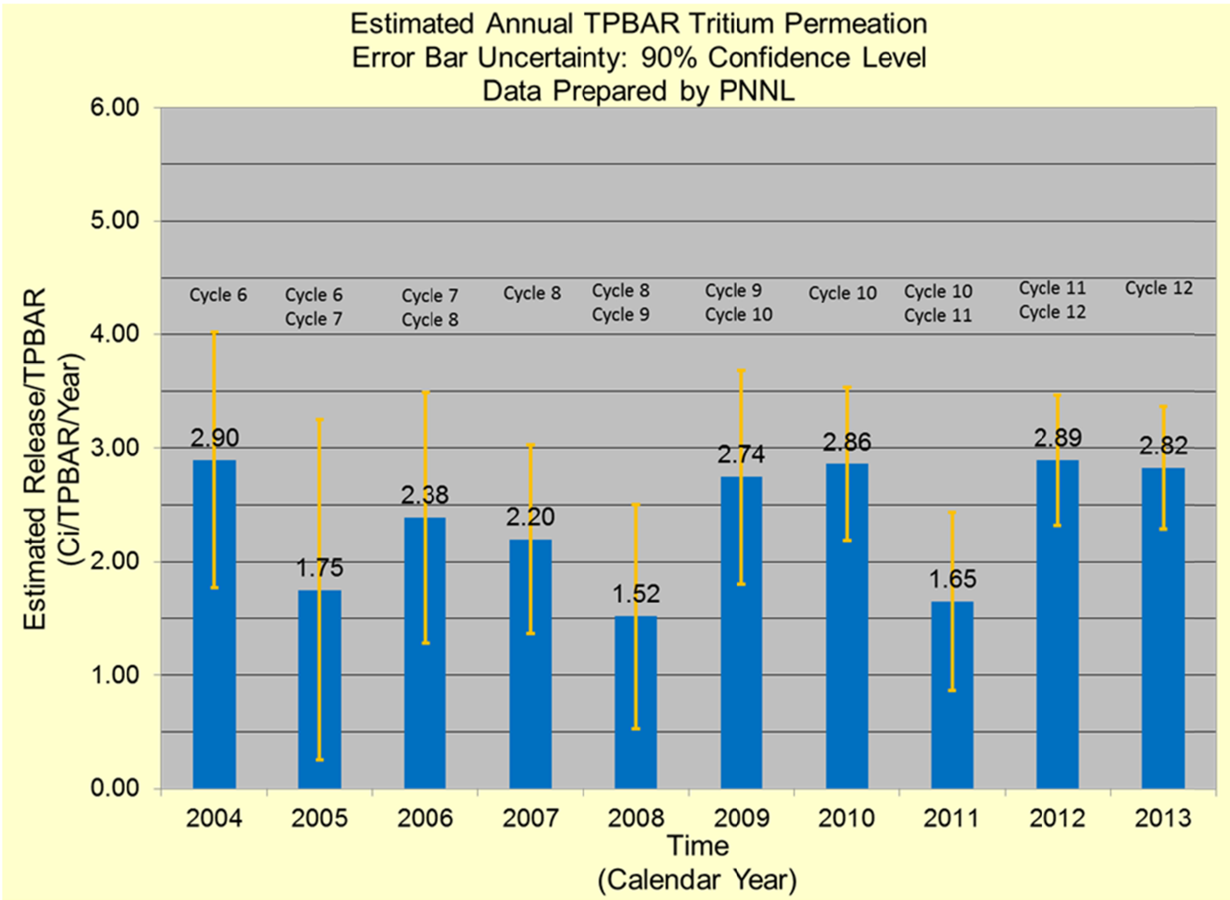
When the TPBAR permeation estimates are presented in a calendar year format (Figure 2), corresponding to the NRC monitoring and reporting requirements, the annualized per TPBAR permeation have consistently remained less than 3 Ci/year. With the approximate 18-month fuel cycles, portions of multiple (i.e., two) fuel cycles will occur periodically in the same calendar years.

Summary of Source Terms

The following source term changes have been made to address the changes in permeation.

Realistic Source Term: This source term is used for evaluation of normal effluent releases and estimating offsite dose. It was updated to reflect a new permeation rate of 5 Ci/TPBAR/year, which bounds the expected permeation rate. The source term was also updated to delete the contribution of two failed TPBARs, because such failures are not expected or realistic. Including the contribution of two failed TPBARs in the prior source term was done for calculation convenience (i.e., all of the sources terms used for different purposes were made to be the same) and represented excessive conservatism.

Figure 2: Estimated Annual TPBAR Permeation for WBN Unit 1 Cycles 6 through 12 (Uncertainty bars represent 90% confidence interval)



Radwaste System Design Basis Source Term: This source term is used for evaluation of radwaste system operation. It was updated to reflect a new permeation rate of 10 Ci/TPBAR/year, which bounds the realistic permeation rate with 100% margin. It also has increased margin by assuming ~40% more TPBARs are loaded (i.e., 2,500 TPBARs). The source term was also updated to delete the contribution of two failed TPBARs, because such failures are not the design basis case for radwaste system operation. It should be noted that the two failed TPBAR assumption previously used reflected an unrealistic and excessively conservative case, because the maximum TPBAR tritium Ci loading occurs at end of cycle life and the maximum RCS tritium concentration due to permeation occurs mid cycle. The mid cycle case is the proper design basis case for radwaste management to support continued operation for the remainder of the cycle. The modified source term provides sufficient margin to bound reasonable off-normal operational cases.

Non-LOCA Accident Source Term: This source term is used for evaluation of abnormal operational occurrences (AOOs) and postulated accidents (PAs). It was updated to reflect a new permeation rate of 10 Ci/TPBAR/year, which bounds the realistic permeation rate with 100% margin. It also has increased margin by assuming ~40% more TPBARs are loaded (i.e., 2,500 TPBARs). It continues to retain conservatism regarding the inclusion of two failed TPBARs. This bounding approach to source term assumptions for accidents is consistent with the accident

evaluation methodology. The modified source term provides sufficient margin to bound AOO and PA cases.

Fuel Handling Accident Source Term: The source term used for the fuel handling accident (FHA) is the same as the one used for the License Amendment 40 evaluation. WBN Unit 1 License Amendment 40 and the current licensing basis consider that all of the tritium content of 24 TPBARs is released into the surrounding water. This is the maximum number of TPBARs that would be in one fuel assembly. Because the design inventory of the TPBARs and the maximum number of TPBARs in one fuel assembly remains the same, the source term released to the surrounding water is not affected. Since issuance of License Amendment 40, WBN Unit 1 has modified the licensing basis for an FHA. License Amendment 92 was approved on June 19, 2013 (ML13141A564) and implemented an Alternative Source Term for the FHA. Included in this amendment was also a change to the amount of tritium that was released to the environment. License Amendment 40 assumed a 100% release and License Amendment 92 assumed a 25% release. The amount of tritium released to the environment is not affected by any of the changes being requested and thus, the current licensing basis remains bounding.

LBLOCA Accident Source Term: The source term used for the large break loss of coolant accident (LBLOCA) evaluations remains unchanged from License Amendment 40. The LBLOCA accident source term assumes that all of the end-of-cycle accumulation of tritium is released from 2,304 TPBARs. This assumption is not affected by any of the changes being requested and remains bounding.

In addition, this review incorporates the experiences and lessons from the previous Tritium Production Fuel Cycles at WBN (Cycles 6 – 12). This review addresses both the onsite and offsite potential radiological impacts of tritium production with 1,792 TPBARs.

Updated plant-specific evaluations (and analyses if required) were performed for WBN using the equations and values given in the Watts Bar Updated Final Safety Analysis Report (UFSAR) and ODCM. The review includes the identification of any significant differences between the updated TPBAR permeation estimates with a 1,900 TPBAR Core (Realistic Basis) and the WBN Unit 1 License Amendment 40 associated with the TPBARs and an assessment for potential impacts.

CONCLUSION

- Upon review of the documents and the analyses described above, this review determined that there were no substantial changes, that is, WBN Unit 1 will continue to demonstrate effluent release performance well within the regulatory As Low as Reasonably Achievable (ALARA) public dose guidelines of 10 CFR Part 50 Appendix I and occupational radiation exposure continues to be bounded by the station dose assessment of record[10], associated with the radiological impact analyses that were relevant to environmental concerns, nor were there any significant new circumstances or information relevant to environmental concerns which bore on the radiological impacts associated with the tritium production program. The impact of WBN Unit 1 operation with a TPC containing up to 2,500 TPBARs (Design Basis) will have a minimal impact on the Radwaste System Design Basis and realistic fission and corrosion product sources and the treatment of these isotopes in liquid and gaseous waste[11]. The Radwaste System Design Basis tritium sources are estimated to increase the amount of tritium that is discharged annually by a factor of about fourteen.
- As indicated in Table 10, "Annual Projected Impact of TPC (1,900 TPBARs) on Effluent Dose to Maximally Exposed Members of the Public and Total Public Dose," the differences noted in the source terms for TPC operation would not affect the ability of the plant to remain within the applicable regulatory requirements relative to radioactivity in effluents to unrestricted areas (i.e., 10 CFR Part 20), the "as low as is reasonably achievable" criterion (i.e., 10 CFR Part 50 - Appendix I). However, Radwaste System Design Basis tritium sources with 2,500 TPBARs are expected to increase the total amount of tritium that is generated in the plant by a factor of fourteen (i.e., from about 1,889 curies per year to approximately 26,889 curies per year).
- Updated program controls provide further refinement to the application of the TPBAR permeation performance metric. The permeation performance metric refinements will facilitate the monitoring of TPBAR cycle-to-cycle performance that will allow TVA and DOE to monitor TPBAR permeation performance as a metric for tracking, trending, and evaluating effectiveness of future design changes and TPBAR performance.

Radiological Impacts of the Proposed Irradiations

Tritium

Tritium is a radioactive isotope of hydrogen with a half-life of 12.3 years. Tritium undergoes beta decay, with a maximum energy of 18.6 KeV. The average energy is 5.7 KeV. This low energy limits the maximum range of a tritium beta to about 6 millimeters in air and 0.0042 millimeters in soft tissue. Therefore, the primary radiological significance of exposure to tritium is in the form of internal exposure. Tritium occurs naturally due to cosmic rays interacting with atmospheric gases. In the most important reaction for natural production, a fast neutron interacts with atmospheric nitrogen.

Chemical Forms and Properties[16]

Tritium is almost chemically identical to the other hydrogen isotopes and can exist in several chemical forms including:

- tritiated water (HTO)
- tritiated gas (HT)
- organically bound tritium (OBT)

Tritiated Water

The most common form of tritium is HTO, where a tritium atom replaces a hydrogen atom in water (H_2O) to form HTO. HTO has the same chemical properties as water and is also odorless and colorless. The majority of tritium in the atmosphere and Commercial Light Water Reactors (CLWR) is in the form of HTO which can be transferred to humans by inhalation, skin absorption (liquid and vapor), or ingestion of drinking water or food. HTO exposure is generally the most important consideration in assessing dose, because HTO quickly reaches equilibrium with water in the body and is distributed uniformly to all soft tissues. International Commission on Radiological Protection (ICRP) (1979[17]) recommended that internalized HTO be assumed to be completely and instantaneously absorbed and distributed uniformly with all body water. As a result, the concentration in sweat, sputum, urine, blood, perspiration, and exhaled water vapor is taken to be the same. HTO is excreted via urine, feces, sweat, and breath.

Tritiated Gas

HT is formed when a tritium atom replaces a hydrogen atom to form a tritium- hydrogen bond. In its elemental form, HT is an invisible, odorless gas chemically identical to hydrogen gas. HT is relatively inert in biological systems and has a very low uptake into body fluids and tissues. The main exposure pathways of HT include inhalation or skin contact with HT-contaminated surfaces. Releases from tritium processing facilities (such as self-luminous light manufactures, tritium recovery facilities, and nuclear fuel processing facilities) represent the primary source of exposure to HT. HT can be oxidized in the atmosphere to HTO.

Organically Bound Tritium

Following an intake of tritium (typically in the form of HTO) by plants or animals, a fraction of the tritium can become incorporated into organic molecules such as carbohydrates, fats, or proteins and is termed OBT. Within the body, OBT can become incorporated into various compounds such as amino acids, sugars, and structural materials. OBT can also enter the body directly by ingestion of tritiated food, by inhalation of volatile organic vapors or aerosols.

Tritium Summary

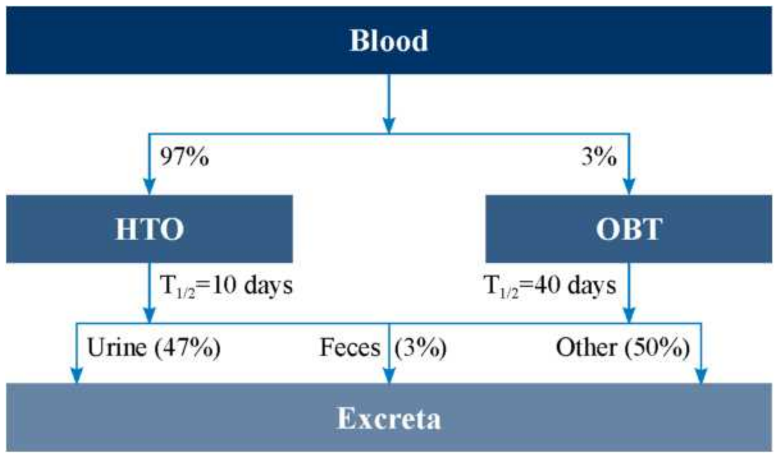
- Tritium is the only radioactive isotope of the element hydrogen.
- Tritium atoms can replace hydrogen in water molecules to form HTO, in organic molecules to form OBT and in air to form HT.
- Tritium is one of the lowest energy beta particle emitters. When it is incorporated into the body, more tritium is required than other radioisotopes to cause the same dose.
- Tritium occurs both naturally and as a by-product of the operation of nuclear power and research reactors. It can pose a health risk if it is ingested through drinking water or food, or if it is inhaled or absorbed through the skin in large quantities.

Dosimetric Considerations

Radiation doses from tritium cannot be measured directly and so are usually estimated by measuring the tritium in bioassay samples (such as urine) or through environmental monitoring (air sampling). Once an estimate of the quantity of tritium in the body is made, the dose can be calculated by using biological models that estimate the concentration of tritium in organs and tissues. For intakes as HTO, the current model assumes instantaneous translocation to blood. It is further assumed that HTO is transferred from the blood, with a biological half-life of 6 hours and then distributed uniformly throughout the body. The model assumes that 97% of tritium taken in remains as HTO once distributed, while 3% is converted to OBT. In adults, HTO is retained with

a biological half-life of 10 days, and OBT is retained with the biological half-life of carbon, which is 40 days.

Figure 3: ICRP Model for the Biokinetics of Tritiated Water[18]



The committed effective dose-per-unit intake (dose coefficient) to adults resulting from the intake of HTO, as recommended by the ICRP (ICRP, 1993[19]; ICRP, 1995a[20]), is based on Figure 3. This model considers the ICRP's recommendations for radiation weighting factors as well as tissue weighting factors. The committed effective dose-per-unit intake is the computed effective dose received up to 50 years following a single intake for adults, and up to 70 years for intakes by infants and children. The value for intakes of HTO by adults computed by the ICRP is 1.8×10^{-11} Sv/Bq (0.066 mrem/µCi).

The Federal Guidance Report 11[21] value (Technical basis for 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[22] for adult committed effective dose-per-unit tritium intake is 1.73×10^{-11} Sv/Bq (0.064 mrem/µCi). Current NRC Regulations were developed prior to the latest ICRP recommendations and do not account for OBT.

Tritium Analysis

Because of the low beta energies, liquid scintillation counting is a convenient, reliable, and practical way of measuring tritium in the liquid phase. The technique consists of dissolving or dispersing the tritiated compound in a liquid scintillation cocktail, and counting the light pulses emitted from the interaction between the tritium betas and the cocktail. The light pulses are counted by a pair of photomultiplier tubes which, when coupled with a discriminator circuit, can effectively distinguish between tritium betas and those from other radioactive sources.

Tritium Source Terms

Regarding tritium sources, in a non-Tritium Production Core (non-TPC), the production of tritium in the RCS is primarily the result of tritium production/release from:

- Fuel Rods (Ternary fission and Integral Fuel Burnable Absorbers (IFBAs)),
- Control Rods,

- Secondary neutron source rods,
- Wet Annular Burnable Absorbers (WABAs),
- RCS Deuterium (Heavy Water) activation,
- RCS Boron activation, and
- RCS Lithium activation.

A review of Westinghouse PWR benchmark tritium data[23] indicates a nominal production/release tritium value of about 870 Ci/year/unit. This nominal value is consistent with the 845 Ci/year/unit average non-TPC tritium effluent total observed over the four year period (1997 – 2000) at WBN and Sequoyah (SQN).

Tritium Source Term Definition and Discussion

Following the review guidance in Chapter 11, "Source Terms," in NUREG-800 Standard Review Plan[24] , TVA uses two source terms for the effluent evaluations: radwaste system design basis source term and realistic source term. The definition of these two source terms is consistent with the description of the source terms found in Section C.I.11 of Regulatory Guide 1.206.[25]

> "*Provide two source terms for (1) the primary coolant and reactor steam for BWRs, and (2) primary and secondary coolants for PWR plants. The first source term is a conservative or Radwaste System Design Basis source term which assumes a Radwaste System Design Basis fuel defect level. Provide the Radwaste System Design Basis reactor primary and secondary coolant fission, activation, and corrosion product activities. The reactor core fission product inventories are determined based on time-dependent fission product core inventories that are calculated by the ORIGEN code. The first source term serves as a basis for:*
>
> *(1) Radwaste system design capability to process radioactive wastes at Radwaste System Design Basis fuel defect level and fission product leakage level,*
>
> *(2) Confirmation of compliance with radioactive gaseous and liquid effluent release standards and effluent monitoring requirements under routine operations and anticipated operational occurrences, and*
>
> *(3) Shielding require ments and compliance with occupational radiation exposure limits.*
>
> *The second source term is a realistic model which represents the expected average concentrations of radionuclides in the primary and secondary coolant. Provide realistic reactor primary and secondary coolant fission, activation, and corrosion product activities. The supporting information should describe expected liquid and gaseous source terms by plant systems, transport or leakage mechanisms, system flow rates, applicable radionuclide partitioning and decontamination factors, etc., and release pathways. For PWRs, provide these activities in the steam generator secondary side for the liquid and steam phases. These values should be determined using the model in ANSI/ANS 18.1-1999,*

NUREG-0016 (BWR-GALE code), and NUREG-0017 (PWR-GALE code).

The realistic source term provides the bases for estimating typical concentrations of the principal radionuclides. This source term model reflects the industry experience at a large number of operating reactor plants. The realistic source term is used to calculate the quantity of radioactive materials released annually in liquid and gaseous effluents during normal plant operation, including AOOs to demonstrate compliance with the liquid and gaseous effluent concentration limits in Table 2 of Appendix B, "Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage," to 10 CFR Part 20; the dose limits in 10 CFR 20.1301, "Dose Limits for Individual Members of the Public"; the compliance requirements in 10 CFR 20.1302, "Compliance with Dose Limits for Individual Members of the Public"; and the ALARA design objectives of Appendix I to 10 CFR Part 50."

Radwaste System Design Basis Source Terms[26]

Gamma ray sources were considered in the plant design; they included fission and corrosion product sources, as well as activation sources such as the nitrogen-16 activity in the primary coolant. The changes in nuclide inventories were addressed in the tritium production NRC SE for WBN Unit 1 License Amendment 40[27], "*TVA has performed an analysis of the radioisotope inventory for a TPC using the ORIGEN2.1 computer code. A comparison of noble gas and iodine activities for a conventional core and a TPC core is provided in Table 2.11.2-1. The Iodine inventories are generally less, with the exception of Iodine 131. The analysis resulted in a minimal increase in this isotope of approximately 2 percent. This increase can be attributed to modeling differences and is not considered significant. This table shows that the isotopic concentrations of the more important noble gases are less for the TPC than for a conventional core."* The August 20, 2001 submittal addressed a TPC with 2,304 TPBARs and is considered bounding for the other than tritium nuclides.

Table 1: License Amendment 40 ORIGEN2.1 Radioisotope Non-TPC and TPC Comparison

Table 2.11.2-1 Comparison of Core Noble Gas and Iodine Activities for a Conventional Core to a Tritium Producing Core (Note 1)		
	Total Core Inventory (Curies)	
Isotope	**Conventional Core**	**TPC**
Kr 85m	3.95E+07	2.69E+07
Kr 85	9.99E+05	8.81E+05
Kr 87	7.59E+07	5.23E+07
Kr 88	1.08E+08	7.38E+07
Xe 133	2.03E+08	1.88E+08
Xe 135m	5.46E+07	3.59E+07
Xe 135	5.55E+07	4.96E+07
Xe 138	1.79E+08	1.59E+08
I 131	8.80E+07	9.01E+07
I 132	1.34E+08	1.31E+08
I 133	1.97E+08	1.88E+08
I 134	2.31E+08	2.08E+08
I 135	1.79E+08	1.76E+08

Note 1: WBN 96-Feed Equilibrium Core End-of-Cycle Operation at 3480 MWt for 510 days.

The cycle quantity of tritium produced and the Radwaste System Design Basis production/release in the RCS (Radwaste System Design Basis activity levels are considered in the process capacity design of plant systems and shielding) for the WBN reactor may be found in Table 11A-1 of the UFSAR. The annual Radwaste System Design Basis for a non-TPC is summarized in Table 2.

Table 2: Non-TPC Tritium Production/Radwaste System Design Basis Values (Annual per UFSAR Table 11A-2)

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% Design, 2% Expected

Release fraction from burnable poison rods = 10% Design, 2% expected

Operating time = 495 days

RCS Lithium concentration = 2.2 parts per million (ppm)

Initial RCS boron concentration = 1100 ppm.

The annual Radwaste System Design Basis tritium production/release with 2,500 TPBARs is summarized in Table 3.

Table 3: 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)
Non-TPC Tritium	14,484	1,889
TPBARs (2,500 with 10 Curies/TPBAR/Year permeation)	15,332,500	25,000
Total	15,346,984	26,889

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

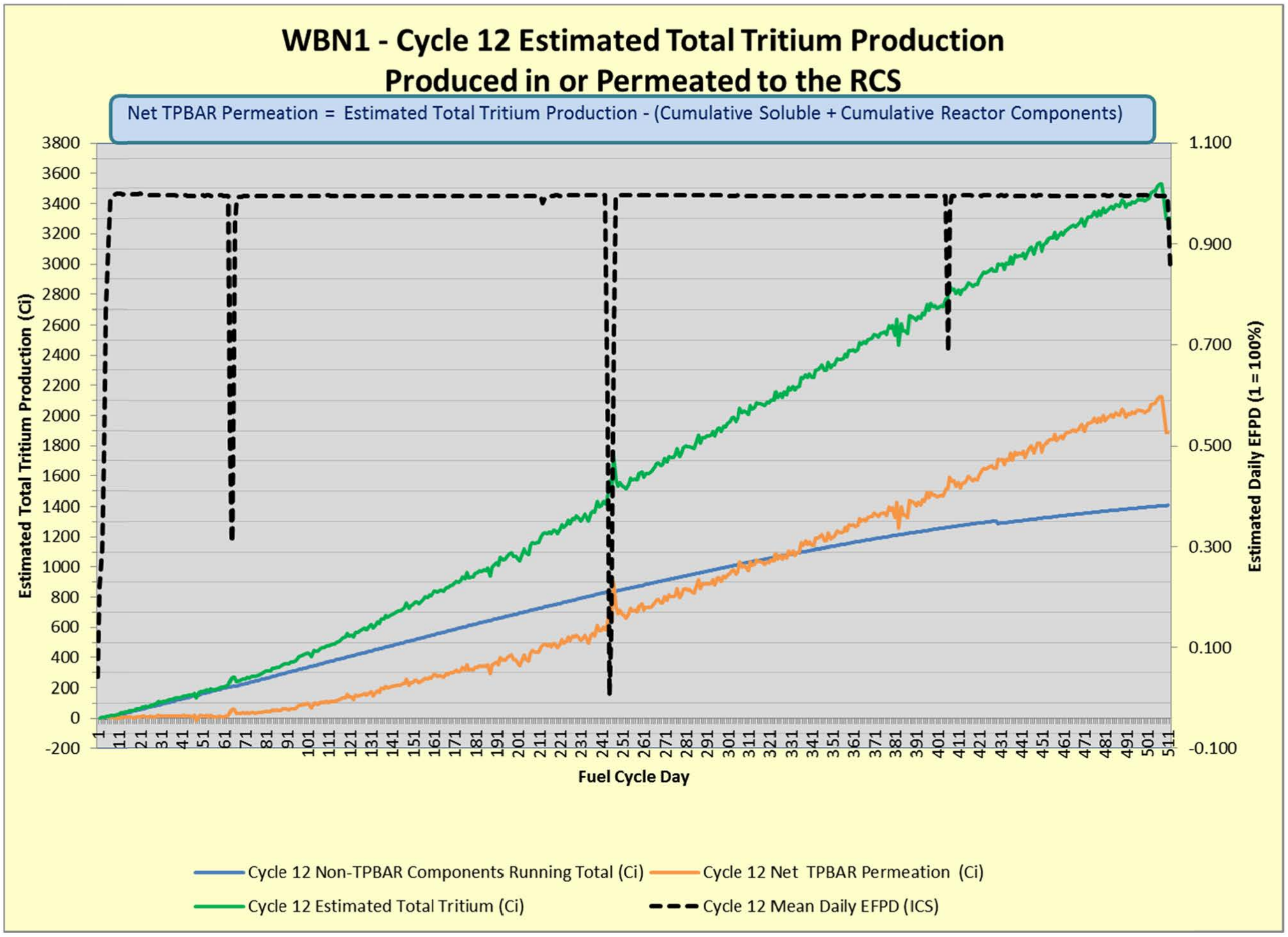
The NRC's regulatory guidance on WBN's nominal tritium production is found in NUREG-0017 R1[28]. The calculated realistic WBN 1 average annual tritium value from NUREG-0017 R1 is 1,392 Ci. The NRC tritium value with the addition of the 9,500 (1,900 TPBARs at 5 Ci/year) for a total average annual 10,892 tritium curies from the TPC was used by TVA to demonstrate continued compliance with the offsite ALARA dose objectives of 10 CFR Part 50 Appendix I.

The Realistic source term was updated from the License Amendment 40 source term to reflect a new permeation rate of 5 Ci/TPBAR/year, which bounds the expected permeation rate. The source term was also updated to delete the contribution of two failed TPBARs, because such failures are not expected or realistic. Including the contribution of two failed TPBARs in the prior source term was done for calculation convenience (i.e., all of the sources terms used for different purposes were made to be the same) and represents excessive conservatism.

WBN Operational Experience with Tritium Production Cores

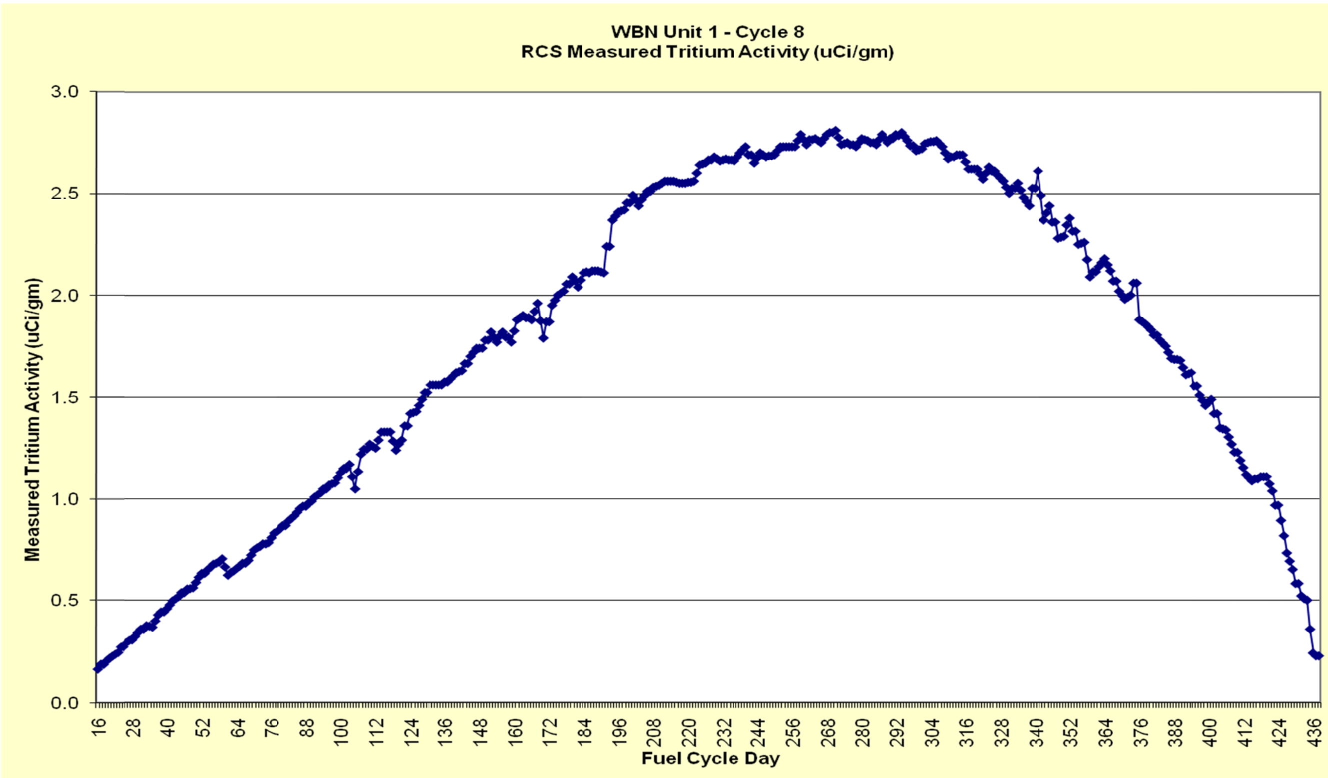
When reviewing station annual tritium effluents, it is important to recognize that plants such as WBN Unit 1 operate with 18-month fuel cycles which tend to generate more non-TPBAR tritium early in the core cycle, owing to higher initial boron concentrations and/or burnable poisons and IFBA rods that are required for reactivity control and more TPBAR-generated tritium later in core life as the tritium inventory within a TPBAR increases from 0 curies at the beginning of the cycle to an average of about 9,200 curies at the end of cycle. Figure 4 provides estimated Cycle 12 daily tritium RCS production/permeation rates for WBN Unit 1 with 540 Mark 9.2 TPBARs and four Lead Use Assemblies. The production by the soluble sources (i.e., Boron, and Lithium) decrease as the RCS is diluted to compensate for fuel burn up (i.e., peak RCS boron 1,615 ppm, End of Cycle RCS boron 62.4 ppm). Reactor component tritium production sources consist of fuel rods, control rods, secondary source rods, and WABAs. Reactor component tritium production tends to remain relatively flat (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 may be related to their physical location within the core (neutron flux and temperature). 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 4: Estimated Daily Tritium Releases to RCS with 540 Mark 9.2 TPBARs and 4 Lead Use Assemblies



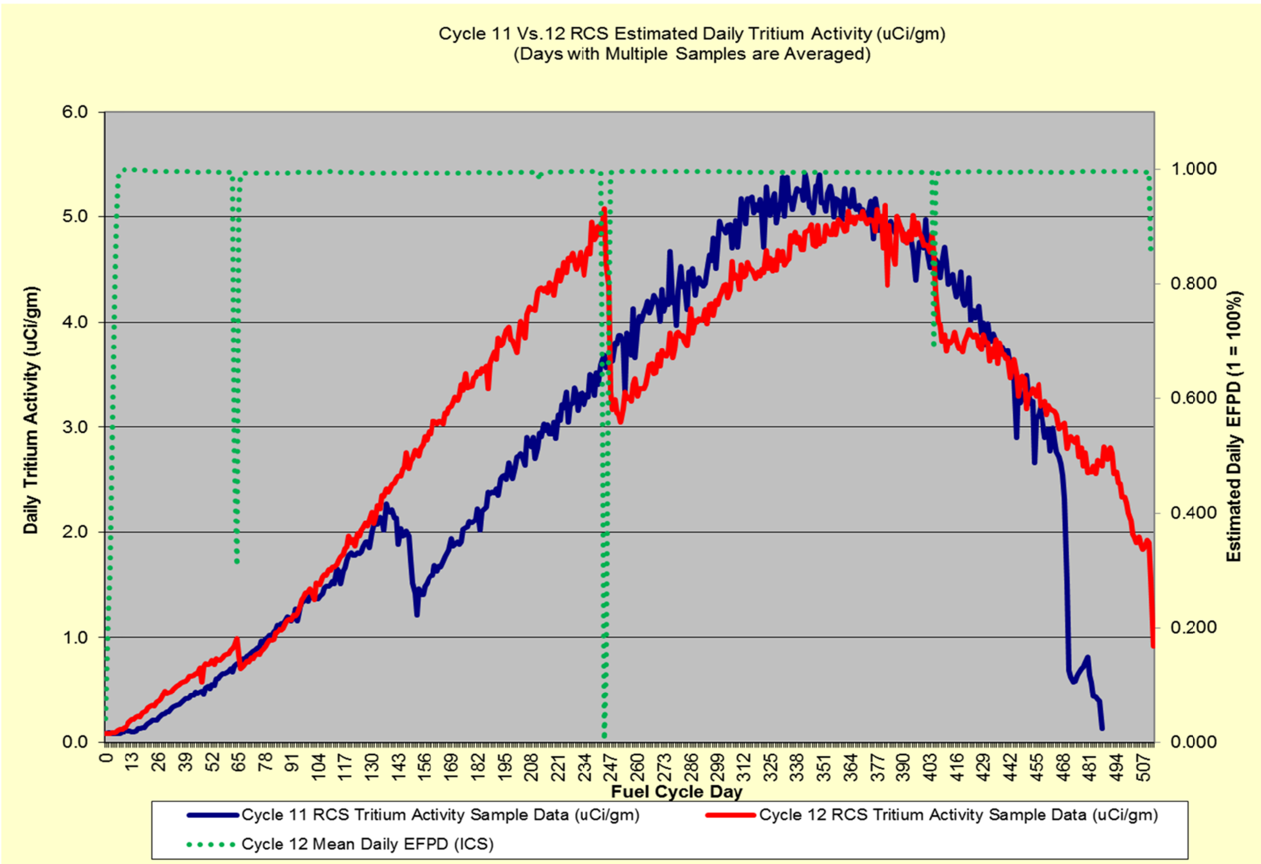
The typical RCS tritium concentrations patterns for breaker–to-breaker runs from WBN Unit 1 Cycle 8 are shown below in Figure 5 as an example. WBN Unit 1 non-tritium production Cycle 3 demonstrated a similar pattern. Cycles with breaker–to-breaker runs tend to demonstrate the highest peak RCS tritium concentrations.

Figure 5: RCS Tritium Concentrations (Breaker–To-Breaker Run) from WBN Unit 1 Cycle 8 (240 TPBARs)



WBN latest complete Tritium Production 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 reductions. A comparison of the daily RCS tritium activity for Cycles 11 (544 TPBARs) and 12 (544 TPBARs) is shown in Figure 6 and demonstrates the variability introduced and effect of down powers and outages on RCS tritium activity.

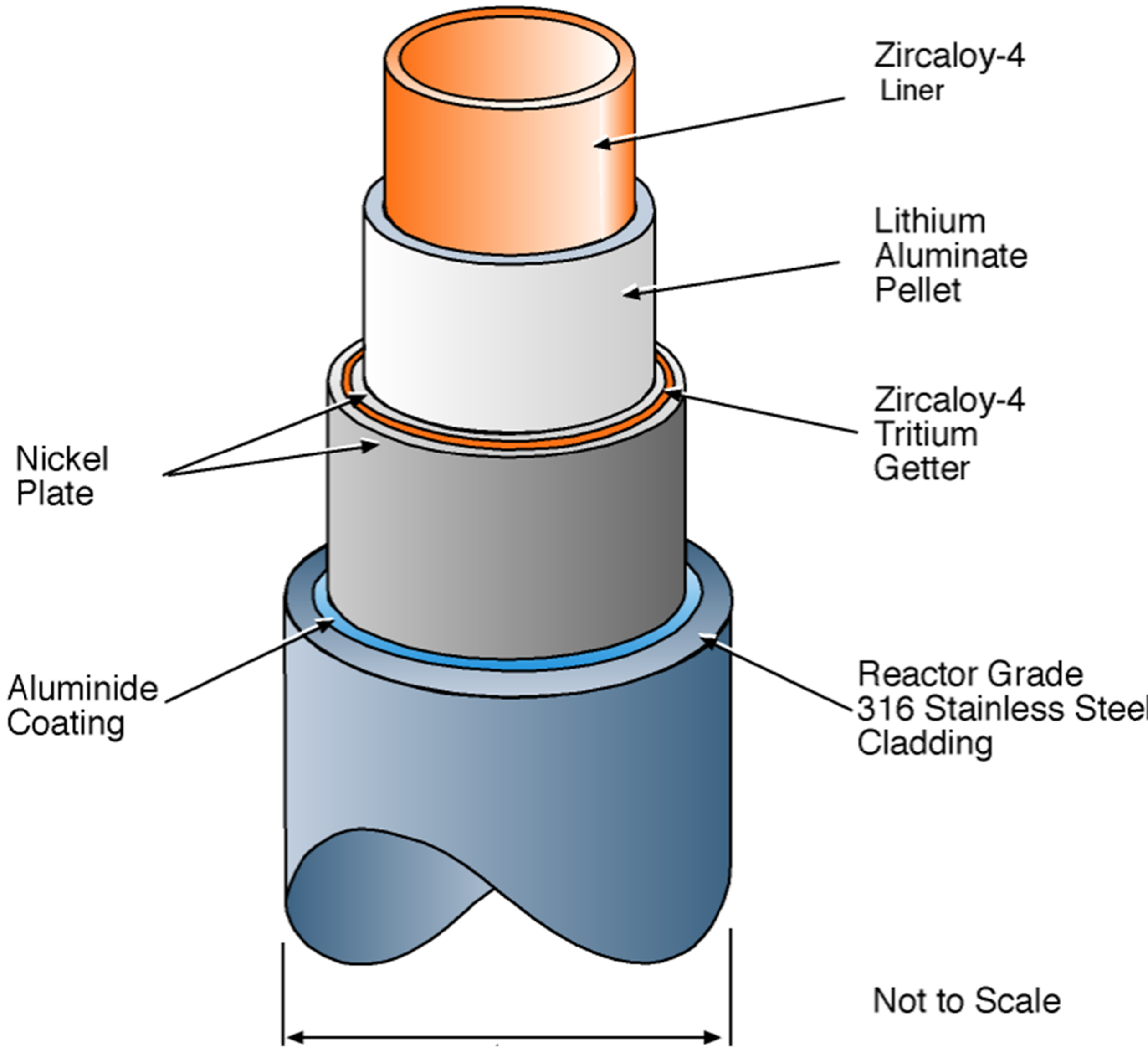
Figure 6: Comparison of the Daily RCS Tritium Activity for Cycles 11 and 12



TPBAR Tritium Permeation

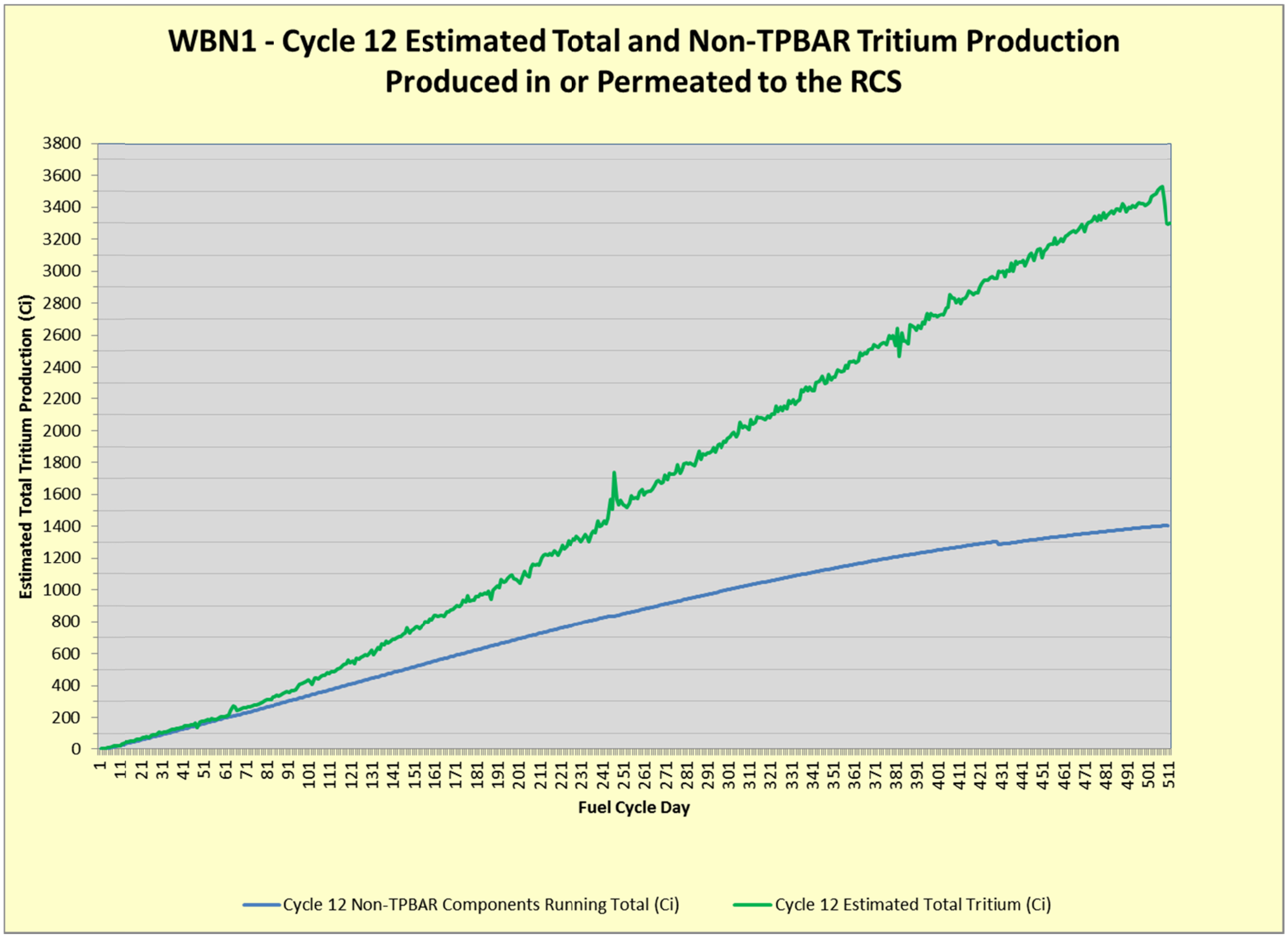
The TPBARs irradiated at WBN are designed with a stainless steel cladding and an aluminized internal coating. The tritium is produced by neutron irradiation of lithium aluminate pellets contained within the cladding and is gettered (collected and retained) by annular zirconium sleeves (getters) around the pellets. The aluminized coating and stainless steel cladding act as a barrier to tritium release (Figure 7). TPBARs are designed and fabricated to retain as much tritium as possible within the TPBAR. Because 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.

Figure 7: Concentric, Cylindrical, Internal Components of a TPBAR[29]



As with other tritium producing components (fuel rods, control rods, secondary neutron source rods, etc.) some of the 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 (Figure 8). 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. Figures 4 and 8 demonstrate this process by using the Cycle 12 estimated tritium production.

Figure 8: Cycle 12 Estimated Total Non-TPBAR and Total Tritium Production/Releases to the 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 estimated 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 sum of the (estimated) 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.

$$T_{Total}(t) = T_{Current\ RCS\ Inventory}(t) + T_{Removed\ Letdown}(t)$$

(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. Thus,

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

$$T_{non\text{-}TPBAR}(t) = T_{Soluble\ Boron}(t) + T_{Lithium}(t) + T_{Fuel\ Rods}(t) + T_{Burnable\ Absorbers}(t) + T_{Control\ Rods}(t) + T_{Secondary\ Source\ Rods}(t)$$ [30]

There can be significant uncertainties in both the total (calculated) cumulative tritium to-date and the projected cumulative tritium generated from non-TPBAR sources. This results in a significant uncertainty in the amount of tritium attributable to TPBARs. The estimated cumulative tritium permeation per TPBAR for WBN Tritium Production Cycles 6 – 12 with a 90% uncertainty are shown on Table 4.

Table 4:[31] Estimated TPBAR Permeation for WBN Cycles 6 through 12 (Uncertainty represents 90% confidence interval)

Cycle Number	Cycle Length (EFPD)	End of Cycle (Ci/TPBAR)	Last 365 Days (Ci/TPBAR/year)
Cycle 6	483.7	3.5 ± 1.1	3.3 ± 1.2
Cycle 7	489.5	3.5 ± 1.1	3.2 ± 1.3
Cycle 8	432.1	2.8 ± 0.8	2.7 ± 0.9
Cycle 9	516.6	3.8 ± 0.8	3.4 ± 0.8
Cycle 10	513.3	4.3 ± 0.7	4.0 ± 0.8
Cycle 11	458.7	3.5 ± 0.5	3.4 ± 0.5
Cycle 12	501.5	3.6. ± 0.6	3.2 ± 0.6

Tritium Impacts on Station Operation

Normal Operation

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% due to flashing and Spent Fuel Pool (SFP) evaporative losses is the assumed gaseous effluent fraction for dose impact modeling (NUREG-0017, Revision 1), whereas WBN Unit 1 effluent history indicates an average of ≈5.0%. 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 max just less than 7.0 µCi/gm. With routine boron control, 2,500 TPBARs at 10 Ci/TPBAR/year the estimated average Design Basis RCS tritium concentration is estimated to be 29.8 µCi/gm. With 1,900 TPBARs at 5 Ci/TPBAR/year, the estimated average Realistic Basis RCS tritium concentration is estimated to be 12 µCi/gm[32].

There is a strong correlation between the RCS tritium concentration and the containment airborne tritium concentration (Station tritium dose). It is understood that containment tritium derived air concentration (DAC) values are a function of the RCS tritium activity, the transfer of tritium from the RCS to the containment atmosphere (leak rate), and the turnover/dilution of the containment atmosphere through periodic and continuous containment venting and purging. Consistent with License Amendment 40, site-specific data collected during extended non-TPC operating cycles (i.e., WBN Unit 1 Cycle 3 and SQN Unit 1 Cycle 10, breaker-to-breaker Non-TPC cycles) have provided useful data to estimate the effect from tritium production on TVA PWR 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 extended cycle tritium peak RCS tritium value of ≈ 2.5 µCi/gm resulted in a containment peak tritium DAC-fraction of <0.15 for both WBN and SQN. The extended cycle tritium average RCS tritium value of ≈ 1.0 µCi/gm resulted in a containment average DAC-fraction of about 0.08.

The projected tritium release to the RCS with a TPC containing TPBARs releasing tritium at the design maximum rate (i.e., Table 3) will result in about a factor of fourteen increase over the Non-TPC tritium production rate, that is,

Ratio = (TPC) 26,889 Ci/year / (Nominal Core) 1,889 Ci/year = 14.2

TVA determined that with no modifications to the current boron-control feed and bleed methodologies (366,000 gallon cycle letdown), the design basis RCS average tritium value will be 29.8 µCi/gm. This mean value would indicate an estimated average containment tritium DAC-fraction of

0.08 DAC-fraction / 1 µCi/gm H3 * 29.8 µCi/gm = 2.38 DAC-Fraction

The design basis estimated containment average tritium DAC-fraction equates to an effective dose rate of

2.38 DAC-fraction * 2.5 mrem/DAC-hour ≈ 6 mrem/hour

Because the primary radiological significance of exposure to tritium is in the form of internal exposure, a potential hazard arises when personnel are exposed to open processes that have been wetted with tritiated liquids. TVA used the site-specific data collected during recent

extended operating cycles to evaluate the additional committed effective dose equivalent from possible increased tritium airborne activity from this potential hazard. The effect on station occupational exposure due to increased tritium concentration in the RCS was estimated based on the historical committed effective dose equivalent (CEDE) reported to the NRC. Based on data in NUREG-0713 volumes 21 through 28 (1999 through 2006), the average collective CEDE for WBN was approximately two person-rem per year. Conservatively assuming that this collective CEDE was entirely due to tritium, the expected increase utilizing the design basis tritium source term would result in the following bounding increase in CEDE:

2.0 person-rem/yr * 29.8 µCi/gm /1 µCi/gm H3 = 59.6 person-rem/yr

It should be noted that in NUREG-0713 volumes 29 through 34 (2007 through 2012), WBN did not report any Collective CEDE. Therefore, because tritium is only one of many isotopes that contributed to the reported CEDE and recent performance has shown a noticeable decline in CEDE, the above estimated increase in dose is extremely conservative; the actual CEDE is expected to be much less.

Additionally, TVA has estimated the occupational dose received due to fuel and TPBAR handling activities. TVA's current estimate of the TPBAR cycle work scope includes pre-cycle preparation activities, post cycle hardware removal and handling activities, TPBAR consolidation (including equipment setup and disassembly), shipping activities, and the processing, packaging, and shipping of the irradiated components. Based on actual dose accrual, the average dose for these activities is 0.46 mrem/TPBAR[33]. Consistent with the difference between the realistic permeation rate and the design basis permeation rate, this value was then multiplied by two. The result was then rounded up to 1 mrem/TPBAR. TVA estimates that when using Radwaste System Design Basis Tritium values for the 2,500 TPBAR core, this additional TEDE is approximately 1.7 rem/year (2.5 rem per TPC cycle) for TPBAR handling and consolidation activities.

Therefore, an additional 61.3 rem/year is estimated for the increase in airborne activity and for fuel and TPBAR handling activities. WBN's current three year collective TEDE per reactor year 2010 – 2012 is 39.998 rem[34]. An additional annual average 61.3 tritium rem would raise the TEDE total to 101.3 rem; a value that remains within the 149 rem assessment[35] total.

Radwaste System Design Basis Operation

The radwaste system design basis source term was updated from the License Amendment 40 source term to reflect a new permeation rate of 10 Ci/TPBAR/year, which bounds the realistic permeation rate with 100% margin. This source term also has increased margin by assuming ~40% more TPBARs are loaded. The source term was also updated to delete the contribution of two failed TPBARs, because such failures are not the design basis case for radwaste system operation. It should be noted that the two failed TPBAR assumption previously used reflected an unrealistic and excessively conservative case, because the maximum TPBAR tritium Ci loading occurs at end of cycle life and the maximum RCS tritium concentration due to permeation occurs mid cycle. The mid cycle case is the proper design basis case for radwaste management to support continued operation for the remainder of the cycle. The modified source term provides sufficient margin to bound reasonable off-normal operational cases.

The effect of WBN Unit 1 operation with a TPC containing up to 2,500 TPBARs (Design Basis) will have a minimal effect on the Radwaste System Design Basis and realistic fission and corrosion product sources and the treatment of these isotopes in liquid and gaseous waste[36]. The Radwaste System Design Basis tritium sources are estimated to increase the amount of tritium that is discharged annually by a factor of about 14. The analyzed gaseous releases are based on

the design basis tritium source term. For liquid releases, the maximum allowable liquid concentration of tritium released to the environment was determined.

Effluent releases to the environment are controlled to meet 10 CFR Part 20 release limits by WBN Unit 1 Technical Specification 5.7.2.7, *Radioactive Effluent Controls Program*. The Radioactive Effluent Release Report is submitted to NRC as required by WBN Unit 1 Technical Specification 5.9.3, *Radioactive Effluent Release Report*. The report includes a summary of the quantities of radioactive liquid and gaseous effluents and solid waste released from the unit.

Release of the radioactive liquids from the liquid waste system is made only after laboratory analysis of the tank contents. If the activity is not below ODCM limits, the liquid waste streams are returned to the waste disposal system for further processing by the mobile demineralizer. Once the fluids are sampled, they are pumped to the discharge pipe through a normally locked closed manual valve and a remotely operated control valve, interlocked with a radiation monitor and a flow element in the Cooling Tower Blowdown (CTB) line. This assures that sufficient dilution flow is available for the discharge of radioactive liquids. The minimum dilution flow required for discharge of radioactivity into the CTB lines is 20,000 gpm.

WBN has three large tanks in the Liquid Radwaste System, including the new Tritiated Water Storage Tank (TWST), to support managing large volume/high tritium concentration RCS releases. The TWST has a capacity of 500,000 gallons, which is significantly more than the volume of the primary coolant and could easily be used to dilute the RCS releases to below the maximum allowable tritium concentration. These tanks can be used for liquid effluent holdup, dilution, and timing of releases to ensure that the 10 CFR Part 20 effluent concentration limit values are met.

TVA has demonstrated that effluent releases to the environment can be controlled to meet the 10 CFR Part 20 release limits for an assumed TPBAR loading of 2,500 TPBARs each with an assumed permeation of 10 Ci/TPBAR/year. The assumed number of 2,500 TPBARs exceeds the requested value of 1,792 TPBARs to conservatively bound the projected environmental impacts. Likewise, the assumed permeation rate exceeds the historical average permeation rate of 3.4 Ci/TPBAR/year to conservatively bound the projected environmental impacts. This increase in tritium was added to the current licensing basis source term for a non-TPC to demonstrate conformance with the 10 CFR Part 20 effluent concentration limit values.

Tables 5 through 7 demonstrate that the liquid releases are below the 10 CFR Part 20 Appendix B Table 2 limits. Tables 8 through 9 demonstrate that the gaseous design release concentrations are below the 10 CFR Part 20 Appendix B Table 2 limits. The designs of the gas and liquid radwaste systems meet the requirements of 10 CFR Part 20.

Table 5: Liquid Releases with No Processing of Condensate Resin Regeneration Waste by Mobile Demineralizers

Nuclide	Exp. Rel. (Ci/year)	Des/Exp Ratio	Design (Ci/year)	Design (µCi/gm)	10CFR20 (ECL, µCi/cc)	Single Unit Operation Design C/ECL	Dual Unit Operation Design C/ECL
Br-84	6.94E-04	2.50	1.73E-03	4.36E-11	4.00E-04	1.09E-07	2.18E-07
I-131	1.06E+00	52.41	5.53E+01	1.39E-06	1.00E-06	1.39E+00	2.78E+00
I-132	1.23E-01	4.00	4.93E-01	1.24E-08	1.00E-04	1.24E-04	2.48E-04
I-133	8.40E-01	26.85	2.25E+01	5.67E-07	7.00E-06	8.10E-02	1.62E-01
I-134	3.23E-02	1.65	5.32E-02	1.34E-09	4.00E-04	3.35E-06	6.69E-06
I-135	4.43E-01	7.91	3.50E+00	8.80E-08	3.00E-05	2.93E-03	5.87E-03
Rb-88	1.03E-02	18.14	1.88E-01	4.72E-09	4.00E-04	1.18E-05	2.36E-05
Cs-134	2.38E-01	40.60	9.64E+00	2.42E-07	9.00E-07	2.69E-01	5.39E-01
Cs-136	2.39E-02	165.20	3.95E+00	9.94E-08	6.00E-06	1.66E-02	3.31E-02
Cs-137	3.18E-01	153.22	4.87E+01	1.22E-06	1.00E-06	1.22E+00	2.45E+00
Cr-51	1.21E-01	0.29	3.51E-02	8.82E-10	5.00E-04	1.76E-06	3.53E-06
Mn-54	6.70E-02	0.47	3.15E-02	7.91E-10	3.00E-05	2.64E-05	5.27E-05
Fe-59	1.40E-02	3.48	4.86E-02	1.22E-09	1.00E-05	1.22E-04	2.44E-04
Co-58	2.01E-01	5.37	1.08E+00	2.72E-08	2.00E-05	1.36E-03	2.72E-03
Co-60	4.01E-02	1.38	5.53E-02	1.39E-09	3.00E-06	4.63E-04	9.27E-04
Sr-89	5.36E-03	22.45	1.20E-01	3.02E-09	8.00E-06	3.78E-04	7.56E-04
Sr-90	4.87E-04	13.49	6.57E-03	1.65E-10	5.00E-07	3.30E-04	6.60E-04
Sr-91	2.98E-03	1.86	5.54E-03	1.39E-10	2.00E-05	6.97E-06	1.39E-05
Y-90	0	15.87	0	0	7.00E-06	0.00E+00	0.00E+00
Y-91	4.75E-04	1115.17	5.30E-01	1.33E-08	8.00E-06	1.67E-03	3.33E-03
Zr-95	1.62E-02	1.71	2.78E-02	6.98E-10	2.00E-05	3.49E-05	6.98E-05
Nb-95	1.34E-02	2.34	3.13E-02	7.88E-10	3.00E-05	2.63E-05	5.25E-05
Mo-99	1.26E-01	785.19	9.88E+01	2.48E-06	2.00E-05	1.24E-01	2.48E-01
Te-132	3.64E-02	145.25	5.28E+00	1.33E-07	9.00E-06	1.47E-02	2.95E-02
Ba-140	4.27E-01	0.31	1.32E-01	3.33E-09	8.00E-06	4.16E-04	8.31E-04
La-140	6.14E-01	0.06	3.69E-02	9.26E-10	9.00E-06	1.03E-04	2.06E-04
Ce-144	1.58E-01	0.08	1.26E-02	3.17E-10	3.00E-06	1.06E-04	2.11E-04
Pr-144	0	0.08	0	0.00E+00	6.00E-04	0.00E+00	0.00E+00
H-3	1252.8	1	1252.8	3.15E-05	1.00E-03	3.15E-02	6.30E-02
H-3 (TPC)	N/A	N/A	N/A	3.26E-04*	1.00E-03	3.26E-01	3.26E-01
Total						3.16E+00	6.32E+00
Total (TPC)						3.45E+00	6.58E+00

* maximum allowable tritium concentration

Note: Dual unit operations consider only Unit 1 with TPC.

Table 6: Liquid Releases with Condensate Resin Regeneration Waste Processed by the Mobile Demineralizers

Nuclide	Exp. Rel. (Ci/year)	Des/Exp Ratio	Design (Ci/year)	Design (µCi/cc)	10CFR20 (ECL, µCi/cc)	Single Unit Operation C/ECL	Dual Unit Operation C/ECL
Br-84	2.26E-04	2.50	5.65E-04	1.42E-11	4.00E-04	3.55E-08	7.11E-08
I-131	3.70E-02	52.41	1.94E+00	4.87E-08	1.00E-06	4.87E-02	9.74E-02
I-132	1.81E-02	4.00	7.23E-02	1.82E-09	1.00E-04	1.82E-05	3.63E-05
I-133	7.29E-02	26.85	1.96E+00	4.92E-08	7.00E-06	7.03E-03	1.41E-02
I-134	8.57E-03	1.65	1.41E-02	3.56E-10	4.00E-04	8.89E-07	1.78E-06
I-135	6.52E-02	7.91	5.16E-01	1.30E-08	3.00E-05	4.32E-04	8.65E-04
Rb-88	9.41E-03	18.14	1.71E-01	4.29E-09	4.00E-04	1.07E-05	2.15E-05
Cs-134	4.02E-02	40.60	1.63E+00	4.10E-08	9.00E-07	4.55E-02	9.11E-02
Cs-136	3.50E-03	165.20	5.79E-01	1.45E-08	6.00E-06	2.42E-03	4.85E-03
Cs-137	5.52E-02	153.22	8.46E+00	2.13E-07	1.00E-06	2.13E-01	4.25E-01
Cr-51	9.70E-03	0.29	2.81E-03	7.07E-11	5.00E-04	1.41E-07	2.83E-07
Mn-54	6.87E-03	0.47	3.23E-03	8.12E-11	3.00E-05	2.71E-06	5.41E-06
Fe-59	3.31E-03	3.48	1.15E-02	2.90E-10	1.00E-05	2.90E-05	5.80E-05
Co-58	3.18E-02	5.37	1.71E-01	4.29E-09	2.00E-05	2.14E-04	4.29E-04
Co-60	1.97E-02	1.38	2.72E-02	6.83E-10	3.00E-06	2.28E-04	4.55E-04
Sr-89	2.67E-04	22.45	5.98E-03	1.50E-10	8.00E-06	1.88E-05	3.76E-05
Sr-90	3.04E-05	13.49	4.10E-04	1.03E-11	5.00E-07	2.06E-05	4.13E-05
Sr-91	3.90E-04	1.86	7.26E-04	1.82E-11	2.00E-05	9.12E-07	1.82E-06
Y-90	0	15.87	0	0	7.00E-06	0	0
Y-91	1.23E-04	1115.17	1.37E-01	3.45E-09	8.00E-06	4.32E-04	8.63E-04
Zr-95	1.91E-03	1.71	3.27E-03	8.22E-11	2.00E-05	4.11E-06	8.22E-06
Nb-95	2.88E-03	2.34	6.75E-03	1.70E-10	3.00E-05	5.65E-06	1.13E-05
Mo-99	5.85E-03	785.19	4.59E+00	1.15E-07	2.00E-05	5.77E-03	1.15E-02
Te-132	1.55E-03	145.25	2.26E-01	5.67E-09	9.00E-06	6.30E-04	1.26E-03
Ba-140	1.44E-02	0.31	4.46E-03	1.12E-10	8.00E-06	1.40E-05	2.80E-05
La-140	2.28E-02	0.06	1.37E-03	3.43E-11	9.00E-06	3.81E-06	7.63E-06
Ce-144	9.49E-03	0.08	7.59E-04	1.91E-11	3.00E-06	6.36E-06	1.27E-05
Pr-144	0	0.08	0	0	6.00E-04	0	0
H-3	1252.80	1	1252.80	3.149E-05	1.00E-03	3.15E-02	6.30E-02
H-3 (TPC)	N/A	N/A	N/A	3.26E-04*	1.00E-03	3.26E-01	3.26E-01
Total						3.56E-01	7.11E-01
Total (TPC)						6.50E-01	9.74E-01

* maximum allowable tritium concentration
Note: Dual unit operations consider only Unit 1 with TPC.

Table 7: Liquid Releases with No Condensate Resin Regeneration Waste Processed by the Mobile Demineralizers and SGBD at Maximum Allowable Concentration with 20,000 gpm Dilution

Nuclide	LRW (Ci/year)	SGB Ci/year Scaled to 4.40 Ci	Des/EXP Ratio	Des (Ci/year)	Liquid (µCi/cc)	ECL (µCi/cc)	Single Unit Operation C/ECL	Dual Unit Operation C/ECL
Br-84	2.26E-04	1.38E-02	2.50	1.44E-02	3.56E-10	4.00E-04	8.91E-07	1.78E-06
I-131	3.60E-02	2.03E-01	52.41	2.09E+00	5.18E-08	1.00E-06	5.18E-02	1.04E-01
I-132	1.80E-02	4.86E-01	4.00	5.58E-01	1.38E-08	1.00E-04	1.38E-04	2.77E-04
I-133	7.22E-02	5.82E-01	26.85	2.52E+00	6.25E-08	7.00E-06	8.93E-03	1.79E-02
I-134	8.55E-03	4.23E-01	1.65	4.37E-01	1.08E-08	4.00E-04	2.71E-05	5.42E-05
I-135	6.49E-02	8.93E-01	7.91	1.41E+00	3.49E-08	3.00E-05	1.16E-03	2.33E-03
Rb-88	9.41E-03	1.06E-01	18.14	2.77E-01	6.87E-09	4.00E-04	1.72E-05	3.44E-05
Cs-134	4.00E-02	6.61E-02	40.60	1.69E+00	4.19E-08	9.00E-07	4.66E-02	9.31E-02
Cs-136	3.48E-03	8.02E-03	165.20	5.83E-01	1.45E-08	6.00E-06	2.41E-03	4.83E-03
Cs-137	5.50E-02	8.82E-02	153.22	8.51E+00	2.11E-07	1.00E-06	2.11E-01	4.22E-01
Na-24	2.54E-02	2.68E-01	1.00	2.94E-01	7.29E-09	5.00E-05	1.46E-04	2.92E-04
Cr-51	9.59E-03	2.25E-02	0.29	2.53E-02	6.28E-10	5.00E-04	1.26E-06	2.51E-06
Mn-54	6.81E-03	1.13E-02	0.47	1.45E-02	3.59E-10	3.00E-05	1.20E-05	2.39E-05
Fe-55	1.11E-02	8.49E-03	1.00	1.95E-02	4.85E-10	1.00E-04	4.85E-06	9.70E-06
Fe-59	3.30E-03	2.08E-03	3.48	1.36E-02	3.37E-10	1.00E-05	3.37E-05	6.74E-05
Co-58	3.01E-02	3.29E-02	5.37	1.94E-01	4.82E-09	2.00E-05	2.41E-04	4.82E-04
Co-60	1.97E-02	3.81E-03	1.38	3.09E-02	7.68E-10	3.00E-06	2.56E-04	5.12E-04
Zn-65	5.22E-04	3.64E-03	1.00	4.16E-03	1.03E-10	5.00E-06	2.06E-05	4.13E-05
Sr-89	2.61E-04	9.87E-04	22.45	6.86E-03	1.70E-10	8.00E-06	2.13E-05	4.25E-05
Sr-90	3.00E-05	8.49E-05	13.49	4.89E-04	1.21E-11	5.00E-07	2.43E-05	4.85E-05
Sr-91	3.88E-04	5.08E-03	1.86	5.80E-03	1.44E-10	2.00E-05	7.20E-06	1.44E-05
Y-90	0	0	15.87	0	0	7.00E-06	0	0.00E+00
Y-91m	2.30E-04	6.26E-04	1.00	8.56E-04	2.12E-11	2.00E-03	1.06E-08	2.12E-08
Y-91	1.23E-04	3.64E-05	1115.17	1.37E-01	3.40E-09	8.00E-06	4.25E-04	8.50E-04
Y-93	1.73E-03	2.16E-02	1.00	2.34E-02	5.80E-10	2.00E-05	2.90E-05	5.80E-05
Zr-95	1.90E-03	2.77E-03	1.71	6.02E-03	1.49E-10	2.00E-05	7.46E-06	1.49E-05
Nb-95	2.87E-03	1.91E-03	2.34	8.63E-03	2.14E-10	3.00E-05	7.14E-06	1.43E-05
Mo-99	5.73E-03	4.37E-02	785.19	4.54E+00	1.13E-07	2.00E-05	5.63E-03	1.13E-02
Tc-99m	4.57E-03	2.02E-02	1.00	2.48E-02	6.15E-10	1.00E-03	6.15E-07	1.23E-06
Ru-103	8.03E-03	5.37E-02	1.00	6.17E-02	1.53E-09	3.00E-05	5.10E-05	1.02E-04
Ru-106	1.04E-01	6.41E-01	1.00	7.45E-01	1.85E-08	3.00E-06	6.16E-03	1.23E-02
Te-129m	1.92E-04	1.35E-03	1.00	1.54E-03	3.83E-11	7.00E-06	5.47E-06	1.09E-05
Te-129	9.97E-04	4.27E-02	1.00	4.37E-02	1.08E-09	4.00E-04	2.71E-06	5.42E-06
Te-131m	1.10E-03	9.53E-03	1.00	1.06E-02	2.64E-10	8.00E-06	3.29E-05	6.59E-05
Te-131	2.77E-04	5.73E-03	1.00	6.01E-03	1.49E-10	8.00E-05	1.86E-06	3.73E-06
Te-132	1.52E-03	1.15E-02	145.25	2.32E-01	5.76E-09	9.00E-06	6.40E-04	1.28E-03

Nuclide	LRW (Ci/year)	SGB Ci/year Scaled to 4.40 Ci	Des/EXP Ratio	Des (Ci/year)	Liquid (µCi/cc)	ECL (µCi/cc)	Single Unit Operation C/ECL	Dual Unit Operation C/ECL
Ba-140	1.40E-02	9.02E-02	0.31	9.45E-02	2.35E-09	8.00E-06	2.93E-04	5.86E-04
La-140	2.22E-02	1.63E-01	0.06	1.64E-01	4.08E-09	9.00E-06	4.53E-04	9.07E-04
Ce-141	4.65E-04	1.06E-03	1.00	1.52E-03	3.77E-11	3.00E-05	1.26E-06	2.52E-06
Ce-143	2.08E-03	1.76E-02	1.00	1.97E-02	4.89E-10	2.00E-05	2.44E-05	4.89E-05
Ce-144	9.34E-03	2.77E-02	0.08	2.85E-02	7.06E-10	3.00E-06	2.35E-04	4.71E-04
Pr-144	0	0	0.08	0	0	6.00E-04	0	0.00E+00
Np-239	1.88E-03	1.47E-02	1.00	1.66E-02	4.12E-10	2.00E-05	2.06E-05	4.12E-05
H-3	1252.80		1	1252.80	3.11E-05	1.00E-03	3.11E-02	6.22E-02
H-3(TPC)	N/A		N/A	N/A	3.26E-04*	1.00E-03	3.26E-01	3.26E-01
Total							3.68E-01	7.36E-01
Total(TPC)							6.63E-01	1.00E+00

* maximum allowable tritium concentration
Note: Dual unit operations consider only Unit 1 with the TPC.

Table 8: Gaseous Release with Containment Purge

Nuclide	Exp. Rel. (Ci/year)	Des/Exp Ratio	Design (Ci/year)	Design (µCi/cc)	10CFR20 (ECL, µCi/cc)	Single Unit Operation C/ECL	Dual Unit Operation C/ECL
Kr-85m	2.58E+01	1.23E+01	3.17E+02	1.10E-10	1.00E-07	1.10E-03	2.19E-03
Kr-85	6.99E+02	3.31E+01	2.31E+04	7.99E-09	7.00E-07	1.14E-02	2.28E-02
Kr-87	1.62E+01	7.45E+00	1.21E+02	4.18E-11	2.00E-08	2.09E-03	4.18E-03
Kr-88	3.85E+01	1.23E+01	4.75E+02	1.64E-10	9.00E-09	1.82E-02	3.65E-02
Xe-131m	1.19E+03	2.91E+00	3.45E+03	1.19E-09	2.00E-06	5.97E-04	1.19E-03
Xe-133m	4.88E+01	4.32E+01	2.11E+03	7.29E-10	6.00E-07	1.21E-03	2.43E-03
Xe-133	3.20E+03	1.11E+02	3.55E+05	1.23E-07	5.00E-07	2.46E-01	4.91E-01
Xe-135m	8.52E+00	5.04E+00	4.29E+01	1.48E-11	4.00E-08	3.71E-04	7.42E-04
Xe-135	1.85E+02	6.97E+00	1.29E+03	4.46E-10	7.00E-08	6.38E-03	1.28E-02
Xe-138	7.66E+00	5.43E+00	4.16E+01	1.44E-11	2.00E-08	7.19E-04	1.44E-03
Br-84	5.07E-02	2.50E+00	1.27E-01	4.38E-14	8.00E-08	5.48E-07	1.10E-06
I-131	1.53E-01	5.24E+01	8.03E+00	2.77E-12	2.00E-10	1.39E-02	2.78E-02
I-132	6.75E-01	4.00E+00	2.70E+00	9.33E-13	2.00E-08	4.67E-05	9.34E-05
I-133	4.58E-01	2.69E+01	1.23E+01	4.25E-12	1.00E-09	4.25E-03	8.51E-03
I-134	1.08E+00	1.65E+00	1.78E+00	6.14E-13	6.00E-08	1.02E-05	2.05E-05
I-135	8.45E-01	7.91E+00	6.69E+00	2.31E-12	6.00E-09	3.85E-04	7.70E-04
Cs-134	2.27E-03	4.06E+01	9.20E-02	3.18E-14	2.00E-10	1.59E-04	3.18E-04
Cs-136	8.01E-05	1.65E+02	1.32E-02	4.57E-15	9.00E-10	5.08E-06	1.02E-05
Cs-137	3.48E-03	1.53E+02	5.33E-01	1.84E-13	2.00E-10	9.20E-04	1.84E-03
Cr-51	5.92E-04	2.90E-01	1.73E-04	5.96E-17	3.00E-08	1.99E-09	3.98E-09
Mn-54	4.31E-04	4.70E-01	2.03E-04	7.01E-17	1.00E-09	7.01E-08	1.40E-07
Fe-59	7.70E-05	3.48E+00	2.68E-04	9.27E-17	5.00E-10	1.85E-07	3.71E-07
Co-58	2.32E-02	5.37E+00	1.24E-01	4.30E-14	1.00E-09	4.30E-05	8.60E-05
Co-60	8.74E-03	1.38E+00	1.21E-02	4.17E-15	5.00E-11	8.33E-05	1.67E-04
Sr-89	2.98E-03	2.25E+01	6.69E-02	2.31E-14	1.00E-09	2.31E-05	4.63E-05
Sr-90	1.14E-03	1.35E+01	1.54E-02	5.33E-15	6.00E-12	8.88E-04	1.78E-03
Zr-95	1.00E-03	1.71E+00	1.71E-03	5.92E-16	4.00E-10	1.48E-06	2.96E-06
Nb-95	2.45E-03	2.34E+00	5.73E-03	1.98E-15	2.00E-09	9.90E-07	1.98E-06
Ba-140	4.00E-04	3.10E-01	1.26E-04	4.34E-17	2.00E-09	2.17E-08	4.34E-08
H-3	1.39E+02	1.00E+00	1.39E+02	4.80E-11	1.00E-07	4.81E-04	9.62E-04
H-3 (TPC)	2.64E+03	1.00E+00	2.64E+03	9.12E-10	1.00E-07	9.12E-03	9.60E-03
C-14	1.12E+01	1.00E+00	1.12E+01	3.87E-12	3.00E-09	1.29E-03	2.58E-03
Ar-41	3.40E+01	1.00E+00	3.40E+01	1.18E-11	1.00E-08	1.18E-03	2.35E-03
total						3.11E-01	6.23E-01
total (TPC)						3.20E-01	6.32E-01

Note: Dual unit operations consider only Unit 1 with the TPC.

Note: Dual unit operation H-3 (TPC) value is the sum of normal H-3 from two units and the TPC-specific H-3 from one unit.

Table 9: Gaseous Release with Continuous Filtered Containment Vent

Nuclide	Exp. Rel. (Ci/year)	Des/Exp Ratio	Design (Ci/year)	Design (µCi/cc)	10CFR20 (ECL, µCi/cc)	Single Unit Operation C/ECL	Dual Unit Operation C/ECL
Kr-85m	9.48E+00	1.23E+01	1.16E+02	4.02E-11	1.00E-07	4.02E-04	8.05E-04
Kr-85	6.78E+02	3.31E+01	2.24E+04	7.75E-09	7.00E-07	1.11E-02	2.21E-02
Kr-87	5.81E+00	7.45E+00	4.33E+01	1.50E-11	2.00E-08	7.48E-04	1.50E-03
Kr-88	1.32E+01	1.23E+01	1.63E+02	5.63E-11	9.00E-09	6.25E-03	1.25E-02
Xe-131m	1.09E+03	2.91E+00	3.18E+03	1.10E-09	2.00E-06	5.49E-04	1.10E-03
Xe-133m	4.31E+01	4.32E+01	1.86E+03	6.44E-10	6.00E-07	1.07E-03	2.15E-03
Xe-133	2.90E+03	1.11E+02	3.22E+05	1.11E-07	5.00E-07	2.23E-01	4.45E-01
Xe-135m	4.68E+00	5.04E+00	2.36E+01	8.15E-12	4.00E-08	2.04E-04	4.08E-04
Xe-135	8.88E+01	6.97E+00	6.19E+02	2.14E-10	7.00E-08	3.06E-03	6.11E-03
Xe-138	4.34E+00	5.43E+00	2.36E+01	8.15E-12	2.00E-08	4.07E-04	8.15E-04
Br-84	5.07E-02	2.50E+00	1.27E-01	4.38E-14	8.00E-08	5.00E-07	1.00E-06
I-131	1.53E-01	5.24E+01	8.00E+00	2.77E-12	2.00E-10	1.38E-02	2.77E-02
I-132	6.73E-01	4.00E+00	2.69E+00	9.30E-13	2.00E-08	4.65E-05	9.30E-05
I-133	4.57E-01	2.69E+01	1.23E+01	4.24E-12	1.00E-09	4.24E-03	8.49E-03
I-134	1.07E+00	1.65E+00	1.77E+00	6.10E-13	6.00E-08	1.02E-05	2.04E-05
I-135	8.42E-01	7.91E+00	6.66E+00	2.30E-12	6.00E-09	3.84E-04	7.67E-04
Cs-134	2.27E-03	4.06E+01	9.20E-02	3.18E-14	2.00E-10	1.59E-04	3.18E-04
Cs-136	8.01E-05	1.65E+02	1.32E-02	4.57E-15	9.00E-10	5.10E-06	1.02E-05
Cs-137	3.48E-03	1.53E+02	5.33E-01	1.84E-13	2.00E-10	9.20E-04	1.84E-03
Cr-51	5.92E-04	2.90E-01	1.73E-04	5.96E-17	3.00E-08	0.00E+00	0.00E+00
Mn-54	4.31E-04	4.70E-01	2.03E-04	7.01E-17	1.00E-09	1.00E-07	2.00E-07
Fe-59	7.70E-05	3.48E+00	2.68E-04	9.27E-17	5.00E-10	2.00E-07	4.00E-07
Co-58	2.32E-02	5.37E+00	1.24E-01	4.30E-14	1.00E-09	4.30E-05	8.60E-05
Co-60	8.74E-03	1.38E+00	1.21E-02	4.17E-15	5.00E-11	8.33E-05	1.67E-04
Sr-89	2.98E-03	2.25E+01	6.69E-02	2.31E-14	1.00E-09	2.31E-05	4.62E-05
Sr-90	1.14E-03	1.35E+01	1.54E-02	5.33E-15	6.00E-12	8.88E-04	1.78E-03
Zr-95	1.00E-03	1.71E+00	1.71E-03	5.92E-16	4.00E-10	1.50E-06	3.00E-06
Nb-95	2.45E-03	2.34E+00	5.73E-03	1.98E-15	2.00E-09	1.00E-06	2.00E-06
Ba-140	4.00E-04	3.10E-01	1.26E-04	4.34E-17	2.00E-09	0.00E+00	0.00E+00
H-3	1.39E+02	1.00E+00	1.39E+02	4.80E-11	1.00E-07	4.81E-04	9.62E-04
H-3 (TPC)	2.64E+03	1.00E+00	2.64E+03	9.12E-10	1.00E-07	9.12E-03	9.60E-03
C-14	1.12E+01	1.00E+00	1.12E+01	3.87E-12	3.00E-09	1.29E-03	2.58E-03
Ar-41	3.40E+01	1.00E+00	3.40E+01	1.18E-11	1.00E-08	1.18E-03	2.35E-03
total						2.70E-01	5.40E-01
total (TPC)						2.79E-01	5.49E-01

Note: Dual unit operations consider only Unit 1 with the TPC.

Note: Dual unit operation H-3 (TPC) value is the sum of normal H-3 from two units and the TPC-specific H-3 from one unit.

Real Time Performance Monitoring

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

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% confidence level of the total uncertainty in the net estimated TPBAR tritium value. That is, if exceeded there is a 5% 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 measured 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 Effective Full Power Day, the Action Level Trigger follows:

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

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 cycle's reactor power history. The lower action level requires more frequent tritium system sampling to monitor, verify, track, and trend the tritium levels. In the unlikely event that the higher action level is exceeded, WBN 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 Technical Instructions.

The WBN Unit 1 License Amendment 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. The fixed action levels were insensitive to variations in the number of TPBARs and RCS water balance and without merit (Figure 6).

Tritium Impacts on Public Dose

Normal Operation

Using the revised realistic TPC source terms for 1,900 TPBARs, the offsite radiation incremental tritium doses calculated for releases of radionuclides in liquid and gaseous effluents during normal operation are summarized in Table 10. This table also lists WBN's regulatory established radioactive effluent guidelines and the estimated non-TPC values.

Table 10: Annual Projected Impact of TPC (1,900 TPBARs) on Effluent Dose to Maximally Exposed Members of the Public and Total Public Dose

	Non-TPC Realistic Dose	TPC Realistic Dose	Incremental Increase from TPC	NRC Annual Effluent Exposure Guideline
Annual Radioactive Gaseous Emissions				
Maximally Exposed Individual (mrem)	0.55	0.55	0	5.00 Whole Body
Maximally Exposed Individual (mrem)	8.8 (Bone) See Note 1	10.6 (Bone)	1.8	15.00 Organ
50-mile Population Dose (Rem)	7.01 (Bone)	10.7 (Bone)	3.69	NA
Annual Radioactive Liquid Emissions				
Maximally Exposed Individual (mrem)	0.40	0.43	0.03	3.00 Whole Body
Maximally Exposed Individual (mrem)	0.55 (Liver)	0.57 (Liver)	0.02	10.00 Organ
50-mile Population Dose (Rem)	3.6 (Thyroid)	6.7 (Thyroid)	3.1	NA

Note 1 - With the inclusion of C-14, as required by Revision 2 of RG 1.21, Bone became the critical organ.

Table 10 demonstrates that the increase in the tritium reactor coolant activity and resultant environmental releases would result in a minor increase to the offsite doses, which continue to remain below the NRC's guidance levels.

Solid Radioactive Waste

For normal TPC operations, the additional solid waste associated with TPCs that TVA will need to handle will be the base plate and thimble plug assemblies that remain after TPBAR consolidation activities. TVA will consolidate and temporarily store these items on-site. Offsite shipment and ultimate disposal is conducted in accordance with agreements between TVA and DOE. WBN Unit 1 License Amendment 40 estimated activity inventory associated with these additional irradiated components[43] (112 base plates and 384 thimble plugs) is 5,921 curies per cycle (180 day post irradiation decay) or an average of 3,527 curies per year when adjusted to reflect measured dose rate[44] for Base Plate with 24 Thimble Plugs following 113 day decay adjusted to 180 days (WBN Survey 010201 #2). This represented an increase from the current WBN Unit 1 UFSAR estimated non-TPC value of 1,800 Ci/year to approximately 5,530 Ci/year for a TPC. This increased activity is associated with metal activation products. The estimated disposal volume of this additional solid waste is 50 cubic feet per TPC operating cycle or an average of 33.3 cubic feet per year. This additional volume is an insignificant increase in the WBN Unit 1 annual estimated non-TPC solid waste (from the UFSAR), from 32,820 cubic feet per year to 32,853 cubic feet per year for a TPC.

WBN Unit 1 License Amendment 40 assessed the environmental impact from the solid radioactive waste associated with the production of 2,304 TPBARs. The WBN revised license amendment establishes 1,792 as the maximum number of TPBARs per cycle.

WBN Unit 1 License Amendment 40 also included an evaluation with the failure of two TPBARs, which resulted in the need to perform more feed and bleed operations. Therefore, an increase in the amount of resins was evaluated. As discussed previously, the Radwaste Design Basis no longer includes two TPBAR failures, so no additional feed and bleed operations are expected, and therefore, no additional resins are evaluated.

Thus, the tritium production solid radioactive waste environmental impact is bounded by the WBN Unit 1 License Amendment 40 impact assessment.

Spent Fuel Generation and Storage

WBN Unit 1 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. The proposed license amendment establishes 1,792 as the maximum number of TPBARs per cycle. This level of TPBAR irradiation will require approximately four additional fresh fuel bundles per cycle.

Thus, the tritium production additional spent fuel generation environmental impact is bounded by the WBN Unit 1 License Amendment 40 impact assessment.

Tritium Impacts on Station Accident Analysis

The American Nuclear Society (ANS) classification of nuclear plant conditions divides' plant conditions into four categories according to anticipated frequency of occurrence and potential radiological consequences to the public. The four categories are as follows:

Condition I: Normal Operation and Operational Transients

Condition II: Faults of Moderate Frequency

Condition III: Infrequent Faults

Condition IV: Limiting Faults

The basic principle applied in relating design requirements to each of the conditions is that the most probable occurrences should yield the least radiological risk to the public and those extreme situations having the potential for the greatest risk to the public shall be those least likely to occur.

TPBARs were designed to withstand the rigors associated with category I through IV events, therefore, no TPBAR failures are predicted to occur during design-basis accidents except for a large break loss of cooling accident (LBLOCA) or a fuel handling accident (FHA) involving TPBARs.

Radiological Consequences of Accidents

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[45] and Federal Guidance Report Number 11[46] dose conversion values for thyroid in the accident analysis for informational purposes. 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 LBLOCA or the FHA.

Large Break Loss of Cooling Accident (LBLOCA)

WBN Unit 1 License Amendment 40 and the current licensing basis consider that all of the tritium content of 2,304 TPBARs is released to the containment atmosphere after an LBLOCA. This is based on a design inventory 1.2 gm of tritium/TPBAR and results in 2.68 x 10^7 Ci of tritium. The design inventory of tritium remains the same. Therefore, the current licensing basis LBLOCA radiological dose consequences analysis (Table 11) is bounding for the 1,792 TPBAR core.

Table 11: Dose Consequences from an LBLOCA

	Current Licensing Basis (CLB)		
Dose (rem)	Control Room (CR)	Exclusion Area Boundary (EAB)	Low Population Zone (LPZ)
Beta	8.97	1.29	2.57
TEDE	2.49	3.58	2.43

Fuel Handling Accident (FHA)

WBN Unit 1 License Amendment 40 and the current licensing basis consider that all of the tritium content of 24 TPBARs (84,490 Ci) is released into the surrounding water after an FHA. This is the maximum number of TPBARs that would be in one fuel assembly. Because the design inventory of the TPBARs and the maximum number of TPBARs in one fuel assembly remains the same, the source term released to the surrounding water is not affected. Since issuance of License Amendment 40, WBN Unit 1 has modified the licensing basis for an FHA. License Amendment 92 was approved on June 19, 2013 (ML13141A564) and implemented Alternative Source Term for the FHA. Included in this was also a change to the amount of tritium that was released to the environment. License Amendment 40 assumed a 100% release and License Amendment 92 assumed a 25% release. The amount of tritium assumed to go airborne after an FHA is not affected by any of the changes being requested. Therefore, the current licensing basis for the FHA remains bounding for the requested changes. Table 12 compares the dose consequences from License Amendment 40 and the current licensing basis.

Table 12: Dose Consequences from an FHA

	License Amendment 40			CLB		
Dose (rem)	CR*	EAB	LPZ	CR*	EAB	LPZ
Beta	4.281	1.377	0.3198	NA	NA	NA
TEDE	4.099	2.979	0.6921	2.869	2.834	0.79

* values represent the bounding case - FHA in the Auxiliary Building

Main Steam Line Break (MSLB) and Steam Generator Tube Rupture (SGTR)

These analyses do not assume any fuel damage. Therefore, the source term is the primary and secondary coolant activity. The primary and secondary coolant activities are in accordance with ANSI/ANS-18.1-1984, except for tritium. License Amendment 40 and the current licensing basis assume that the tritium concentration is based on the expected tritium concentration and two TPBAR failures. This source term was updated to reflect a new permeation rate of 10 Ci/TPBAR/year, which bounds the realistic permeation rate with 100% margin. It continues to retain conservatism regarding the inclusion of two failed TPBARs. This bounding approach to source term assumptions for accidents is consistent with accident evaluation methodology. The modified source term provides sufficient margin to bound AOO and PA cases.

WBN Unit 1 License Amendment 40 and the current licensing basis determined the expected tritium concentration assuming a permeation rate of 1 Ci/TPBAR/year, 2,304 total TPBARs, and two failed TPBARs. This results in a concentration of 98.4 µCi/gm. The assumed RCS tritium activity to support the requested changes is based on 2,500 TPBARs with an assumed permeation rate of 10 Ci/TPBAR/year and two failed TPBARs. This results in a concentration of 124.9 µCi/gm.

The radiological consequences of the MSLB and SGTR with a 2,500 TPBAR core remain well within 10 CFR Part 100 and General Design Criteria (GDC) 19 dose limits as shown in Table 13.

Table 13: Dose Consequences from MSLB and SGTR Accidents

Main Steam Line Break

Dose (rem)	CLB			New		
Pre-Accident Spike	CR	EAB	LPZ	CR	EAB	LPZ
Beta	6.30E-02	9.27E-03	4.34E-03	6.37E-02	9.28E-03	4.35E-03
TEDE	4.58E-01	1.92E-01	8.75E-02	4.66E-01	1.92E-01	8.76E-02
Accident Initiated Spike						
Beta	9.93E-02	2.55E-02	2.98E-02	9.98E-02	2.55E-02	2.98E-02
TEDE	6.29E-01	3.48E-01	4.69E-01	6.35E-01	3.49E-01	4.69E-01

Steam Generator Tube Rupture

	CLB			New		
Pre-Accident Spike	CR	EAB	LPZ	CR	EAB	LPZ
Beta	9.50E-01	2.03E-01	6.22E-02	9.62E-01	2.04E-01	6.25E-02
TEDE	1.15E+00	1.21E+00	3.49E-01	1.28E+00	1.22E+00	3.52E-01
Accident Initiated Spike						
Beta	9.34E-01	2.33E-01	7.15E-02	9.45E-01	2.35E-01	7.19E-02
TEDE	5.50E-01	1.06E+00	3.08E-01	6.50E-01	1.08E+00	3.14E-01

[1] 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).

[2] 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 (ADAMS Accession No. ML022540925).

[3] TVA Letter to NRC dated March 22, 2005, “Watts Bar Nuclear Plant (WBN) Unit 1 - Tritium Production Program - Unit 1 Cycle 6 Operating Experience,” (ADAMS Accession No. ML050870454).

[4] 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,” (ADAMS Accession No. ML071210604).

[5] 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),” (ADAMS Accession No. ML090090044).

[6] TVA WBN Unit 1 Licensing Basis Post-LOCA subcriticality evaluation establishes a 1,792 TPBAR Core load as the maximum configuration. This evaluation uses a 1,900 TPBAR TPC Source Term to provide an additional margin when evaluating Realistic Effluent Releases and a 2,500 TPBAR TPC Source Term to provide an additional margin when evaluating Design Basis Effluent Releases.

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

[8] TTP-1-3085, Revision 0, WBN-1 Cycle 12 TPBAR Tritium Release, Deduced From Analysis of RCS Data. July 18, 2014. Pacific Northwest National Laboratory, Richland, Washington

[9] 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. (ADAMS Accession No. ML071210604)

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

[11] WBNTSR-100, Revision 12 “Design Releases to Show Compliance with 10CFR20”. July 16, 2013

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[21] EPA-520/1-86-020, Federal Guidance Report No. 11 1988 *Limiting Values Of Radionuclide Intake And Air Concentration And Dose Conversion Factors For Inhalation, Submersion, And Ingestion.* Washington, D.C.

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[24] NUREG-800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, dated June 1987 and latest revision, by U.S. NRC.

[25] Regulatory Guide 1.206. U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research Division 1, June 2007

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

[27] 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 (ADAMS Accession No. ML022540925).

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

[29] TTQP-1-015, Revision 19, "Description of the Tritium-Producing Burnable Absorber Rod for the Commercial Light Water Reactor. Pacific Northwest National Laboratory, Richland, Washington.

[30] TTP-1-3016, Revision 1, MARK 9.2 (FLG Design) TPBAR Tritium Release, Deduced from Analysis and Qualification of WBN Cycle 9 RCS Data. Pacific Northwest National Laboratory, Richland, Washington.

[31] TTP-1-3085, Revision 0, WBN-1 Cycle12 TPBAR Tritium Release, Deduced From Analysis Of RCS Data. Pacific Northwest National Laboratory, Richland, Washington.

[32] WBNNAL3003, Revision 5. Reactor Coolant and Secondary Side Activities in Accordance with ANS1/ANS-18,1-1984

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[45] 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

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