2 STANDARD REVIEW PLAN EVALUATION

2.2.1 Accidental Releases of Liquid Effluents Evaluation

This evaluation is addressed in Section 2.11.3.

2.4 REACTOR

2.4.2 Fuel Design Evaluation

2.4.2.1 Fuel Assembly Structural Integrity

A confirming check was performed to verify that the fuel assembly structural integrity is not impacted by the TPBARs. The structural adequacy of Westinghouse fuel assembly design is evaluated using NRC requirements for combined seismic and LOCA loads per Appendix A to the SRP 4.2 and the approved methodology (Reference 1). The grid load results for the fuel assembly design in Watts Bar Unit 1 were reviewed. Based on the combined seismic and LOCA grid load there is a sufficient amount of grid load margin.

The total weight for 24 TPBARs plus the holddown assembly is approximately 62 lbs, which is approximately 4% of the weight of a typical fuel assembly. Because the TPBAR assembly is a hanging structure supported by the top nozzle adapter plate of the fuel assembly and the rodlets are hanging in the guide thimble tubes, the added weight can be considered to be a part of the fuel assembly nozzle support. The added TPBAR assembly weight, together with the rodlet stiffness, has an insignificant effect on the fuel assembly's dynamic characteristics. Therefore, the design basis analyses/evaluations performed for the fuel assembly structural integrity assessment for Watts Bar remain applicable. Furthermore, it is concluded that the LOCA and seismic combined loads will not be affected for Watts Bar Unit 1 containing TPBARs.

2.4.2.2 Fuel Rod Design

The incorporation of the TPBARs in the core alters the fuel management and subsequently the duty of the fuel relative to a design without TPBARs. This change in fuel duty has been assessed to determine if all fuel rod design criteria can be satisfied.

Design models used in the evaluation of fuel rod design criteria have been licensed by the NRC for design applications up to a lead rod average burnup of 60,000 MWD/MTU, Reference 2. The NRC-approved PAD code, with NRC-approved models for in-reactor behavior, References 3 and 4, is used to calculate the fuel rod performance over its irradiation history. As was done for the Topical Report, fuel rod design evaluations for the Tritium Production Core (TPC) fuel were performed using these NRC-approved models in References 3 and 4 and standard design methods to demonstrate that all fuel rod design criteria, References 2 and 5, are satisfied.

The specific assumptions used in the verification of the fuel rod design criteria for the Watts Bar TPC include: (1) Watts Bar TPC specific operating conditions (core power, flow rate, inlet temperature, system pressure), and (2) fuel rod duty (steady state rod powers, axial power shapes, Condition II local rod powers, etc.).

To ensure reliable operation, fuel rod design criteria have been established which must be satisfied for all operating conditions consistent with Condition I and/or Condition II events. The criteria pertinent to the fuel rod design are as follows:

- Rod Internal Pressure
- Cladding Stress
- Cladding Strain
- Cladding Oxidation and Hydriding
- Fuel Temperature
- Cladding Fatigue
- Clad Flattening
- Fuel Rod Axial Growth

Each of these key fuel rod design criteria were evaluated for the fuel rods in the TPC. The evaluations showed that all fuel rod design criteria are met for the TPC design. The use of TPBARs has no significant impact on meeting the fuel rod design criteria. The fuel duty experienced by the fuel rods in the TPC design was not significantly different from typical reload design and the resulting fuel rod performance parameters of rod internal pressure, cladding corrosion, cladding stress, cladding strain and cladding fatigue were similar to those seen in non-TPC reload designs.

Fuel rod design analysis of rod internal pressure, corrosion, cladding stress, strain and fatigue are typically performed for each reload cycle utilizing plant and cycle specific data related to operating conditions and fuel rod duties.

2.4.2.3 References

1. WCAP-9401-P-A, "Verification Testing and analyses of the 17x17 Optimized Fuel Assembly," Westinghouse Proprietary Class 2, August 1981.

2. Davidson, S. L., et al., "Extended Burnup Evaluation of Westinghouse Fuel," WCAP-10125-P-A, December 1985.

3. Weiner, R. A., et al., "Improved Fuel Performance Models for Westinghouse Fuel Rod Design and Safety Evaluations," WCAP-11873-A, August 1988.

4. Davidson, S. L., Nuhfer, D. L., "VANTAGE+ Fuel Assembly Reference Core Report," WCAP-12610-P-A, April 1995.

5. Kersting, P. J. et al., "Assessment of Clad Flattening and Densification Power Spike Factor Elimination in Westinghouse Nuclear Fuel," WCAP-13589-A, March 1995.

2.4.3 Nuclear Design

In Reference 1, the first and equilibrium cycle TPC designs based on a typical Westinghouse four-loop PWR were described and characterized. The overall goal of these conceptual core designs and their associated analyses was to establish the feasibility of using a typical Westinghouse PWR for large-scale production of tritium. In this section, TPC designs based upon the Watts Bar Unit 1 nuclear plant will be described and compared to the designs of Reference 1. The performance of the Watts Bar TPC designs relative to core design bases and key safety parameter limits will be discussed.

The Watts Bar TPC designs are very similar in most respects to the topical report TPC designs. As discussed in Reference 1, however, TPC designs differ from conventional core designs principally in the areas of fuel and core management. Briefly, TPBARs have a large residual reactivity penalty relative to conventional burnable absorbers, primarily due to their large ^{6}Li loading and the low (relative to ^{10}B) thermal neutron absorption cross section of ^{6}Li. To achieve a given cycle energy, then, a Tritium Production Core must load a larger number of feed assemblies at a higher ^{235}U enrichment than a conventional core. Furthermore, TPBARs are discrete burnable absorbers that insert into fuel assembly guide thimbles. As such, they can only be placed in fuel assembly locations without control rods. Since TPBARs are generally placed in feed assemblies, the result is a core loading pattern where once-burned fuel assemblies are placed in control rod locations and feed fuel assemblies with TPBARs are placed in interior core locations without control rods.

Despite these loading pattern constraints and fuel management differences, the Watts Bar TPC loading patterns produce power distributions and peaking factors that are very similar to current Watts Bar core designs and to the topical report TPC designs. Similarly, core physics parameters, such as reactivity coefficients, are generally within typical ranges assumed for the current cores. To briefly characterize these designs, Table 2.4.3-1 compares a number of core design and core operating parameters for a recent Watts Bar core design, the topical report TPC design, and a Watts Bar TPC design. Differences between the topical report TPC designs and the Watts Bar TPC designs are indicated by boldface type.

2.4.3.1 Methodology

The TPC topical report briefly described the computer codes used to analyze tritium production cores (References 2 and 3). Specifically, the modifications made to the PHOENIX-P and ANC neutronics codes for TPBAR modeling were discussed. Since 1998, the PHOENIX-P and ANC codes have continued to evolve through implementation of enhancements designed to improve accuracy and user convenience. The versions of these codes that include TPBAR modeling capability--called PHOENIX-L and ANC-L, respectively--have also evolved to be consistent with the standard code versions. The most significant code upgrades relative to the code versions used in the Topical Report relate to a cross section library upgrade and an enhancement made to increase the number of material regions used to model burnable absorbers (including TPBARs).

As discussed in Reference 1, the original cross section library employed by PHOENIX-L used 42 energy groups. As described in Reference 4, a cross section library upgrade increased the number of energy groups to 70. This is now the standard cross section library used by Westinghouse for analysis of conventional core designs. Included in this new library are 70 group cross section sets for ^{6}Li, ^{7}Li, ^{3}He, and T, the principal isotopes important to TPBAR modeling. This new library has been used in the development of models for the Watts Bar TPC designs.

Reference 1 also described the geometric modeling of TPBARs in PHOENIX-L. Specifically, a four-region model was employed consisting of the following regions: (1) inner plenum region, (2) the TPBAR $LiAlO_2$ pellet, (3) the TPBAR cladding and getter materials homogenized with the guide thimble material, and (4) the moderator region (coolant). Enhancements to PHOENIX-P and PHOENIX-L permit more than four regions to be used. Consequently, the above four-region model has been replaced with a six-region model that eliminates the need for homogenization of guide thimble with the TPBAR cladding region. In this enhanced model, the six regions are as follows: (1) inner plenum region, (2) the TPBAR $LiAlO_2$ pellet, (3) the TPBAR cladding and getter materials, (4) moderator region between the TPBAR and guide thimble, (5) the guide thimble, and (6) the moderator region in the remainder of the cell. This kind of representation is the standard model for conventional discrete burnable absorbers as well (e.g., Wet Annular Burnable Absorbers).

No changes have been made to the fundamental solution algorithms of the standard code versions (PHOENIX-P and ANC) for TPBAR modeling in PHOENIX-L and ANC-L codes. Consequently, References 5, 6, and 7 remain appropriate references for these code versions.

2.4.3.2 Design Bases

The design bases used in the nuclear design of the fuel and reactivity control systems for the Watts Bar TPC designs are the same as those described in Section 4.3 of the Watts Bar UFSAR (Reference 8) and are very similar to those employed in the TPC Topical Report. The specific design bases discussed in Reference 8 include the following: Fuel Burnup, Negative Reactivity Feedbacks (Reactivity Coefficients), Control of Power Distribution, Maximum Controlled Reactivity Insertion Rate, Shutdown Margins with Vessel Head in Place, Shutdown Margin for Refueling, Stability, and Anticipated Transients Without Trip. Provided below is a brief discussion of these design bases and their relationship to TPBARs and the Watts Bar TPC designs.

Fuel Burnup

Basis:

The fuel rod design basis is described in Section 4.2 of Reference 8.

Discussion:

As in the TPC designs discussed in the Topical Report, the initial excess reactivity of the Watts Bar TPC designs is larger than a typical Watts Bar core design in order to compensate for the large residual reactivity penalty of the TPBARs at EOL. This initial excess reactivity is effectively controlled by the combined worths of the integral fuel burnable absorbers, the soluble boron in the reactor coolant (chemical shim concentration), and the TPBARs themselves. In this sense, the TPBARs function like conventional pyrex burnable absorbers or Wet Annular Burnable Absorbers (WABAs). Relative to discharge burnup, the fuel average discharge burnup for the TPC designs is smaller than typical because of the large feed region size. The average discharge burnup for the equilibrium cycle Watts Bar TPC is about 40000 MWD/MTU. A conventional Watts Bar core design achieves an average discharge burnup of about 48000 MWD/MTU. A limitation on installed excess reactivity or average discharge burnup is not required other than as is quantified in terms of other design bases, such as core negative reactivity feedback and shutdown margin, discussed below.

Negative Reactivity Feedbacks (Reactivity Coefficients)

Basis:

The fuel temperature coefficient will be negative and the moderator temperature coefficient of reactivity will be non-positive for power operating conditions, thereby providing negative reactivity feedback characteristics.

Discussion:

The Topical Report TPC designs assumed a positive moderator temperature coefficient (MTC) of +7 pcm/°F up to 70% power, ramping to 0 pcm/°F at full power. For the Watts Bar TPC designs, however, a negative moderator temperature coefficient limit was assumed at all power levels, consistent with the current Watts Bar licensing basis. The inventory of burnable absorbers in the TPC designs, including both integral fuel burnable absorbers (IFBA) and TPBARs, is established to ensure that the MTC is negative at all operating conditions. The Doppler feedback in the Watts Bar TPC designs is always negative, and is roughly comparable to the Doppler feedback observed in conventional Watts Bar core designs. The total power coefficient for the TPC designs is always negative at all power levels.

Control of Power Distributions

Basis:

As described in Reference 8, the nuclear design basis is that, with at least a 95% confidence level:

1. The fuel will not be operated at greater than the average linear power multiplied by $F_Q(z)$ under normal operating conditions, including an allowance of 0.6% for calorimetric error. $F_Q(z)$ is the heat flux hot channel factor and is specified in the Watts Bar Core Operation Limit Report (COLR).

2. Under abnormal conditions, including the maximum overpower condition, the fuel peak power will not cause melting as defined in Section 4.4.1.2 of Reference 8.

3. The fuel will not operate with a power distribution that violates the departure from nucleate boiling (DNB) design basis (i.e., the departure from nucleate boiling ratio (DNBR) shall not be less than the design limit DNBR discussed in Section 4.4.1 of Reference 8) under Condition I and II events, including the maximum overpower condition.

4. Fuel management will be such that rod powers and burnups are consistent with the assumptions in the fuel rod mechanical integrity analysis of Section 4.2 of Reference 8.

Discussion:

The power distributions for the Watts Bar TPC designs were analyzed to ensure that the above design basis was met. The Watts Bar technical specifications place limits on power peaking (F_Q and $F_{\Delta H}$) and axial flux difference (AFD) for Condition I operation. Using the standard design methods of References 9 and 10, a range of radial and axial power distributions were calculated and analyzed for the Watts Bar TPC designs to ensure that the peaking factor limits and DNB design basis were met. Relaxed Axial Offset Control (RAOC), as described in Reference 10, was assumed. Condition II power shapes were analyzed as well to demonstrate that the overpower kW/ft limit of 22.4 was met. This ensures that fuel melting criteria are satisfied.

Maximum Controlled Reactivity Insertion Rate

Basis:

The maximum reactivity insertion rate due to withdrawal of Rod Cluster Control Assemblies (RCCAs) or by boron dilution is limited. This limit, expressed as a maximum reactivity change rate of 75 pcm/sec, is set such that peak heat generation rate and DNBR do not exceed the maximum allowable at overpower conditions.

The maximum reactivity worth of control rods and the maximum rates of reactivity insertion employing control rods are limited so that a rod withdrawal or rod ejection accident will not cause rupture of the coolant pressure boundary or disruption of the core internals to a degree which would impair core cooling capacity.

Following any Condition IV event (rod ejection, steam line break, etc.), the reactor can be brought to the shutdown condition, and the core will maintain acceptable heat transfer geometry.

Discussion:

The discussion of Reference 8 applies to the Watts Bar TPC designs. Reactivity addition associated with an accidental withdrawal of a control bank (or banks) is limited by the maximum rod speed (or travel rate) and by the worth of the bank(s). For the Watts Bar reactor, the maximum control rod speed is 45 inches per minute and the maximum rate of reactivity change considering two control banks moving is less than 75 pcm/sec.

To ensure that the reactor can be brought to a shutdown condition following a large break LOCA, the Refueling Water Storage Tank boron concentration will be raised to a minimum of 3600 ppm. This is necessary because of: (1) the lower worth of boron in Tritium Production Cores relative to conventional cores, and (2) the relatively low minimum boron concentration of the ice in the ice containment (1800 ppm). The ice boron concentration, which will not be increased, is significantly smaller than the post-LOCA subcriticality sump boron requirement. Consequently, the RWST concentration must be raised higher to compensate. A minimum RWST boron concentration of 3600 ppm will ensure post-LOCA subcriticality for the Watts Bar TPC designs.

Shutdown Margins With Vessel Head In Place

Basis:

Minimum shutdown margin requirements as specified in the Watts Bar Technical Specifications are required in all power operating modes, hot standby, hot shutdown, and cold shutdown conditions.

In all analyses involving reactor trip, the single, highest worth Rod Cluster Control Assembly is postulated to remain untripped in its full-out position (stuck rod criterion).

Discussion:

The discussion provided in Reference 8 for these bases applies to the Watts Bar TPC designs. The shutdown margin (SDM) requirement for Modes 1 and 2 was 1.3 $\%\Delta\rho$ for the Reference 1 designs. For Watts Bar, however, the SDM requirement is slightly higher at 1.6 $\%\Delta\rho$. The presence of 57 RCCAs in the Watts Bar core, versus 53 in the Reference 1 core, provides additional SDM. Also, Watts Bar employs Hybrid Ag-In-Cd/B_4C RCCAs, whereas Reference 1 employed standard Ag-In-Cd RCCAs. Hybrid RCCAs have slightly higher worth. These features result in sufficient SDM such that the higher requirement of 1.6$\%\Delta\rho$ for Modes 1 and 2 is met for the Watts Bar TPC designs. This assessment assumes the highest worth control rod is stuck out upon trip.

Shutdown Margin for Refueling

Basis:

When fuel assemblies are in the pressure vessel and the vessel head is not in place, k_{eff} will be maintained at or below 0.95 with control rods and soluble boron. Further, the fuel will be maintained sufficiently subcritical that removal of all rod cluster control assemblies will not result in criticality.

Discussion:

The discussion of Reference 8 applies to the Watts Bar TPC designs. As for current Watts Bar core designs, the boron concentration required to meet the refueling shutdown criteria for Watts Bar TPC designs will be calculated using standard methods and specified in the COLR.

Stability

Basis:

The core will be inherently stable to power oscillations at the fundamental mode.

Spatial power oscillations, should they occur, can be reliably and readily detected and suppressed.

Discussion:

The discussions provided in References 1 and 8 apply to the Watts Bar TPC designs. No changes to the reactor control and protection systems are required for the Watts Bar TPC designs, so that suppression of and protection against power oscillations at the fundamental mode will occur just as for current Watts Bar core designs. While no specific xenon stability studies were performed as part of this study, azimuthal and diametral oscillations due to xenon effects are expected to be self-damping for the TPC designs since the reactivity feedbacks of the Watts Bar TPC designs are comparable to current core designs.

However, just as for the current core designs, axial xenon oscillations may occur. Such oscillations can be readily detected using the excore detectors and controlled using the control banks.

2.4.3.3 Core Design Descriptions

The following gives a description of an equilibrium cycle Watts Bar TPC design. A brief discussion of transition cycle designs is also provided.

Representative equilibrium and transition cycle core designs have been developed. These designs were developed to satisfy a number of objectives and constraints. Specifically, the following objectives and constraints played an important role in determining the overall fuel management, detailed loading patterns, and tritium production for the core designs:

1. Cycle Energy: The cycle energy requirement determines how much excess reactivity must be loaded into the core in the form of feed fuel assemblies of a specified ^{235}U enrichment. Because TPBARs are a reactivity penalty, a larger number of TPBARs or a higher linear loading of ^{6}Li makes achieving a given cycle energy more difficult. The energy requirement effectively sets the number of required feed assemblies and their enrichment. The cycle energy objective for the Watts Bar TPC designs is 510 EFPD at 3459 MW_{th}. For each design, a small power coastdown (4%-5%) is required to achieve this energy.

2. Maximum Fuel Enrichment: For design purposes, a maximum enrichment limit of 4.95 w/o is employed. The licensed manufacturing limit is 5.0 w/o. This, combined with the number of feed assemblies, establishes the core excess reactivity needed to achieve the cycle energy requirement.

3. Maximum Number of Feed Assemblies: The maximum number of feed assemblies to be considered is 96. This leads to essentially a two-region core in the equilibrium cycle with 96 feed assemblies, 96 once-burned assemblies, and one twice-burned assembly in the core center. Feed region sizes larger than 96 assemblies would lead to poorer fuel management and accelerated filling of the spent fuel pool.

4. Tritium Production Objectives: The tritium production objective establishes the required number of TPBARs and the required ^{6}Li loading. The number of TPBARs and the loading should be set high enough to achieve the desired total tritium production and a reasonable production per TPBAR (about 1 gram per TPBAR for interior TPBARs), but low enough to ensure that the cycle energy requirement can be met. Also, the design limit on maximum tritium production (1.2 grams per TPBAR) must be met.

5. Safety Analysis Limits: In addition to the cycle energy and tritium production objectives, the core must meet all the required safety and operational limits, including power peaking factor limits, shutdown margin requirements, LOCA limits, etc. Also, limits on vessel fluence must be accommodated in the core design to ensure that the reactor vessel lifetime is not compromised.

6. Operational Limits: The core design must provide sufficient operational flexibility. For example, the control rod insertion limits and axial flux difference envelope must be such that the core can be operated in typical manner, without undue limitations and constraints.

7. Critical Boron Concentration Limit: TVA has established 1250 ppm as the maximum critical boron concentration at HFP, equilibrium xenon conditions. This limit determines, in part, the number of integral burnable absorbers (IFBA) required.

Accordingly, core designs were developed to achieve the tritium production objectives within the limits of safety, cycle energy requirements, fuel management objectives, and other design constraints discussed above. The equilibrium cycle design is discussed below in detail. Transition cycle designs are also briefly described. Key differences relative to the Reference 1 core designs will be discussed.

Equilibrium Cycle Core Design

The equilibrium cycle core design employs 96 VANTAGE+ (Reference 11) feed assemblies with a fuel enrichment of 4.95 w/o ^{235}U. The cycle energy achieved is 510 EFPD at a power level of 3459 MW$_{th}$. A small power coastdown is needed to achieve this cycle energy. The cycle burnup is 19772 MWD/MTU. A total of 2304 TPBARs are used, with 2048 TPBARs in interior core locations and 256 TPBARs (16 clusters of 16 TPBARs) in peripheral assemblies. The TPBARs on the periphery effectively suppress the power in key locations important to peak reactor vessel fluence. A total of 92 TPBAR clusters are used in fresh fuel, while 20 clusters are used in once-burned fuel, 16 on the core periphery and 4 near the core center. Four feed assemblies placed in control rod locations have no TPBARs. No TPBARs are used in secondary source locations or their symmetric counterparts.

The TPBAR ^{6}Li linear loading is 0.036 g/in in all TPBARs. The TPBAR active region is 132 inches (cold), centered on the fuel stack (at hot conditions). A total of 9792 IFBA rods are also used. The IFBA region has a length of 130 inches, offset 1 inch downward from the core midplane. The IFBA coating is 2.35 mg ^{10}B per inch, with the exception of 16 assemblies located at positions F-11, G-11, and their symmetric counterparts; these assemblies use 1.96 mg ^{10}B per inch to reduce fuel rod internal pressure. A single 4.95 w/o fuel enrichment is used with fully enriched (4.95 w/o) annular blanket pellets in the top 8 inches and bottom 6 inches of the IFBA rods.

Fuel management information for the equilibrium cycle is given in Table 2.4.3-5. Table 2.4.3-6 gives a depletion summary. As Table 2.4.3-6 shows, the core power peaking factors and axial offset are well behaved. Figure 2.4.3-4 gives the quarter-core equilibrium cycle core loading pattern. Figures 2.4.3-17 through 2.4.3-20 give radial power distributions at various cycle burnups. The core design produces 2065 grams of tritium, an average of 0.896 grams per TPBAR. The peak TPBAR produces about 1.060 grams, significantly less than the design limit of 1.2 grams.

In a typical low leakage loading pattern, the assemblies on the periphery are mostly low reactivity, twice-burned assemblies that naturally operate at very low powers. This kind of loading pattern limits the accumulation of fluence on the reactor vessel. Because the equilibrium cycle TPC uses a large feed region (96 assemblies or about half the core), the burned assemblies placed on the core periphery are only once-burned; they are, therefore, more reactive and operate at higher powers than in a typical core. This, obviously, will result in higher vessel fluences with the potential for shortening the vessel lifetime.

To mitigate this problem, this core design employs TPBARs in key locations on the periphery to reduce the powers in specific assemblies important to peak vessel fluence. Specifically, quarter-core positions B-13 and C-14 and their symmetric counterparts are most important to the peak vessel fluence. Of secondary importance are the A-11, E-15, and symmetric positions. This core design places clusters of 16 TPBARs in these assembly locations. While these TPBARs produce only a modest amount of tritium, they are effective in reducing the power in these assemblies to levels that are typical of current Watts Bar core designs.

The Watts Bar equilibrium cycle TPC design is similar in many respects to the Reference 1 equilibrium cycle design. Both designs employed large feed regions with high ^{235}U enrichments, loaded a large number of TPBARs, and placed TPBARs primarily in feed assemblies in non-RCCA locations. The Reference 1 design, however, used 140 feed assemblies and placed feed assemblies with TPBARs in <u>all</u> locations on the core periphery (excluding control rod locations). Thus, this design loaded 3344 TPBARs, whereas the Watts Bar TPC design loaded 2304 TPBARs. Another key difference relates to the fuel rod designs. Both cores use the VANTAGE+ fuel assembly design,[11] but the Watts Bar TPC design employs a larger fuel rod and fuel pellet diameter relative to the Topical Report design (see Table 2.4.3-1). The larger fuel rod diameter reduces the H/U ratio in the lattice, leading to a lower thermal neutron flux. The smaller thermal flux leads, in turn, to a lower ^{6}Li reaction rate in the TPBAR. To compensate for this, a higher ^{6}Li linear loading (0.036 g/in) is used for the Watts Bar equilibrium cycle design relative to the Reference 1 design (0.030 g/in) with the result that interior TPBARs produce about the same amount of tritium in both designs. The TPBAR active region is slightly longer in Watts Bar (132 inches) versus Reference 1 (128.5 inches). The slightly longer TPBARs in Watts Bar help to reduce axial power peaking at the top and bottom of the core. Finally, enrichment zoning was employed in the Reference 1 designs to shape the intra-assembly power distribution and reduce power peaking. Enrichment zoning was not used in Watts Bar; however, peaking factors are comparable to the Reference 1 designs and well within limits.

Transition Cycles

Because of the large number of feed assemblies (96) used in this fuel management scheme, only three cycles are needed to reach equilibrium. In a first transition cycle, it will be necessary to load significantly fewer TPBARs with a lower ^{6}Li loading relative to the equilibrium cycle design discussed above. This is primarily due to the relatively lower enrichment and higher average burnup of the burned fuel in a first transition cycle. As Table 2.4.3-1 indicates, typical Watts Bar feed enrichments in current core designs are in the range of 4.39 to 4.698 w/o ^{235}U and a typical feed region size is 76 assemblies. TPC designs, however, require feed enrichments of 4.95 w/o ^{235}U and, in this fuel management scheme, 96 feed assemblies. Because of this difference in feed region sizes, many more twice burned assemblies would be used in a first transition cycle relative to an equilibrium cycle. As a consequence, the lower enrichment of the burned fuel combined with the use of more twice-burned fuel leads to a reduction in excess core reactivity. Therefore, fewer TPBARs can be loaded if the same cycle energy is to be achieved. A typical first transition cycle, for example, would load 96 feed assemblies at 4.95 w/o ^{235}U and 1424 TPBARs at a linear ^{6}Li loading of 0.034 g/in to achieve the target cycle energy of 510 EFPD.

A second transition cycle would also feed 96 assemblies at 4.95 w/o ^{235}U. Thus, in a second transition cycle, there would be two full regions at 4.95 w/o--the feed fuel and the once-burned fuel. This totals 192 fuel assemblies. Only a single lower enrichment fuel assembly would then be needed to complete the core inventory. This assembly would be placed in the core center. A typical second transition cycle, then, would load 96 feed assemblies at 4.95 w/o ^{235}U and 2224 TPBARs at a linear ^{6}Li loading of 0.034 g/in to achieve the target cycle energy of 510 EFPD. The 2224 TPBARs in this design are only 80 TPBARs less than in the equilibrium cycle.

A third transition cycle would be very similar to the equilibrium cycle described above.

Tritium Production

Table 2.4.3-7 summarizes the expected tritium production of the Watts Bar Tritium Production cores. For comparison, tritium production data for the Reference 1 equilibrium cycle is given as well. As the table shows, the maximum expected TPBAR tritium production in all cases is well below the 1.2 gram limit. The average tritium production per TPBAR is smaller in the Reference 1 design due to its large number of TPBARs loaded on the core periphery relative to the Watts Bar designs. The Watts Bar first transition cycle had the highest average tritium production per TPBAR, 0.988 grams, primarily because it had no TPBARs on the core periphery. In the first transition cycle, twice-burned fuel was placed in key locations on the core periphery for vessel fluence control, so that TPBARs were not needed in these locations. Because of the lower thermal flux in the Watts Bar fuel lattice, TPBARs in the Watts Bar designs deplete less than in the Reference 1 equilibrium cycle. The higher ^{6}Li fraction remaining values for the Watts Bar TPC designs reflect this.

2.4.3.4 Key Safety Parameters

To characterize how the Watts Bar TPC designs perform with respect to core physics parameters important to operation and safety, Table 2.4.3-8 provides a comparison of various nuclear design parameters, including miscellaneous reactivity coefficients, kinetics parameters, control rod worths, neutron fluxes, and boron concentrations. Values for the Watts Bar TPC equilibrium cycle, the Reference 1 equilibrium cycle, and a current Watts Bar core design are provided.

Relative to current Watts Bar core designs, TPC designs will be characterized by lower boron worths, slightly lower control rod worths, more negative moderator temperature coefficients near BOL, higher critical boron concentrations, and lower thermal neutron fluxes. All of these phenomena are related to the large thermal neutron absorption cross section of the TPC cores. The large absorption cross section occurs because the large number of TPBARs, the large number of IFBA fuel rods, and the high fuel enrichment. The high cross section reduces the thermal neutron flux and the worth of thermal neutron absorbers like soluble boron. These same trends were observed for the Reference 1 designs.

The power distributions of the Watts Bar TPC designs are very well behaved. Figures 2.4.3-17 through 2.4.3-20 provide quarter-core relative power distributions for the Watts Bar TPC equilibrium cycle for a number of different cycle burnups. The $F_{\Delta H}$ design limit of 1.528 (without uncertainties) is met for these designs with ample margin.

The Relaxed Axial Offset Control (RAOC) methodology of Reference 10 was used to generate Condition I and Condition II power shapes for the Watts Bar TPC designs for comparison to the $F_Q^T(z)$ and Overpower kW/ft limits. In RAOC, power shapes are generated at various power levels and burnups for a wide range of xenon shapes and covering the allowed operating spaces for control rod insertion and axial flux difference (AFD). As permitted by the Technical Specifications, the AFD envelope is specified each operating cycle as part of the Core Operating Limits Report. The allowable AFD envelope assumed in these analyses is the same as used in current Watts Bar core designs. At full power the allowable AFD ranges from +6% to –15%, while at 50% power the allowable AFD ranges from +20% to –31%. The $F_Q^T(z)$ limit is met with considerable margin. Sufficient margin is available to accommodate the small local power peaking attributed to the TPBAR pencil gaps.

Overpower protection prevents fuel damage and maintains fuel integrity during overpower transients caused by either operator errors or control rod malfunctions. To meet the overpower requirements, the linear power density during transients should not exceed the 22.4 kW/ft limit.

Two categories of overpower transients are considered. The first category involves control rod malfunctions as well as operator errors in control rod positioning. Control rod malfunctions include rod bank withdrawal accidents. The second category involves accidental boration and dilution accidents. These accidents are assumed to occur during any time in life and during normal operating procedures. The results of the Condition II analyses for the Watts Bar TPC designs show that the linear power does not exceed the 22.4 kW/ft limit during postulated overpower transients.

Table 2.4.3-9 provides the reactivity and kinetics parameter assumptions used in the Watts Bar reference safety analysis. The Watts Bar TPC designs fall within the limits and ranges assumed with the single exception of the Doppler-only power coefficient at full power for the Steamline Break with Rod Withdrawal at Power event (SLB with RWAP). The least negative Doppler-only power coefficient at 100% power for the TPC designs was slightly less negative than the reference analysis assumption. This deviation is similar to Doppler defect deviation described for Reference 1 designs. To accommodate this deviation, the Steamline Break with Rod Withdrawal at Power event was reanalyzed with less negative Doppler feedback. Acceptable results were obtained. This event is discussed in detail in Section 2.15.

Using the methodology of Reference 9, other key safety parameters were examined as well. For example, the shutdown margin requirement of 1.6 $\%\Delta\rho$, which is a key assumption for the steamline break event, was met for the Watts Bar TPC designs. Except for the Doppler-Only power coefficient deviation discussed above and the required RWST boron concentration increase, all the key safety parameters typically assumed in the Watts Bar reference safety analyses apply to the Tritium Production Cores. This conclusion will be reconfirmed for each future Watts Bar TPC design using standard reload core design methodology. As for current cores, deviations of key safety parameters from previous assumptions will be evaluated as part of the reload safety evaluation process to determine the impact of the deviations on affected transients.

2.4.3.5 Effects of Extended Shutdown

The effects of extended shutdown were examined in Reference 1 for the equilibrium cycle design. For an extended shutdown near end-of-life, the build-up of ^{3}He through tritium decay can have a significant impact on core reactivity. Reference 1 showed that the ^{3}He build-up after a six-month shutdown can reduce the critical boron concentration at HFP by about 80 ppm upon startup. This build-up also reduces the cycle energy since the ^{3}He depletes slowly, much like a burnable absorber.

For the Watts Bar TPC designs, the reactivity effects of ^{3}He build-up will be smaller than for the Reference 1 designs because of the smaller number of TPBARs and the harder neutron spectrum in the Watts Bar fuel lattice. The power distribution impact of the ^{3}He build-up is also expected to be small. For future Watts Bar TPC designs, the effects of ^{3}He build-up for extended shutdown will be evaluated for specific reload cores. Core operational data and limits will be updated, as necessary, to ensure that the core is operated within safety analysis and Technical Specification limits.

Analyses and testing of irradiated absorber pellets and getters by PNNL show that for core physics calculations, ^{3}He generated by tritium decay in TPBAR components during a lengthy reactor outage can be assumed to remain in the solid components that contained the parent tritium. During reactor startup and subsequent operation, these TPBAR components (pellets and getters) will begin to release ^{3}He to the TPBAR free volume, but complete release occurs over a period of days to weeks.

2.4.3.6 Conclusion

In this section, the nuclear design aspects of Watts Bar Tritium Production Cores have been presented. The design bases employed are the same as those for current Watts Bar core designs. In the TPC designs, the TPBARs function in a manner that is similar to conventional burnable absorbers. While the depletion behavior of the TPBARs is different than that of conventional burnable absorbers, this does not lead to significant differences in core physics behavior. The behavior of the designs with respect to power distributions, reactivity coefficients, and other core physics parameters is quite comparable to current Watts Bar core designs. Calculation and analysis of key safety parameters have demonstrated that, with the exceptions of the least negative Doppler-only power coefficient and minimum RWST boron concentration, the key safety parameters fall within the ranges and limits normally assumed. These exceptions do not invalidate the conclusions of the safety analysis.

Based on the above, it is concluded that viable TPC designs can be developed for Watts Bar that achieve typical cycle energy goals, generate large amounts of tritium, and meet typical design and safety limits.

2.4.3.7 References

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3. Letter from J. A. Scalice, TVA, to Document Control Desk, Watts Bar Nuclear Plant (WBN) Unit 1 - Technical Specification Change 97-001 - Tritium Producing Burnable Absorber Rod (TPBAR) - Watts Bar Cycle 2 Model Comparison With and Without TPBARs – PHOENIX-P/ANC Computer Software Changes, Docket No. 50-390.

4. Letter from N. J. Liparulo, Westinghouse Electric Corporation, to Document Control Desk dated March 18, 1997, Westinghouse ENDF/B-IV-based Library for PHOENIX-P/ANC, NSD-NRC-97-5026.

5. Nguyen, T. Q. et al., Qualification of the PHOENIX-P/ANC Nuclear Design System for Pressurized Water Reactor Cores, WCAP-11596-P-A, June 1988 (Westinghouse Proprietary).

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9. Davidson, S. L. (Ed.), et al., Westinghouse Reload Safety Evaluation Methodology, WCAP-9272-P-A (Westinghouse Proprietary) and WCAP-9273-NP-A (Non-proprietary), July 1985.

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11. Davidson, S. L. and Ryan, T. L. (Ed.), VANTAGE+ Fuel Assembly Reference Core Report, WCAP-12610-P-A, April 1995.

Table 2.4.3-1 Core Design and Operating Parameters and Selected Design Limits

Parameter	**Topical Report TPC Design**	**Recent Watts Bar Core Design**	**Watts Bar TPC Design**
Number of fuel assemblies	193	193	193
Feed enrichments (w/o ^{235}U)	4.60-4.95	4.39-4.698	4.95
Number of feed assemblies	**140**	76	**96**
Number of control rods (RCCAs)	**53**	57	**57**
Control rod material	**Ag-In-Cd**	Hybrid B_4C/Ag-In-Cd	**Hybrid B_4C/Ag-In-Cd**
Core power level (MW_{th})	**3565**	3459	**3459**
Avg. linear power density (kW/ft)	**5.68**	5.52	**5.52**
System pressure (psia)	2250	2250	2250
HZP moderator temperature (°F)	557.0	557.0	557.0
HFP moderator T_{avg} (°F)	**589.7**	591.6	**591.7**
Fuel lattice and assembly design	17x17 VANTAGE+	17x17 VANTAGE+	17x17 VANTAGE+
Fuel rod OD (in. cold)	**0.360**	0.374	**0.374**
Fuel pellet OD (in. cold)	**0.3088**	0.3225	**0.3225**
Cladding and guide thimble material	ZIRLO™	ZIRLO™	ZIRLO™
TPBAR ^{6}Li linear loading (g/in)	**0.030**	N/A	**0.034-0.036**
IFBA ^{10}B linear loading (mg/in)	**1.5**	2.20-2.35	**1.96-2.35**
Active fuel height (in. cold)	144	144	144
Target cycle length (MWD/MTU)	**21,564**	18,805	**19,800**
Target Effective Full Power Days	**494**	483	**510**
Core loading (MTU)	**81.6**	88.9	**89.1-89.3**
$F_{\Delta H}^{N}$ limit (with uncertainties)	1.65	1.65	1.65
F_{Q}^{T} limit (with uncertainties)	2.50	2.50	2.50
Core control strategy	RAOC	RAOC	RAOC
Most positive MTC limit (pcm/°F)	**+7.0 to 70% power, +0.0 at 100 % power**	0.0	**0.0**
Shutdown margin requirement (%$\Delta\rho$)	**1.30**	1.60	**1.60**
TPBAR tritium production limit (g)	1.20	N/A	1.20

Table 2.4.3-5 Fuel Management Information for the Watts Bar 96 Feed Equilibrium Cycle Tritium Production Core

Region	Number of Assemblies	Enrichment w/o U-235	Fuel Loading (MTU)	BOL Average Burnup (MWD/MTU)	EOL Average Burnup (MWD/MTU)	IFBA Fuel Rods
Feed	96	4.95	44.383	0	22534	9792
Once-Burned	96	4.95	44.383	22534	39516	9792
Twice-Burned	1	4.95	0.4613	30971	53185	128

Table 2.4.3-6 Watts Bar TPC Equilibrium Cycle Depletion Summary

Cycle Burnup (MWD/MTU)	Relative Power	Critical Boron (ppm)	F_Q	$F_{\Delta H}$	F_Z	Axial Offset (%)
0	1.000	1708	1.693	1.442	1.155	1.72
150	1.000	1236	1.658	1.437	1.123	-2.66
1000	1.000	1222	1.603	1.391	1.134	-3.25
2000	1.000	1237	1.599	1.384	1.151	-3.91
3000	1.000	1241	1.612	1.376	1.158	-4.33
5000	1.000	1185	1.646	1.412	1.151	-4.59
7000	1.000	1078	1.667	1.432	1.138	-4.56
9000	1.000	939	1.659	1.438	1.127	-4.33
11000	1.000	781	1.633	1.430	1.120	-3.93
13000	1.000	609	1.605	1.413	1.120	-3.78
15000	1.000	430	1.569	1.393	1.113	-3.21
17000	1.000	245	1.558	1.371	1.113	-3.04
19000	1.000	58	1.560	1.360	1.114	-3.02
19510	1.000	10	1.560	1.360	1.115	-3.15
19700	0.971	10	1.527	1.359	1.092	-1.77
19772	0.961	10	1.493	1.359	1.071	-0.36

Table 2.4.3-7 Tritium Production for the Watts Bar and Topical Report Tritium Production Cores

Parameter	Topical Report Equilibrium Cycle	Watts Bar 1st Transition Cycle	Watts Bar 2nd Transition Cycle	Watts Bar Equilibrium Cycle
Number of TPBARs	3344	1424	2224	2304
Initial ^{6}Li Linear Loading (g/in)	0.030	0.034	0.034	0.036
Active Absorber Height (in)	128.5	132	132	132
Average ^{6}Li Fraction Remaining	0.558	0.547	0.601	0.610
Average Grams of Tritium Produced Per TPBAR	0.839	0.988	0.867	0.896
Peak Grams of Tritium Produced Per TPBAR*	1.044	1.034	1.028	1.060
Total Grams of Tritium Produced	2805	1407	1929	2065

* Average over the TPBARs in the assembly channel producing the most tritium (4 channels per assembly). The true maximum may be slightly higher. All values are best estimate.

Table 2.4.3-8 Nuclear Design Parameters

Parameter Description	Watts Bar Recent Cycle	Topical Report TPC Eq. Cycle	Watts Bar TPC Eq. Cycle
Reactivity Coefficients			
Moderator Temperature Coefficients (pcm/°F)			
Near BOL, HZP, No Xenon	-2.1	1.3	-2.9
BOL, HFP, Eq. Xenon	-15.9	-9.9	-16.4
EOL, HFP, Eq. Xenon	-39.3	-32.9	-36.9
Boron Coefficients (pcm/ppm)			
BOL, HZP	-6.5	-6.3	-5.3
BOL, HFP	-6.1	-6.0	-5.0
EOL, HZP	-7.9	-7.6	-6.0
EOL, HFP	-7.5	-7.5	-5.8
Doppler-Only Power Coefficients (pcm/% Power)			
BOL, HZP	-14.4	-11.2	-12.7
BOL, HFP	-8.8	-7.5	-8.3
EOL, HZP	-12.5	-10.5	-12.1
EOL, HFP	-8.4	-7.5	-8.3
Total Power Coefficients (pcm/% Power)			
BOL, HZP	-17.4	-15.7	-17.6
BOL, HFP	-15.1	-10.9	-14.8
EOL, HZP	-35.7	-29.8	-33.3
EOL, HFP	-32.3	-24.7	-29.6
Doppler Temperature Coefficients (pcm/°F)			
BOL, HZP	-2.0	-1.7	-1.9
BOL, HFP	-1.5	-1.3	-1.4
EOL, HZP	-2.1	-1.9	-2.0
EOL, HFP	-1.6	-1.5	-1.6

Note: All values best estimate.

Table 2.4.3-8 Nuclear Design Parameters (cont.)

Parameter Description	Watts Bar Recent Cycle	Topical Report TPC Eq. Cycle	Watts Bar TPC Eq. Cycle
Kinetics Parameters			
Delayed Neutron Fraction, β_{eff}			
BOL	0.00606	0.00653	0.00628
EOL	0.00505	0.00532	0.00532
Prompt Neutron Lifetime (ℓ^*), µsec			
BOL	12.14	11.80	9.93
EOL	14.32	13.40	10.87
HZP Control Rod Worths (pcm)			
Bank D BOL/EOL*	1243/1166	555/591	1256/1248
Bank C BOL/EOL	1106/1146	1148/1147	1056/1295
Bank B BOL/EOL	995/1157	860/851	1143/788
Bank A BOL/EOL	1222/1125	645/660	1116/1590
Shutdown Banks BOL/EOL	3249/3249	3559/3497	3035/2623
*BOL with No Xenon, EOL with HFP Eq. Xenon	57 RCCAs	53 RCCAs	57 RCCAs
HFP Core Average Neutron Fluxes (n/cm^2-sec)			
BOL			
Thermal	3.59E13	3.67E13	2.88E13
Fast	3.10E14	3.17E14	3.08E14
>1 Mev	8.4E13	8.5E13	8.3E13
EOL			
Thermal	4.16E13	4.23E13	3.19E13
Fast	3.19E14	3.28E14	3.20E14
>1 Mev	8.6E13	8.8E13	8.6E13
Thermal Flux < 0.625 ev, Fast Flux > 0.625 ev			

Note: All values best estimate.

Table 2.4.3-8 Nuclear Design Parameters (cont.)

Parameter Description	Watts Bar Recent Cycle	Topical Report TPC Eq. Cycle	Watts Bar TPC Eq. Cycle
Boron Concentrations (ppm)			
HFP, ARO, BOL, No Xenon, Critical	1534	1752	1708
HFP, ARO, BOL, Eq. Xenon, Critical	1122	1341	1236
HZP, ARO, BOL, No Xenon, Critical	1775	1942	1994
HZP, ARI, BOL, No Xenon, $k_{eff} = 0.99$	710	1003	683
CZP, ARI, BOL, No Xenon, $k_{eff} = 0.95$	1683[*]	1979[+]	2010[+]
[*] 50°F, [+] 68°F			

Note: All values best estimate.

Table 2.4.3-9 Reactivity Coefficients and Kinetics Parameters Values and Ranges Assumed in Watts Bar Transient Analyses

Parameter	Value or Range
Least Positive Moderator Density Coefficient (Δk/gm/cc)	0.0
Most Positive Moderator Density Coefficient (Δk/gm/cc)	0.43
Least Negative Doppler-Only Power Coefficient (except for SLB with RWAP*), (pcm/%)	-9.55 (HZP) to –6.05 (HFP)
Least Negative Doppler-Only Power Coefficient for SLB with RWAP, (pcm/%)	-11.75 (HZP) to –8.25 (HFP)
Most Negative Doppler-Only Power Coefficient (pcm/%)	-19.4 (HZP) to –12.6 (HFP)
Doppler Temperature Coefficient (pcm/°F)	-2.90 to –1.0
Delayed Neutron Fraction, β_{eff}	0.0044 to 0.0075
Maximum Reactivity Insertion Rate for Two Banks Moving Together at HZP (pcm/sec)	75

* Steamline Break with Rod Withdrawal at Power

Note: The Watts Bar TPC designs fall within the above ranges with the exception of the least negative Doppler-only power coefficient for SLB with RWAP. This was also the case in the recent Watts Bar non-TPC reload design. A value of –7.94 pcm/% was calculated at HFP, which is slightly outside of the range assumed for the transient. See Section 2.15.2.2 for the evaluation of the acceptability of this value.

	H	G	F	E	D	C	B	A
8	2x	Feed 128 20	1x	Feed 128 20	1x	1x	Feed 128 0	1x
9	Feed 128 20	1x 20	Feed 104 20	Feed 128 24	Feed 128 20	1x	Feed 80 20	1x
10	1x	Feed 104 20	1x	Feed 128 24	Feed 128 24	Feed 128 20	1x	1x
11	Feed 128 20	Feed 128 24	Feed 128 24	1x	Feed 128 24	1x	Feed 0 20	1x 16
12	1x	Feed 128 20	Feed 128 24	Feed 128 24	1x	Feed 80 20	1x	
13	1x	1x	Feed 128 20	1x	Feed 80 20	Feed 0 20	1x 16	
14	Feed 128 0	Feed 80 20	1x	Feed 0 20	1x	1x 16		
15	1x	1x	1x	1x 16				

Region
 # IFBAs
 # TPBARs

Notes: (1) 1x=once-burned, 2x=twice-burned
(2) # IFBAs only indicated for fresh fuel.

Figure 2.4.3-4
Watts Bar Tritium Production Core Equilibrium Cycle Loading Pattern

0 MWD/MTU
1708 PPM

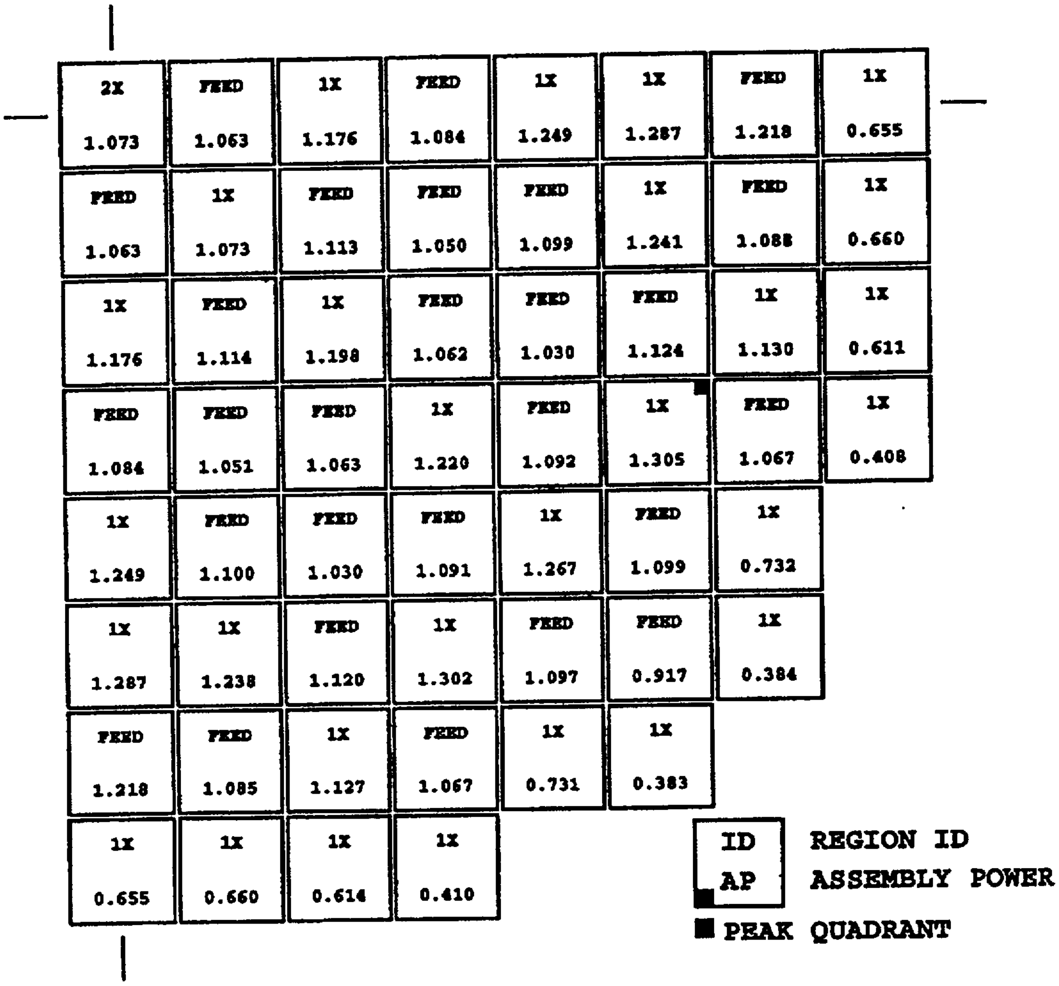
2X 1.088	FEED 1.083	1X 1.192	FEED 1.100	1X 1.253	1X 1.281	FEED 1.201	1X 0.629
FEED 1.083	1X 1.092	FEED 1.133	FEED 1.065	FEED 1.108	1X 1.237	FEED 1.075	1X 0.635
1X 1.192	FEED' 1.133	1X 1.213	FEED 1.076	FEED 1.039	FEED 1.128	1X 1.117	1X 0.589
FEED 1.100	FEED 1.066	FEED 1.077	1X 1.231	FEED 1.102	■ 1X 1.310	FEED 1.062	1X 0.395
1X 1.253	FEED 1.108	FEED 1.039	FEED 1.101	1X 1.274	FEED 1.102	1X 0.720	
1X 1.281	1X 1.234	FEED 1.123	1X 1.306	FEED 1.100	FEED 0.913	1X 0.374	
FEED 1.201	FEED 1.071	1X 1.113	FEED 1.063	1X 0.720	1X 0.373		
1X 0.629	1X 0.635	1X 0.592	1X 0.397				

ID	REGION ID
AP	ASSEMBLY POWER
■	PEAK QUADRANT

REGION IDENT.	NUMBER OF ASSEMBLIES	POWER SHARING	BURNUPS TOTAL	BURNUPS CYCLE
2X	1	1.088	30971	0
FEED	96	1.086	0	0
1X	96	0.913	22534	0

Figure 2.4.3-17
Watts Bar TPC Equilibrium Cycle Assembly Power Distribution
At 0 MWD/MTU, HFP, No Xenon, ARO

150 MWD/MTU
1236 PPM



2X 1.073	FEED 1.063	1X 1.176	FEED 1.084	1X 1.249	1X 1.287	FEED 1.218	1X 0.655
FEED 1.063	1X 1.073	FEED 1.113	FEED 1.050	FEED 1.099	1X 1.241	FEED 1.088	1X 0.660
1X 1.176	FEED 1.114	1X 1.198	FEED 1.062	FEED 1.030	FEED 1.124	1X 1.130	1X 0.611
FEED 1.084	FEED 1.051	FEED 1.063	1X 1.220	FEED 1.092	1X 1.305	FEED 1.067	1X 0.408
1X 1.249	FEED 1.100	FEED 1.030	FEED 1.091	1X 1.267	FEED 1.099	1X 0.732	
1X 1.287	1X 1.238	FEED 1.120	1X 1.302	FEED 1.097	FEED 0.917	1X 0.384	
FEED 1.218	FEED 1.085	1X 1.127	FEED 1.067	1X 0.731	1X 0.383		
1X 0.655	1X 0.660	1X 0.614	1X 0.410				

ID REGION ID
AP ASSEMBLY POWER
■ PEAK QUADRANT

REGION IDENT.	NUMBER OF ASSEMBLIES	POWER SHARING	BURNUPS TOTAL	CYCLE
2X	1	1.073	31133	162
FEED	96	1.080	162	162
1X	96	0.919	22671	137

Figure 2.4.3-18
Watts Bar TPC Equilibrium Cycle Assembly Power Distribution
At 150 MWD/MTU, HFP, Equilibrium Xenon, ARO

9000 MWD/MTU
939 PPM

2X 1.149	FEED 1.253	1X 1.270	■ FEED 1.321	1X 1.252	1X 1.174	FEED 1.230	1X 0.616
FEED 1.253	1X 1.162	FEED 1.311	FEED 1.285	FEED 1.270	1X 1.154	FEED 1.044	1X 0.597
1X 1.270	FEED 1.312	1X 1.281	FEED 1.262	FEED 1.208	FEED 1.159	1X 0.960	1X 0.521
FEED 1.321	FEED 1.286	FEED 1.263	1X 1.247	FEED 1.168	1X 1.119	FEED 0.859	1X 0.336
1X 1.252	FEED 1.271	FEED 1.209	FEED 1.167	1X 1.120	FEED 0.975	1X 0.596	
1X 1.174	1X 1.153	FEED 1.156	1X 1.117	FEED 0.974	FEED 0.755	1X 0.320	
FEED 1.230	FEED 1.042	1X 0.957	FEED 0.860	1X 0.596	1X 0.320		
1X 0.616	1X 0.597	1X 0.523	1X 0.337				

ID REGION ID
AP ASSEMBLY POWER
■ PEAK QUADRANT

REGION IDENT.	NUMBER OF ASSEMBLIES	POWER SHARING	BURNUPS TOTAL	CYCLE
2X	1	1.149	41230	10260
FEED	96	1.152	10125	10125
1X	96	0.847	30394	7861

Figure 2.4.3-19
Watts Bar TPC Equilibrium Cycle Assembly Power Distribution
At 9000 MWD/MTU, HFP, Equilibrium Xenon, ARO

19772 MWD/MTU
10 PPM

2X 1.070	FEED 1.187	1X 1.162	FEED 1.257	1X 1.176	1X 1.129	FEED ■ 1.243	1X 0.672
FEED 1.187	1X 1.082	FEED 1.229	FEED 1.230	FEED 1.244	1X 1.123	FEED 1.079	1X 0.656
1X 1.162	FEED 1.230	1X 1.181	FEED 1.225	FEED 1.213	FEED 1.186	1X 0.989	1X 0.583
FEED 1.257	FEED 1.231	FEED 1.226	1X 1.193	FEED 1.188	1X 1.118	FEED 0.894	1X 0.379
1X 1.176	FEED 1.244	FEED 1.214	FEED 1.188	1X 1.121	FEED 1.026	1X 0.653	
1X 1.129	1X 1.122	FEED 1.184	1X 1.117	FEED 1.026	FEED 0.810	1X 0.369	
FEED 1.243	FEED 1.078	1X 0.988	FEED 0.895	1X 0.653	1X 0.369		
1X 0.672	1X 0.656	1X 0.585	1X 0.381				

ID	REGION ID
■ AP	ASSEMBLY POWER

■ PEAK QUADRANT

REGION IDENT.	NUMBER OF ASSEMBLIES	POWER SHARING	BURNUPS TOTAL	CYCLE
2X	1	1.070	53185	22214
FEED	96	1.147	22534	22534
1X	96	0.852	39516	16982

Figure 2.4.3-20
Watts Bar TPC Equilibrium Cycle Assembly Power Distribution
At 19772 MWD/MTU, 96.1% Power, Equilibrium Xenon, ARO

2.4.4 Thermal and Hydraulic Design Evaluation

2.4.4.1 Introduction

Thermal/Hydraulic (T/H) design of the core is verified to assure safe operation and integrity of the core and fuel assemblies for operation and transients categorized under Condition I, normal operation, and Condition II, incidents of moderate frequency from which the plant is expected to recover. An evaluation has been performed considering the application of the TPBARs in Watts Bar Unit 1 for thermal/hydraulic design. The result of this evaluation is a confirmation that the thermal/hydraulic design conditions will continue to be acceptable with respect to design criteria under such a core configuration.

2.4.4.2 Methodology

The methodology that was pursued to arrive at the conclusion of acceptability of TPBARs is consistent with current standard methods for components inserted into cores of Westinghouse design and with the Topical Report.

With insertion of the TPBAR, some performance differences were seen and accommodated, for which input to the evaluation was developed. Calculations were performed with the T/H design code, VIPRE-01 (Reference 1). This result is used to define core conditions, such as core and assembly flow and channel enthalpy rise, which are taken as boundary conditions for the response of the TPBAR.

The normal Thermal/Hydraulic DNB related reload analyses were performed using VIPRE-01, assuming incorporation of the TPBARs. This resulted in the following detailed Thermal Hydraulic evaluations.

1. An axial power shape study was performed to assure that the limiting power distributions used in design would still be valid in the presence of the TPBAR. This compares power shapes resulting from depletion during operation of the cycles to reference shapes used as the basis for thermal/hydraulic design analyses.

2. The Steamline Break with Rod Withdrawal at Power transient was analyzed to demonstrate the continued acceptability of the DNBR design basis for this transient.

3. Zero Power Hypothetical Steamline Break was analyzed to demonstrate that the DNBR design basis was met.

In addition, the core bypass flow limit was shown to be met with the presence of the TPBARs.

2.4.4.3 Significant Input Parameters and Assumptions

The geometry of the thimble and TPBAR is taken in a consistently conservative direction with respect to dimensional tolerance for input in the model. A bounding value of the enthalpy rise peaking factor and bounding axial power distributions are used for computation of the fuel rod side boundary conditions, as well as for heat generation within the absorber. Generic power distribution profiles are generally used for thermal/hydraulic DNBR analyses. The core component model is fairly explicit in terms of loss coefficients for orifice flow paths, friction, etc. Standard inputs were used for these values in the calculations. The T/H evaluations were performed based on the current Westinghouse fuel design for Watts Bar Unit 1.

2.4.4.4 Acceptance Criteria

The objective of the thermal/hydraulic design is to assure the continued integrity of the core. For fuel rods, this is met by demonstrating that DNB will not occur on the most limiting fuel rod on at least a 95 percent probability at a 95 percent confidence level.

For core components, this is reflected in assuring the mechanical integrity of the thimble and component such that the component remains functional, can be removed/reinserted and that the fuel assembly retains its structural soundness and remains serviceable.

To guard against the debilitating effect of excessive heating and corrosion, the design criterion is taken that the integrity of the guide thimble tubes and TPBAR cladding are maintained. The acceptance criteria are (1) there will be no surface boiling from the TPBAR within the dashpot region of the thimble and (2) there will be no bulk boiling in the thimble along its length. In addition, the sum of the flows through all the thimble/component combinations must be less than allowed by bypass flow limits used to assure adequate flow for core cooling.

2.4.4.5 Results

The axial power shape comparison showed that with the assumption of the current operation strategy, the reference power shapes assumed in the current safety analysis for Watts Bar would remain bounding. The TPBAR would not present any excessive power distribution changes beyond those, which are already bounded within the thermal/hydraulic design bases.

The results of the DNB analyses showed that the DNBR design basis was met. This includes the results of the detailed analyses listed in Section 2.4.4.2. The bypass flow limits were met with margin.

The analysis of the TPBAR component showed that the acceptance criteria were met. There was no bulk boiling in the thimble or surface boiling in the dashpot.

2.4.4.6 Conclusions

The work performed to assess effects of application of TPBAR on Watts Bar Unit 1 has demonstrated that these components can be applied with no adverse effect on the thermal/hydraulic design. Bases will continue to be met for the structural integrity of the assembly due to thermal and hydraulic effects. Bypass flow will remain within limits. The DNB criterion will continue to be met with no feature of the TBPAR challenging cooling capacity of the core.

The DNB analyses were based on projected axial power shapes for the cores with TPBARs and the core bypass evaluations were based on projected core loading patterns with TPBARs. Future analyses will be done to show that these are applicable for the cycle specific core loading patterns. Any other future changes that could affect the analyses will be done in the cycle specific analyses.

2.4.4.7 References

1. WCAP-14565-P-A, "VIPRE-01 Modeling Qualification for Pressurized Water Reactor Non-LOCA Thermal-Hydraulic Safety Analysis," October 1999.

2.9 AUXILIARY SYSTEMS

2.9.1.1 Overhead Load Handling System

The 125/10 Ton Auxiliary Building Crane is the only overhead handling system involved in TPBAR related handling. It handles new fuel assemblies equipped with TPBARs, empty consolidation canisters, the consolidation frame during assembly/disassembly/transport, and shipping casks. The handling of new fuel assemblies and empty consolidation canisters are well within the capacity and are consistent with existing handling procedures for the crane, and therefore require no further evaluation.

Handling of the Consolidation frame in the Auxiliary Building is accomplished within the NUREG-0612 program requirements as embodied in the response to Generic Letter 81-07. Additionally, because handling of the consolidation frame in the cask loading pit is in close proximity to irradiated fuel in the spent fuel pool, additional design considerations/requirements are established as follows:

- The consolidation frame weighs less than 1/2 of the crane hook capacity. Together with other installed crane safety features, this renders the crane equivalent single-failure-proof for this load.
- The lifting device for the consolidation frame will be designed, fabricated, tested, and examined in accordance with ANSI N14.6 for critical loads. This renders the lifting device equivalent single-failure-proof for this lift.

Shipping cask handling considerations are addressed in Section 1.5.1.

2.9.1.2 Chemical and Volume Control System

The Chemical and Volume Control System (CVCS) provides for boric acid addition, chemical additions for corrosion control, reactor coolant clean up and degasification, reactor coolant make-up, reprocessing of water letdown from the RCS, and RCP seal water injection. During plant operation, reactor coolant flows through the shell side of the regenerative heat exchanger and then through a letdown orifice. The regenerative heat exchanger reduces the temperature of the reactor coolant and the letdown orifice reduces the pressure. The cooled, low-pressure water leaves the reactor containment and enters the auxiliary building. A second temperature reduction occurs in the tube side of the letdown heat exchanger followed by a second pressure reduction due to the low-pressure letdown valve. After passing through one of the mixed bed demineralizers, where ionic impurities are removed, coolant flows through the reactor coolant filter and enters the volume control tank (VCT).

In the assessment of CVCS operation at the revised required boron concentrations, the current system design was evaluated to determine if the functional operability of the system and its components are maintained for the TPC.

The results of the evaluation determined the minimum post-LOCA sump pH concentration for the Watts Bar TPC to be 7.8. This pH value falls below the current Watts Bar minimum value of 8.0.

For the TPC, it was determined that the rate of boration with a single boric acid transfer pump operating is sufficient to take the reactor from full power operation to 1% shutdown in the hot condition, with no rods inserted, in less than 125 minutes. For the current core designs, this time is 90 minutes. In less than 100 additional minutes, enough boric acid can be injected via the normal boron charging path to compensate for xenon decay. The revised value of 100 minutes reflects utilization of a realistic value for pump flow rate. The previous value of 200 minutes was based on a conservative (less than design) boration flow rate. These values are consistent with the boration requirements of current core designs.

From a "systems" perspective, CVCS operation at the revised boron concentration was reviewed. The overall conclusion from this assessment is that the incorporation of TPBARs will not require any system changes for the CVCS to perform its design basis functions.

2.9.6 Process and Post Accident Sampling System Evaluation

TVA has performed an evaluation of the production of tritium using TPBARs in WBN and determined that no additional sampling points are needed beyond those presently required by plant technical specifications during the normal plant operating and refueling operations with a TPC. Evaluation of potential leaching of chemical contaminants from TPBARs has determined that the effect of these potential chemical contaminant releases into the Reactor Coolant System (RCS) or the Spent Fuel Pool will not require any changes to WBN's existing sampling frequencies. However, procedures will be revised prior to TPBAR irradiation to require liquid sampling in the spent fuel pool for tritium while moving and storing irradiated TPBARS. While irradiated TPBARs are stored in the spent fuel pool, tritium sampling will be conducted on a weekly basis. When moving irradiated TPBARs, the spent fuel pool will be sampled daily (TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience). Additionally, action levels will be established in plant procedures to require increased sampling of the RCS if tritium concentrations greater than the expected range are noted as indicated in Table 2.9.6-1.

Table 2.9.6-1 RCS Enhanced Tritium Sampling Program

RCS Tritium Concentration (μCi/g)	Action#
Non-TPC	Weekly Sample
TPC < 9 μCi/g [expected range]	Three times a Week
TPC > 9 μCi/g and < 15 μCi/g [upper limit of expected range]	Sample daily
TPC > 15 μCi/g [beyond expected range]	Initiate response to determine causes and activities to mitigate impact. Expand tritium monitoring

Actions and action levels are based on the projected 9 TCi/g maximum tritium concentrations for a TPC. TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience.

2.11 RADIOACTIVE WASTE MANAGEMENT

2.11.2 Source Terms

Reactor Core

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.

Reactor Coolant System

The methodologies of ANSI/ANS 18.1-1984 were used to calculate reactor coolant activities. The comparison of noble gases and iodine activities in the RCS, as shown in Table 2.11.2-2, demonstrates that the radioisotopic inventory is the same for the TPC and a conventional core. This is expected since operation with a TPC will not affect operational controls associated with management of the RCS.

Tritium

With respect to tritium sources, in a non-TPC, the production of tritium in the RCS is primarily the result of three processes:

- Ternary fission,
- Boron activation, and
- Lithium activation.

A review of Westinghouse Pressurized Water Reactors benchmark tritium data indicates a nominal production/release tritium value of about 870 Ci/y/unit. This nominal value is consistent with the 845 Ci/y unit average tritium effluent total (Table 2.11.3-2) observed over the past four years (1997 - 2000) at WBN and SQN and will be used in the balance of this discussion.

When reviewing station annual tritium effluents, it is important to recognize that plants such as WBN and SQN operate with 18-month fuel cycles which tend to generate more tritium early in the core cycle, owing to higher initial boron concentrations and/or burnable poisons and Integral Fuel Burnable Absorber rods that are required for reactivity control. This results in increasing concentration of tritium in the RCS during the first half of the fuel cycle when discharges from the RCS are relatively small since the amount of feed and bleed necessary to reduce the RCS boron concentration is minimal. However, as the boron concentration is reduced and additional feed and bleed of the RCS is necessary to accommodate boron removal, the amount of primary coolant that is removed increases and the RCS tritium concentrations are reduced over the latter parts of the cycle.

TPBARs are designed and fabricated to retain as much tritium as possible within the TPBAR. Since the TPBAR produced tritium is chemically bonded within the TPBAR, virtually no tritium is available in a form that could permeate through the TPBAR cladding. However, it is assumed that while operating with a TPC, some of the tritium inventory in the TPBARs may permeate the cladding material and be released to the primary coolant. The design goal for this permeation process is less than 1,000 Ci per 1,000 TPBARs per year from the core average rod. Thus a single TPBAR may release more than 1 Ci/year, but the total release for 1,000 TPBARs will be less than 1,000 Ci/year. As the TPC will contain up to 2,304 TPBARs at WBN, the total design basis tritium input from the maximum number of TPBARs is 2,304 Ci/y into the RCS. The design basis sources of tritium for the RCS, on a fuel cycle basis, are summarized in Table 2.11.2-3.

In addition to the maximum design basis TPBAR permeation release, a potential release scenario is the failure of one or more of the TPBARs. It has been assumed that two TPBARs under irradiation would fail and the entire inventory of tritium would be released to the primary coolant. At the end of the operating cycle, the maximum available tritium in a single TPBAR is calculated to be about 11,600 Ci. While, the occurrence of one or two failed TPBARs is considered to be beyond that associated with reasonable design basis considerations, the assumption of two failed TPBARs is documented in Reference 1.

The TPC projected annual tritium RCS source values are summarized in Table 2.11.2-4.

Table 2.11.2-1 Comparison of Core Noble Gas and Iodine Activities for a Conventional Core to a Tritium Producing Core[1]

Isotope	Total Core Inventory (Curies)	
	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

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

Table 2.11.2-2 Comparison of Reactor Coolant Noble Gas and Iodine Activities for a Conventional Core to a Tritium Producing Core

Isotope	RCS Activity at Shutdown (μCi/g)	
	Conventional Core	TPC
Kr-85m	1.71E-01	1.71E-01
Kr-85	2.66E-01	2.66E-01
Kr-87	1.61E-01	1.61E-01
Kr-88	3.00E-01	3.00E-01
Xe-133	2.53E+00	2.53E+00
Xe-135m	1.39E-01	1.39E-01
Xe-135	9.04E-01	9.04E-01
Xe-137	3.65E-02	3.65E-02
Xe-138	1.29E-01	1.29E-01
I-131	4.77E-02	4.77E-02
I-132	2.25E-01	2.25E-01
I-133	1.49E-01	1.49E-01
I-134	3.64E-01	3.64E-01
I-135	2.78E-01	2.78E-01

Table 2.11.2-3 Design Basis Sources of Tritium in the Primary Coolant for the Tritium Production Core Operating Cycle

Tritium Source	Curies
Tritium Producing Burnable Absorber Rods	3,456 (design basis value, actual value will be developed based on operating experience)
Ternary Fission	1,770 (design basis value, actual value is estimated to be 350)
Integral Fuel Burnable Absorbers	40
Control Rods	95
Coolant soluble boron	460
Coolant soluble lithium	176
Deuterium	4
Total Design Basis Tritium	6,001

Table 2.11.2-4 TPC Projected Annual RCS Tritium Source Values

RCS Tritium Sources	Estimated Annual Tritium Release to RCS (Ci)	Estimated Peak RCS Tritium Concentration (μCi/g)
Non-TPC with nominal tritium release	870	≈ 2.5
TPC with nominal tritium release and design basis permeation from TPBARs	3,170	≈ 9.0[1]
TPC with nominal tritium release, design basis permeation from TPBARs and one TPBAR failure having instantaneous release at end of operating cycle	14,770	≈ 53
TPC with nominal tritium release, design basis permeation from TPBARs and two TPBAR failures having instantaneous release at end of operating cycle	26,370	≈ 105

1. The projected tritium release to the RCS with a TPC containing TPBARs releasing tritium at the design maximum rate will result in about a factor of four increase over the current tritium production rate, that is, Ratio = (TPC) 3,170 Ci/yr/(Nominal Core) 870 Ci/yr = 3.6.

2.11.3 Liquid Waste Management Systems

TVA has performed an evaluation and determined that for normal TPBAR operation (permeation only), TVA will maintain normal RCS feed and bleed operation for boron control throughout the cycle. Primary coolant discharge volumes with a TPC will therefore be comparable with current plant practice. The maximum tritium level in the RCS, as discussed above under Section 2.11.2, is anticipated to be about 9 μCi/g.

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

The projected tritium release to the RCS with a TPC containing TPBARs releasing tritium at the design maximum rate will result in about a factor of four increase over the current tritium production rate, that is,

Ratio = (TPC) 3,170 Ci/yr/(Nominal Core) 870 Ci/yr = 3.6.

By extrapolation (Ratio times the RCS maximum tritium levels noted during extended operating cycles) it has been calculated that with no modifications to TVA's current boron-control feed and bleed methodologies, the design basis RCS maximum tritium values will approximate 9 µCi/g with a cycle mean of ≈ 3.6 µCi/g. These values would indicate an estimated containment peak tritium DAC-fraction of ≈ 0.6 and an average containment tritium DAC-fraction of about 0.3. The design basis estimated containment average tritium DAC-fraction equates to an effective dose rate of about 0.7 mrem/h.

The TVA TPC estimated end of cycle (pre-flood up) RCS tritium values are projected to be in the 0.4 - 1.2 µCi/g range. For TPBAR abnormal operation, TVA will establish two tritium RCS action levels >9 µCi/g and >15 µCi/g. The lower action level will require more frequent sampling (once/day) to monitor the RCS tritium levels. In the unlikely event that the higher action level is exceeded, TVA will take further action to minimize the onsite and offsite radiological impacts of abnormal RCS tritium levels. These actions may include, but are not limited to; initiating actions to determine cause, more frequent tritium monitoring of RCS as well as other potentially impacted areas such as containment, increased feed and bleed of the RCS to reduce the tritium concentration, and the temporary onsite storage of tritiated liquids to ensure that the discharge concentration limits are met. The actions levels described above will be used in response to what TVA believes to be extremely unlikely abnormal increases of the tritium levels in the RCS. Plant-specific procedures will be developed before TPBAR irradiation utilizing these action levels.

Population doses from liquid and airborne effluent releases associated with both TPC normal and abnormal operation (failure of two TPBARs under irradiation and the associated inventory of tritium is assumed to be released to the primary coolant) will remain below applicable ODCM limits, and tritium release concentrations will remain within 10 CFR 20 and ODCM release limits.

In addition, TVA has reviewed the current radioactivity monitoring programs for outdoor liquid storage tanks and has verified that the existing programs provide an appropriate level of assurance with a TPC. The current programs ensure that with an uncontrolled release of the tanks' contents the resulting radioactivity would be less than the regulatory limits at the nearest potable water supply or the nearest surface water supply.

Utilizing the revised TPC source terms, the offsite radiation doses calculated for releases of radionuclides in liquid and gaseous effluents during normal and abnormal TPC operations are summarized in Table 2.11.3-2.

The impacts to the public from a WBN TPC are an increase in projected total body exposure of the maximally exposed individual via the liquid effluent pathway of 0.08 mrem in a year and an increase of 0.120 mrem in a year to the maximally exposed individual's maximally exposed organ (liver) via the liquid effluent pathway. For the gaseous effluent pathway, the maximum real pathway projected dose to the thyroid increases 2.6 mrem in a year.

These data, including a comparison to the station's regulatory established radioactive effluent limits, are shown in Table 2.11.3-3.

Table 2.11.3-2 Station Annual Liquid and Gaseous Tritium Effluents (Curies)

SQN	Liquid	Gas	Total	Gas %
1997	1559.00	45.29	1604.29	2.82%
1998	1905.00	83.72	1988.72	4.21%
1999	998.00	34.26	1032.26	3.32%
2000	2832.40	62.65	2895.05	2.16%
STATION MEAN	1832.60	56.48	1880.08	3.13%
UNIT MEAN	911.80	28.24	940.04	3.00%
WBN	**Liquid**	**Gas**	**Total**	**Gas %**
1997	639.20	2.56	641.76	0.40%
1998	712.58	7.45	720.03	1.03%
1999	368.43	8.58	377.01	2.28%
2000	1116.00	14.70	1130.70	1.30%
STATION MEAN	694.06	8.32	559.61	1.49%
UNIT MEAN	694.06	8.32	559.61	1.49%
TVA	**Liquid**	**Gas**	**Total**	**Gas %**
PWR UNIT MEAN	839.19	21.61	845.15	2.56%

Table 2.11.3-3 Annual Projected Impact of TPC on Effluent Dose to Maximally Exposed Members of the Public

Pathway - Maximally Exposed Individual	Total Body (mrem)	Critical Organ (mrem)	Annual Regulatory Guidelines[1] (mrem)	Percent of Guideline
Liquid				
Current Core	0.72	NA	3.00	24.0%
TPC	0.72	NA	3.00	24.0%
TPC with one TPBAR Failure	0.76	NA	3.00	25.3%
TPC with two TPBAR Failures	0.80	NA	3.00	26.7%
Current Core (Liver)	NA	0.96	10,00	9.6%
TPC (Liver)	NA	1.00	10.00	10.0%
TPC with one TPBAR Failure (Liver)	NA	1.04	10.00	10.0%
TPC with two TPBAR Failures (Liver)	NA	1.08	10.00	10.1%
Gaseous				
Current Core (Noble Gases)	0.56	NA	5.00	11.2%
TPC (Noble Gases)	0.56	NA	5.00	11.2%
TPC with one TPBAR Failure (Noble Gases)	0.56	NA	5.00	11.2%
TPC with two TPBAR Failures (Noble Gases)	0.56	NA	5.00	11.2%
Current Core (Thyroid)	NA	7.50	15.00	50.0%
TPC (Thyroid)	NA	9.41	15.00	62.7%
TPC with one TPBAR Failure (Thyroid)	NA	9.75	15.00	65.0%
TPC with two TPBAR Failures (Thyroid)	NA	10.10	15.00	67.3%

1. Title 10 Code of Federal Regulations Part 50 Appendix I.

2.11.4 Gaseous Waste Management Systems

As concluded in both the DOE topical report and NRC SER, the amount of increase in the radioactive gaseous effluents and the associated dose values are insignificant given the normal evaporative losses from the reactor refueling cavity water and the spent fuel pit water as release paths.

Watts Bar specific data collected during the Lead Test Assembly evaluation program yielded tritium airborne activity levels near the spent fuel pool of less than the detection limit of 1×10^{-9} µCi/ml. The spent fuel pool tritium concentration values over the six month test period averaged around 1×10^{-2} µCi/g.

However, as there is a remote possibility of another release path involving a damaged or dropped assembly or irradiated TPBAR, TVA will monitor for airborne tritium in the spent fuel pool area when moving fuel containing irradiated TPBARs or while consolidating irradiated TPBARs. Prior to initial TPBAR irradiation, TVA will modify the Auxiliary Building and Shield Building Exhaust tritium sampling to continuous. Plant specific procedures will be developed before TPBAR irradiation addressing these actions. TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience.

In addition, with regard to the waste gas decay tank, TVA will perform sampling for tritium before releases while irradiating TPBARs. TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience. Plant specific procedures will be developed before TPBAR irradiation addressing these actions.

2.11.5 Solid Waste Management Systems Evaluation

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 consolidation. TVA will consolidate and temporarily store these items on-site. Offsite shipment and ultimate disposal is assumed in accordance with agreements between TVA and DOE. The estimated activity inventory associated with these additional irradiated components (Reference 3) (112 base plates and 384 thimble plugs) when adjusted to reflect measured dose rate from Base Plate with 24 Thimble Plugs following 113 day decay adjusted to 180 days is 5,921 Ci per cycle (180 day post irradiation decay) or an average of 3,527 Ci per year. This represents an increase from the current WBN Updated Final Safety Analysis Report (UFSAR) estimated value of 1,800 Ci per year to approximately 5,530 Ci per year. 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 annual estimated solid waste (UFSAR), from 32,820 cubic feet per year to 32,853 cubic feet per year.

TVA's current estimate of the TPBAR cycle work scope includes pre-cycle preparation activities, post cycle removal and handling activities, TPBAR consolidation (including equipment setup and disassembly) and shipping activities, and the processing, packaging, and shipping of the irradiated components for an estimated total of 2,500 man-hours in a 1 mrem/hour radiation field. TVA estimates that on a TPC basis, this additional TEDE is about 1.7 rem per year for TPBAR handling and consolidation activities (2.5 rem per TPC cycle). This estimated additional 1.7 rem per year is an increase of 1.1% of the current WBN station dose assessment of 149 rem (UFSAR), an amount that remains bounded by the station dose assessment of record. Given this small additional ManRem increase for TPBAR handling, consolidation, processing, packaging, and shipping activities, the impact of the increased curies associated with the irradiated components is considered insignificant.

For abnormal TPC operation (TPBAR failure – see Sections 2.11.2 and 2.11.3), where increased feed and bleed operation may be used to reduce tritium levels in the RCS, the increased resins that may result from the increased feed and bleed operation will be stored at TVA in suitable containers. Offsite shipment and ultimate disposal will be according to established agreements between TVA and DOE. The amount of increase associated with abnormal TPC operation is estimated to be an additional 600 Ci and an additional 30 cubic feet. This additional volume is an insignificant increase in the WBN annual estimated solid waste (UFSAR), from 32,820 cubic feet per year to 32,850 cubic feet per year.

2.11.6 Process and Effluent Radiological Monitoring and Sampling Systems

TVA has reviewed its process and effluent monitoring and sampling equipment program and determined that this program requires minor modifications for a Tritium Production Core (TPC). These changes are limited to the modification of the Auxiliary Building and Shield Building Exhaust tritium sampling from periodic grab samples to continuous sampling, and sample frequency enhancements to the existing monitoring programs, as discussed above under Sections 2.9.6, 2.11.3 and 2.11.4. Plant specific procedures will be developed before TPBAR irradiation addressing these actions. TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience. No other changes to TVA's current program are warranted.

TRITIUM MONITORING

In this section, the various techniques used to monitor for tritium in gases (primarily air) and in liquids are discussed.

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 tritium oxide in room air is to use a "cold finger" or dehumidifier unit to freeze or condense the tritium oxide 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.

Liquid Scintillation Counting

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 sources.

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.

2.11.7 References

1. DOE/EIS – 0288, March 1999, *Final Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor.*

2. Watts Bar Nuclear Plant, *Updated Final Safety Analysis Report (UFSAR).*

3. Pacific Northwest National Laboratory, 1999, *Unclassified Bounding Source Term, Radionuclide Concentrations, Decay Heat, and Dose Rates for the Production TPBAR, TTQP-1-111 Rev. 1.*

2.12 RADIATION PROTECTION

2.12.2 Radiation Sources

As discussed above, under Sections 2.11.2 and 2.11.3, TVA has performed an evaluation of the radiation sources for the TPC and determined that the core source term for the maximum irradiation level of 96 fuel assemblies is bounded by the existing source term of record for WBN. In addition, the transition cycles to this maximum level, as well as lower irradiation feed levels, were analyzed. They are also bounded by the source term of record.

2.12.3 Radiation Protection Design Features and Dose Assessment

Tritium is a radioactive isotope of hydrogen with a half-life of 12.3 years, which 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 and the only potential hazard comes when personnel are exposed to open processes that have been wetted with tritiated liquids. Therefore, the design features of the plant that deal with contamination and airborne radioactivity control such as drain and ventilation systems are of potential concern. TVA agrees with the findings of both the DOE topical report and NRC SER that there is negligible impact to these systems by a TPC. TVA has concluded there will be minimal impact on estimated annual Total Effective Dose Equivalent (TEDE) values. TVA has evaluated the additional deep-dose equivalent to select station personnel during TPBAR consolidation and the additional committed effective dose equivalent from possible increased tritium airborne activity in containment. TVA estimates on a TPC basis, this additional

TEDE, is about 1.7 rem per year for TPBAR handling and consolidation activities (2.5 rem per TPC cycle) and 1.5 rem per year for the additional committed effective dose equivalent from possible increased tritium airborne activity in containment. This possible additional 3.2 rem per year is an increase of 2.3% of the current station dose assessment of 149 rem (Reference 1) and is considered to be bounded by the station dose assessment of record.

The annual radiological exposure estimates in the TPC Topical Report did not consider additional committed effective dose equivalent, as it was assumed that RCS tritium levels would be maintained at non-TPC levels. The TPBAR handling and consolidation activities were estimated in the Topical Report to require 2 individuals working a single twelve hour shift in a 2.5 mrem/hour radiation field. TVA's estimate of the TPBAR cycle work scope includes; the pre-cycle preparation activities, post cycle removal and handling activities, TPBAR consolidation (including equipment setup and disassembly) and shipping activities, and the processing, packaging, and shipping of the irradiated components for an estimated total of 2,500 man-hours in a 1 mrem/hour radiation field.

2.12.4 Operational Radiation Protection Program

TVA has evaluated the current program and determined that there will be no major impact due to inclusion of a TPC. The program modifications are adjustments or changes in scope, rather than major program revisions. Additional monitoring instrumentation and sample equipment to allow better assessment of plant tritium airborne activity will be procured. Plant specific procedures addressing these actions will be developed before TPBAR irradiation.

Tritium Internal Dosimetry Program

A tritium internal dosimetry program requires the determination of the presence or absence of tritium through specific monitoring of the facility and individual workers. It includes the analysis and measurement of tritium in bioassay samples, the evaluation of intakes, and the calculation and assignment of doses from those measurements. It involves evaluation of the intake (Derived Air Concentrations (DACs), supplemented by the evaluation of bioassay data.

TVA has adopted an evaluation level *(EL)* of 50 mrem committed effective dose equivalent from intakes occurring in a year for employees. TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience. The derived limit for the amount of radioactive materials taken into the body of an adult worker by inhalation or ingestion in a year is the Annual Limit on Intake (ALI). One stochastic ALI is equivalent to 5,000 mrem. An intake of a single radionuclide equal to 0.01 of the stochastic ALI or a mixture of radionuclides with a value of 0.01 relative to the stochastic ALI values will yield an *EL*. This is equivalent to 20 DAC hours based on stochastic values.

TVA's *EL* is conservative with respect to the guidance provided by the Nuclear Regulatory Commission in Regulatory Guide 8.9, U.S. Nuclear Regulatory Commission, *Regulatory Guide 8.9 – Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program*. Regulatory guidance sets the evaluation level at 0.02 of the stochastic ALI. This is equivalent to 40 DAC hours based on stochastic values.

Because of differences in physical properties and metabolic processes, each individual's dose resulting from an internal exposure is unique. In other words, the same radionuclide intake to multiple individuals will likely cause different doses to each individual. However, for very small intakes anticipated, the use of reference man physiological data and biokinetic modeling is adequate to estimate Committed Effective Dose Equivalent, demonstrate compliance with regulatory requirements, and to provide assurance of an appropriate level of protection to workers with respect to internal radiation exposure (References 2 and 3).

Tritium Bioassay Program

The TVA tritium bioassay program will follow the guidance of U.S. Nuclear Regulatory Commission, *Regulatory Guide 8.9 – Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program*. Procedures for the bioassay program will be reviewed and upgraded to ensure sufficient assessment of tritium intake before TPBAR irradiation.

Tritium Monitoring

In this section, the various techniques used to monitor for tritium in gases (primarily air), in liquids, and on surfaces are discussed.

Air Monitoring

Portable ionization chamber instruments will be used for measuring water vapor forms of tritium (HTO) in the station. The output is usually given in units of concentration (typically $\mu Ci/m^3$). Such devices require only an electrically polarized ionization chamber, suitable electronics, and a method for moving the gas sample through the chamber-usually a pump. For real-time tritium monitoring, the practical lower limit of sensitivity range is about one $\mu Ci/m^3$ (0.05 Derived Air Concentration). External background radiation, noble gas, or the presence of radon can reduce the sensitivity of the instrument. TVA has tentatively selected SCINTREX Portable Tritium-in-air Monitor Model 309a, or equivalent, as the instrument of choice.

Air Sampling

Tritium air sampling differs from real-time monitoring in that 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} $\mu Ci/ml$.

Surface Monitoring

Tritium contamination will be routinely monitored by smears, which are wiped over a surface and then analyzed by liquid scintillation counting. TVA will develop a routine surveillance program that may include smear surveys in laboratories, process areas, and lunchrooms. In most locations within our facility, weekly or monthly routine smear surveys may be sufficient. The frequency will be dictated by operational experience and the potential for contamination. In addition to the routine survey program, special surveys will be made following spills or on potentially tritium contaminated material being transferred to a less controlled area to prevent the spread of contamination from controlled areas. TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience.

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.

Liquid Scintillation Counting

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 sources.

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.

2.12.5 Radiological Environmental Monitoring Program

TVA has reviewed the WBN Radiological Environmental Monitoring Program (REMP) to identify any needed changes to implement the Tritium Production Program. The following REMP changes will be made after receiving NRC license amendment approval but prior to irradiation of the first TPBARs. TVA will review and modify actions, action levels, and sample frequencies, as necessary, based on TPC operating experience.

- Atmospheric Moisture - Selected atmospheric sampling stations will be modified to include the collection of atmospheric moisture. Collection will be performed at least biweekly.
- Surface Water - Perform tritium analysis on samples collected every four weeks (composite sample collected by automatic sampling system) from the downstream and upstream sampling locations.
- Public Water - Perform tritium analysis on samples collected every four weeks (composite sample collected by automatic sampling system) from downstream public water systems.
- Ground Water - Perform tritium analysis on samples collected every four weeks from the site monitoring wells. Add monthly grab sampling at locations for the nearest (within five mile radius) offsite users of ground water as the source of drinking water.

2.12.6 References

1. Watts Bar Nuclear Plant, Updated Final Safety Analysis Report (UFSAR).

2. National Council on Radiation Protection and Measurements, Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition, NCRP Report No. 87, February 1987.

3. International Commission on Radiological Protection (ICRP) *Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation* ICRP Publication 54. 1987, Oxford: Pergamon.

2.13 CONDUCT OF OPERATION

2.13.1.1 Training

The irradiation of TPBARs will require the review, revision, or development of the following programs:

- Handling, consolidating, and shipping TPBARs.
- General employee training to address TPBAR irradiation.
- Onsite staff training on basic TPC core operation.

As programs and procedures are revised or developed, training will be conducted for TVA personnel. Implementation will include identification/completion of additional training to ensure personnel are adequately trained to perform required activities in a safe and efficient manner.

2.13.1.2 Emergency Planning

TVA has reviewed the Radiological Emergency Preparedness Program (REP) to identify any needed changes to implement the Tritium Production Program. TVA will review and modify actions, action levels, as necessary, based on TPC operating experience. The following REP changes will be made:

- **Dose Codes** - Modify TVA dose codes to include tritium component.
- **Tritium Monitoring & Sampling** - Provide real time offsite tritium monitoring (Scintrex Model 309A or equivalent) and grab sampling (MSA Escort ELF Sampling Pump or equivalent) for TVA and State of Tennessee Field Teams.
- **Sample Analysis** - Establish tritium sample collection, analysis, and interpretation protocols.
- **Procedures** - Modify Emergency Action Levels and decision logic and the Emergency Preparedness Implementing Procedures as required.
- **Training** - Conduct appropriate training for TVA and State of Tennessee Emergency Responder personnel.

- **Dosimetry** - Establish bioassay collection, analysis, and interpretation protocols with respect to tritium for TVA and State of Tennessee Emergency Responder personnel.

- **Validation** - Conduct Tabletop Walkthroughs, Field Sampling Training Exercises, and a joint TVA and State of Tennessee Site Exercise to demonstrate proficiency of tritium-related emergency activities.

2.13.1.3 Administrative, Operating and Maintenance Procedures

Programs, processes, procedures, and instructions will be reviewed and revised as necessary to ensure continued safe operation with a TPC. While some level of tritium already exists in Watts Bar due to normal reactor operations, special cautions will be incorporated into existing procedures as necessary to ensure personnel are aware of activities where tritium production may result in increased tritium levels and associated hazards. The existing administrative process for controlling changes, from identification through implementation, including any required training is not affected by the incorporation of TPBARs.

2.13.2 Safeguards and Security Evaluation

Additional security for the TPBARs will be provided for the period from arrival onsite to installation in the core and the reactor head is installed. Additional security will also be implemented when the head is removed until the TPBARs are shipped offsite. No security measures, in excess of those normally in place, are required while the assemblies are being irradiated. DOE will continue to be the cognizant security agency. NRC's security oversight and responsibilities will remain the same as at all other CLWRs. DOE Chicago has reviewed the Physical Security Plan for TPBARs and revisions are in process. Also, walkdowns of the storage area at Watts Bar and Sequoyah were conducted during their visit for familiarization of these areas and processes. The storage areas were found to be acceptable to DOE during their review.

Material control and accountability of TPBARs will be in accordance with Special Nuclear Material Control procedures which cover shipment, storage, and movement of un-irradiated and irradiated TPBARs, and consolidation of irradiated TPBARs. TVA will revise the Special Nuclear Material Control procedures to describe the actions to be taken by TVA to protect and account for TPBARs while on site.

2.14.2 Initial Test Program

Testing for the impact of irradiation of a quantity of TPBARs will occur during plant startup with such a core. The monitoring will begin with the TPBARs' receipt, continue through low power physics testing, power ascension, and for one cycle of plant operation of approximately 18 months. Routine monitoring will be performed of core power distribution, critical boron, levels of tritium in the RCS liquid and plant environs. Existing procedures are adequate to test and monitor the impact of the TPBARs.

Post-irradiation examination of a representative sample of the TPBAR assemblies will be conducted on site after the first and second cycles. Five to ten percent of the TPBAR assemblies will be visually examined for gross anomalies such as loss of structural integrity or malformation. The need for this surveillance activity will be reviewed after the second production cycle. Changes to this surveillance requirement will be made depending on the results of the previous examinations.

At the conclusion of the fuel cycle, a report that summarizes the behavior of the TPBARs in the reactor and the impact on the plant shall be prepared and made available.

2.15 ACCIDENT ANALYSIS

2.15.2 Safety Evaluation for the Non-LOCA Accidents

The non-LOCA safety analysis parameters have been determined for the Watts Bar reload core design using TPBARs. These parameters were compared to the parameters used in the current applicable safety analysis for Watts Bar. (The Fuel Handling Accident is discussed separately in Section 2.15.6.6.) This evaluation shows:

1. No changes have been identified in the nominal plant operating conditions (power, coolant temperature, pressure and flow rate) assumed in the plant safety analysis in order to accommodate the TPBARs. Therefore, the existing safety analysis calculations for Watts Bar are not affected by any changes in plant parameters as a result of the TPBARs.

2. No changes to the reactor core thermal hydraulic characteristics or power peaking factors, which could affect the core thermal limits (DNBR and overpower), have been identified as a result of the use of TPBARs. Therefore, the plant thermal limit protection system setpoints do not change as a result of the TPBARs.

3. The nuclear design and fuel rod design calculations performed for the TPBAR reload core design have identified one safety analysis parameter as being outside of the bounds of the current applicable reload safety analysis parameters. The safety analysis parameter identified is the least-negative Doppler-Only Power Coefficient for Steam Line Break with Coincident Rod Withdrawal at Power (SLB w/RWAP). The equation for this parameter changed from -11.75 + 0.035Q (pcm/%) to -12.3+0.0437Q (pcm/%), where Q is a percentage of full power. Due to this change, the SLB w/ RWAP must be re-analyzed (see Section 2.15.2.2).

4. Due to post-LOCA subcriticality requirements, the Cold Leg Accumulator and Refueling Water Storage Tank (RWST) boron concentrations are being increased to accommodate the use of TPBARs. This change increases the maximum accumulator and RWST boron concentrations from 2700 to 3800 ppm. The only non-LOCA event that assumes accumulator actuation is the Major Rupture of a Main Steam Line event (UFSAR Section 15.4.2.1). This event, however, assumes delivery of the minimum amount of boron to the core to maximize the expected return to power. Therefore, the current licensing basis MSLB analysis bounds the proposed conditions and the results and conclusions presented in the UFSAR remain valid. For an increase in the maximum RWST boron concentration, only the non-LOCA events that assume ECCS actuation with maximum boron concentration are potentially affected. The only non-LOCA event that assumes a maximum RWST boron concentration is the Inadvertent Operation of ECCS event (UFSAR Section 15.2.14). A specific evaluation of the impact of increasing the maximum boron concentration in the inadvertent ECCS actuation event is provided in Section 2.15.2.1.

A confirming check of the key safety analysis parameters used in the Watts Bar UFSAR analyses for the following non-LOCA events resulted in the conclusion that the TPBAR core design has not changed any of these bounding values. Therefore, the Watts Bar safety analysis for each of these non-LOCA events is unaffected by the TPBAR core design.

Transients Unaffected by the TPC

UFSAR Section	Transient
15.2.1	Uncontrolled RCCA Bank Withdrawal from a Subcritical Condition
15.2.2	Uncontrolled RCCA Bank Withdrawal at Power
15.2.3	RCCA Misalignment
15.2.4	Uncontrolled Boron Dilution
15.2.5	Partial Loss of Forced Reactor Coolant Flow
15.2.6	Startup of an Inactive Reactor Coolant Loop at an Incorrect Temperature
15.2.7	Loss of External Electrical Load and/or Turbine Trip
15.2.8	Loss of Normal Feedwater
15.2.9	Loss of Offsite Power to the Station Auxiliaries
15.2.10	Excessive Heat Removal Due to Feedwater System Malfunctions
15.2.11	Excessive Load Increase Incident
15.2.12	Accidental Depressurization of the Reactor Coolant System
15.2.13	Accidental Depressurization of the Main Steam System
15.3.4	Complete Loss of Forced Reactor Coolant Flow
15.3.6	Single RCCA Withdrawal at Full Power
15.4.2.1	Major Rupture of a Main Steam Line
15.4.2.2	Major Rupture of a Main Feedwater Pipe
15.4.4	Single Reactor Coolant Pump Locked Rotor
15.4.6	RCCA Ejection

As discussed previously, the Inadvertent Operation of Emergency Core Cooling System (UFSAR Section 15.2.14) assumes maximum RWST boron concentration and is, therefore, potentially impacted by the proposed increase to 3800 ppm. This effect is evaluated in Section 2.15.2.1.

In addition to the transients listed in the UFSAR, a special steamline break core response analysis is performed for Watts Bar with the assumption of coincidental RCCA withdrawal due to exposure of the turbine impulse transmitters or the excore detector equipment to an adverse environment. This event, the Steam Line Break with Coincident Rod Withdrawal at Power (SLB w/RWAP) event, was also evaluated with regard to the impact of the TPBAR core design. The least negative Doppler-only power coefficient at full power for this event was slightly less negative for the TPBAR core design than that used in the current Watts Bar analysis. Therefore, this event was reanalyzed for the TPBAR core design. That analysis is discussed in Section 2.15.2.2.

2.15.2.1 Inadvertent Operation of ECCS

The Inadvertent Operation of ECCS event is the only non-LOCA event potentially impacted by an increase in RWST boron concentration. For the DNB case, an increase in the boron concentration would result in a decrease in reactor power, hence a decrease in coolant temperature and pressure. The decrease in reactor power and coolant temperature result in a benefit to the DNBR, while a decrease in pressure results in a decrease in DNBR. Thus, the opposing DNB trends offset each other, resulting in no impact to the DNB case due to the increase in boron concentration. With respect to the pressurizer fill case, reactor trip is assumed to occur at event initiation and core boron concentration does not impact post-trip decay heat generation, resulting in no impact on pressurizer filling results. The TPBAR core design has not changed any other bounding values assumed for the key safety analysis parameters used in the analysis of this event. Therefore, the analysis of this event is not adversely affected by the TPBAR core design.

2.15.2.2 Steam Line Break with Coincident RCCA Withdrawal at Power

This event was postulated as a result of Information Notice IE 79-22, and addresses concerns related to non-safety grade equipment being subjected to an adverse environment from high energy line breaks inside or outside containment. The consequence of interest is that the high-energy steam line break could fail the automatic rod control system cabling / equipment and subsequently cause the rods to withdraw from the core. Such a rod withdrawal, along with the return to power caused by the RCS cooldown due to the steam line break, would lead to a rapid power excursion and could potentially lead to an adverse core condition.

The Steam Line Break with Coincident RWAP accident is classified as either a Condition III or Condition IV event based on break size; break sizes less than 6 inches in diameter are considered a Condition III event and those greater than 6 inches in diameter are considered Condition IV events. However, Condition II criteria are used for this accident because they are conservative with respect to the Condition III and Condition IV event criteria.

The RCCA withdrawal during the steam line break is dependent on the rod control system being in the automatic mode. At zero power, the rod control system is in the manual mode, and therefore could not inadvertently withdraw rods due to equipment/cabling being exposed to an adverse condition. As a result, the coincidental RCCA withdrawal can only be postulated for a steam line break from an "at power" initial condition.

Method of Analysis and Assumptions

During the key safety parameter evaluation, the least-negative Doppler-only Power Coefficients (DPCs) used in the current analysis of record for the SLB w/ RWAP event could not be supported for the TPBAR program. Therefore, revised DPCs were calculated for use in the TPBAR reanalysis. The least-negative DPCs are used in this analysis because the amount of negative reactivity due to the change in nuclear power is conservatively minimized. Since this event results in a nuclear power increase from the initiation of the event until reactor trip, the least-negative DPCs allow the power excursion to continue at a rapid rate, thus maximizing the peak heat flux, which is conservative in terms of the minimum departure from nucleate boiling ratio (DNBR).

The following three cases were analyzed to ensure that the acceptance criteria for this event are met.

1. 0.6 ft^2 break size (DNBR and kW/ft)
2. 0.6 ft^2 break size with a feedwater temperature reduction from 440°F to 420°F (kW/ft)
3. 0.65 ft^2 break size (kW/ft)

The control rods are assumed to withdraw at maximum speed and maximum rod worth coincidentally with the steam line break. Thus, the amount of positive reactivity added to the core during the transient is maximized, and as a result, peak heat flux is maximized to provide the most limiting minimum DNBR and peak linear heat generation (kW/ft).

Case 1 has been shown to be DNBR-limiting since it generates the highest heat flux, but all three cases require peak linear heat generation rate (kW/ft) evaluations to ensure the most limiting case has been identified. Note that the break sizes represent those that are at or near the point at which the reactor trips on OPΔT, which yields the most conservative DNBR and kW/ft results.

Results

The results for this analysis demonstrate that the Condition II criteria are met. The minimum DNBR for Case 1, the only case requiring DNBR analysis, is maintained above the design basis throughout the event. The peak kW/ft evaluations demonstrate that all three cases remain below the limit.

The impact of the more limiting Doppler-only Power Coefficients does not cause this analysis to violate any of the Condition II acceptance criteria (primarily minimum DNBR and peak kW/ft) and, based on this, the SLB w/ RWAP analysis supports the TPBAR program.

2.15.2.3 Conclusion

The non-LOCA analyses continue to meet the applicable acceptance criteria for the TPBAR core design.

2.15.5 LOCA Evaluations

2.15.5.1 TPBAR Response to Large and Small Break LOCA

In order to assess the potential for interaction of the TPBARs with the LOCA transients, it was necessary to first estimate the response of the TPBARs to the design basis LOCAs, both large and small breaks. The TPBAR generates minimal heat during a LOCA and is heated primarily by radiation from the fuel rods to the fuel assembly guide thimble and radiation from the thimble across the gap to the TPBAR. Generally, convection of the steam and entrained liquid on the outer thimble surface provides cooling comparable to that experienced by the fuel rods. However, there are instances when the thimble/TPBAR can be heated, rather than cooled, by the fluid in the surrounding channels. The heatup of the TPBAR was modeled in a conservative fashion using assumptions generally selected to maximize the TPBAR thermal response.

The LOCTA_JR code (Reference 1), which was used to calculate the TPBAR temperatures during a LOCA for the Tritium Production Core Topical Report (Reference 2), was also used in this evaluation. As a result of their review of the Topical Report, the NRC identified the review of the LOCTA_JR code as an Interface Item for any plant specific implementation of a Tritium Production Core. The LOCTA_JR documentation has since been submitted by TVA for NRC review and the NRC issued a safety evaluation documenting its acceptance of this code for use in licensing analyses (see Section 1.5.16).

LOCTA_JR uses as boundary conditions the cladding temperature of the surrounding fuel rods and the core steam and entrained liquid convective heat transfer coefficients and temperatures. The boundary conditions are taken from Best Estimate (LBLOCA) and Appendix K (SBLOCA) analyses of record for the Watts Bar Plant.

The following modeling assumptions are made due to the component geometry and the pertinent heat transfer mechanisms:

1. Steam flow in the annulus between the TPBAR and the thimble will be minimal due to (1) the low heat generation rate in the TPBAR and resulting low steaming rates in the annulus and (2) the tendency of TPBAR swelling to block the annulus. Since steam flow in the annulus would tend to reduce the TPBAR temperatures, it is conservatively neglected.

2. Temperature calculations in the thimble and TPBAR can be performed 1-dimensionally at the elevations of high fuel rod temperature since axial conduction effects are negligible.

3. Heat transfer to the outer surface of the thimble will include radiant heat transfer from the fuel rods and convective cooling from the core steam and entrained liquid flows. The fuel rod temperatures and fluid conditions are boundary conditions to the calculations and are obtained from the Best Estimate Large Break LOCA and Appendix K Small Break LOCA analyses.

4. Heat transfer in the thimble/TPBAR annulus consists of radiation and conduction through the steam.

5. Zirc/water oxidation will be calculated on the exterior surface of the thimble. In the thimble/ TPBAR annulus, oxidation of the thimble will be neglected due to the lack of significant steam flow.

6. Heat generation in the TPBAR is included in the thermal calculations although the post-LOCA heating rates in the TPBAR are negligible.

7. Due to the high thermal conductivity of gases within the TPBAR and the low heatup rates, radial temperature gradients inside the TPBAR are minimal. The mean heat capacity of the TPBAR is input as the product of layer weighted density and specific heat, and a mean temperature is calculated.

An impact analysis on the TPBAR rod was performed for the large break LOCA scenario using boundary conditions from the Watts Bar Unit 1 analysis of record. The transient boundary conditions for the LBLOCA case are taken from the Reference 3 analysis report, maximum cladding oxidation case (a cold leg break). This maximum oxidation case was chosen since it was one of the more severe cases from a PCT standpoint from the Reference 3 analysis. That is, it has a PCT above the 95th percentile, and therefore will have boundary conditions that are in the conservative direction from the TPBAR standpoint. It is noted that several assessments are in place against the Reference 3 analysis, such as code revisions, mini-uprate and a 50.59 evaluation on accumulator line/pressurizer surge line data. The net result of these assessments is a benefit to the 2nd Reflood PCT and, therefore, these assessments were conservatively neglected for this analysis.

Because of uncertainties that are inherent with the application of the LOCA hot rod heat transfer coefficient (HTC) to the guide thimble, two cases were run for the LBLOCA. The first case is considered to be a reasonable approach, while the second case was performed to quantify an upper bound response of the TPBARs under LBLOCA conditions. In this second case, the base HTC was modified twice during the transient. From 30 to 140 seconds it was increased by about a factor of 8, after which it was set equal to zero for the remainder of the transient. The purpose here was twofold, 1) to show the overall influences on the transient by variances of the HTC and 2) to attempt to maximize thimble temperature throughout the transient to quantify what the upper bound temperature could possibly be under this extreme.

For LBLOCA, the first case resulted in a guide thimble temperature of 1782°F, while the second case resulted in an upper bound, limiting guide thimble temperature of 1910°F. The corresponding TPBAR temperatures for these cases are 1738°F and 1892°F, respectively. It should be noted that the burst model for LOCTA_JR was not used in these runs since, as discussed in Reference 2, TPBAR swelling/burst is expected to be less severe than what would be experienced for the hot rod.

For SBLOCA, a temperature of 1004°F (including assessments) was calculated for the guide thimble and 990°F for the TPBAR. Assessments which are in place against the current SBLOCA analysis result in a net PCT penalty of 24°F and have, therefore, been applied directly to these results. Again the burst behavior, (or lack thereof in this case) depicted in Reference 2 is considered to be applicable in this case as well, particularly because calculated thimble/TPBAR temperatures are less than those presented in Reference 2.

Conclusions

The maximum TPBAR temperature reached during a SBLOCA for Watts Bar is considerably lower than that reported for a SBLOCA in Reference 2 (1447°F). Reference 2 determined that the TPBARs would not burst for a SBLOCA, therefore it is considered unlikely that the TPBARs will burst during a SBLOCA in Watts Bar. The maximum TPBAR temperature reached during a cold leg LBLOCA for Watts Bar is comparable to that calculated for a LBLOCA in the Reference TPC (1833°F), and consequently bursting of the TPBAR cladding would be expected under these conditions. The peak TPBAR temperatures for both SBLOCA and LBLOCA are below the values used by PNNL in the TPBAR design analyses.

2.15.5.2 Interaction of TPBARs with LBLOCAs

The Reference 2 discussion of the effects of TPBARs on LBLOCAs with respect to axial and radial power distribution and swelling and burst effect of the TPBARs is still applicable. Reference 2 concluded that the effect of the TPBARs on the axial and radial power distributions does not cause an adverse impact on the LBLOCA. It also concluded that since the flow channels adjacent to the thimbles are formed by three fuel rods and one thimble, the effects of fuel rod swelling and burst will have the major influence on total channel blockage and the effects of TPBAR and the resultant thimble swelling will be less significant. Blockage of the channels adjacent to the thimble should be equal or less than predicted for a typical fuel rod channel and coolable geometry is not a concern. However, it is noted that some fragmentation of the TPBAR cladding may occur. In spite of the shielding provided by the thimble tubing, some particle impact on the adjacent fuel is possible. This should be insignificant since all hot assembly fuel rods will have burst prior to TPBAR cladding failure. Thus, any particle impacts on the adjacent fuel rods would have no significant effect. (It is noted that fuel rod burst elevation and TPBAR burst elevation would differ due to the variation in burst time and the shift in the hot spot to higher core elevations with time.)

In addition, an evaluation has been performed considering key core design parameters related to LBLOCAs with respect to Tritium Production Cores (TPCs). This evaluation indicates that current and future key parameters can be met for TPCs except for items related to post-LOCA subcriticality (see Section 2.15.5.4). In order to maintain post-LOCA subcriticality, the boron concentration in the accumulators is being increased to a range of 3500 to 3800 ppm, and the RWST boron concentration is being increased to a range of 3600 to 3800 ppm. Accumulator boron concentration is used in the Best Estimate LOCA point kinetics model to maintain sub-criticality during the reflood period of the transient. During the refill period of the LBLOCA transient, the water in the reactor vessel is almost entirely from the accumulators since most, if not all, RCS inventory has either blown out the break or has flashed to steam. After this, during the reflood period, make-up is from RWST water. Because the mixed fluid from both of the sources has experienced minimal dilution from the RCS, the final concentration would be somewhere in the range between 3500 and 3600 ppm. The analysis in support of the post-LOCA Long Term Core Cooling requirements (see Section 2.15.5.4, below) demonstrates that the core remains subcritical with a sump boron concentration which is less than 3500 ppm. Therefore, this shows that the core will remain subcritical during the transient as well as after. As such, it is concluded that the proposed minimum concentrations of 3500 ppm for the accumulators and 3600 ppm for the RWST will be acceptable for the Watts Bar TPC design from a Best Estimate LOCA standpoint. In addition, there is no increase in the Best Estimate LBLOCA PCT, therefore there continues to be a high level of probability that the ECCS acceptance criteria limit is not exceeded with regard to the LBLOCA analysis. Therefore, the current Watts Bar Best Estimate Large Break LOCA analysis is applicable for the Watts Bar TPC.

2.15.5.3 Interaction of TPBARs with SBLOCAs

As for the LBLOCA, the Reference 2 discussion of the effects of TPBARs on SBLOCAs is still applicable. In addition, an evaluation has been performed considering key core design parameters related to SBLOCAs with respect to Tritium Production Cores (TPCs). This evaluation indicates that current and future key parameters for SBLOCA can be met for TPCs. There is no increase in the SBLOCA PCT and the current Watts Bar Small Break LOCA analysis is applicable for the Watts Bar TPC.

2.15.5.4 Effect of TPBARs on Post-LOCA Sump Boron Concentration

Post-LOCA subcriticality has been evaluated for the Watts Bar TPC equilibrium cycle based on minimum boron concentrations of 3500 and 3600 ppm in the accumulators and the RWST, respectively. Critical boron calculations were performed at post-LOCA conditions for cycle burnups spanning the range from BOL to EOL. At all cycle burnups, subcriticality margin was identified and post-LOCA subcriticality was confirmed. The expected margin is 8 ppm at the limiting time in life (BOL) when very conservative assumptions are made with respect to TPBAR failure, leaching, and lithium-aluminate pellet loss with no control rod insertion. Substantial additional subcriticality margin was identified (> 200 ppm) when control rod insertion was credited for the cold leg break LBLOCA and when the TPBAR failure assumptions were relaxed for a hot leg break LBLOCA, as discussed below. (The Westinghouse Owners Group currently has a program underway to document credit for control rod insertion during a cold leg LBLOCA.)

During a cold leg break, substantial heat-up of the TPBAR cladding is possible. For TPBARs with significant tritium production, cladding breach can occur at LOCA conditions if the cladding temperature and internal pressure of the TPBARs reach limiting values. Consequently, the post-LOCA critical boron calculations performed for the Watts Bar TPC equilibrium cycle conservatively assumed that all the TPBARs would fail (except for TPBARs in low power, low temperature locations on the core periphery) and that 50% of the lithium would be lost through leaching. In addition, all of the helium-3 was assumed to be lost. Moreover, because the rupture of the TPBAR cladding can be energetic, it was conservatively assumed that up to 12 inches of $LiAlO_2$ pellets would be lost from the TPBARs as well. (See Section 3.8.3.2.) With these conservative assumptions, the expected subcriticality margin at the limiting time in life was 8 ppm. This is particularly conservative since, at this time in life, no TPBAR failures would be anticipated due to the low internal pressure of the TPBARs.

In addition, for a cold leg break, control rod insertion is expected due to the low forces on the reactor upper internals. For this scenario, credit for control rods was evaluated (all rods in minus a single worst stuck rod) and the subcriticality margin was determined to be greater than 200 ppm for a cold leg break. This margin value considers the possibility of sump boron dilution at the time of hot leg switchover.

The subcriticality margin for a hot leg break LBLOCA was also considered. For a hot leg break, control rod insertion is not assumed. During a hot leg break, however, heat-up of the TPBAR cladding is expected to be insignificant, with the result that no TPBAR failures occur. With these assumptions, the margin to the post-LOCA sump boron concentration for a hot leg break was again demonstrated to be greater than 200 ppm.

In conclusion, subcriticality has been shown for the Watts Bar TPC designs for a cold leg break with TPBAR failures and no control rod insertion. In addition, greater than 200 ppm margin to the post-LOCA sump boron concentration is expected for a cold leg break, assuming TPBAR failures and control rod insertion. Greater than 200 ppm margin is also expected for a hot leg break, assuming no credit for control rods and no TPBAR failures.

2.15.5.5 Effect of TPBARs on Switchover to Hot Leg Recirculation

The Hot Leg Recirculation Switchover Time analysis is performed to determine the time at which hot leg recirculation should be initiated in order to preclude boron precipitation in the core post-LOCA. This switchover time is impacted by the boron concentration.

Post-LOCA analyses performed for the Watts Bar TPC with a maximum boron concentration of 3800 ppm in the RWST and accumulators, indicate that switchover to hot leg injection recirculation mode cooling must occur 5.5 hours after a LOCA in order to preclude precipitation of boron in the core. This includes the SI interruption duration at switchover to hot leg injection recirculation mode cooling.

It is further noted that after 60 minutes, the charging and safety injection pumps, which take their suction from the discharge of the RHR pumps, can provide sufficient flow to maintain core cooling. Therefore, direct injection into the RCS from the RHRs is not required for hot leg recirculation because the safety injection pumps can provide adequate flow to back flush the core for mitigation of boron precipitation.

2.15.5.6 References

1. WCAP-15409, Rev 1, "Description of the Westinghouse LOCTA_JR 1-D Heat Conduction Code for LOCA Analysis of Fuel Rods," September 2000.

2. NDP-98-181, Rev 1, "Tritium Production Core (TPC) Topical Report, (Unclassified, Non-Proprietary Version)," February 10, 1999.

3. WCAP-14839, Revision 1, "Best Estimate Analysis of the Large Break Loss of Coolant Accident for the Watts Bar Nuclear Plant," August 1998.

2.15.6 Radiological Consequences of Accidents

This section addresses the potential radiological impact of operation for various design basis accidents with the maximum number of TPBARs installed. The radiological consequences of these accidents are affected primarily by the addition of tritium to the accident source terms. To appropriately account for the radiological consequences of the increased tritium in the TPC, TVA has included calculated Total Effective Dose Equivalent (TEDE) and Federal Guidance Report Number 11 (Reference 1) dose conversion values for thyroid in the accident analysis. TPBARs were designed to withstand the rigors associated with category I through IV events, therefore, no TPBAR failures are predicted to occur during the design-basis accidents except for the large break loss of cooling accident (LBLOCA) or the fuel handling accident. It has been determined that operation with a TPC will not result in exceeding established regulatory guidelines

2.15.6.1 Loss of AC Power

The environmental consequences of a loss of normal AC power to the plant auxiliaries involves the release of steam from the secondary system. This will not result in a release of radioactivity unless there is leakage from the reactor coolant system (RCS) to the secondary system in the steam generator. A conservative analysis of the potential offsite doses resulting from this accident is presented with steam generator leakage as the prevalent parameter. This analysis also incorporates assumptions of one percent defective fuel, and steam generator leakage prior to the postulated accident for a time sufficient to establish equilibrium specific activity levels in the secondary system. The Standard Review Plan (NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition") does not specify offsite dose limits for the loss of AC power event. Since loss of AC power does not result in any fuel failure, the offsite dose limits are assumed to be 10% (small fraction) of the 10 CFR 100 dose guidelines (i.e., 30 rem thyroid and 2.5 rem whole body).

Conclusion

The calculated control room operator doses are a small fraction of the 10 CFR 50 Appendix A, General Design Criteria (GDC) limits.

2.15.6.2 Waste Gas Decay Tank Failure

The gaseous waste processing system is designed to remove fission product gases from the reactor coolant. The system consists of a closed loop with waste gas compressors, waste gas decay tanks (WGDTs) for service at power and other WGDTs for service at shutdown and startup. The maximum amount of waste gases stored occurs after a refueling shutdown at which time the gas decay tanks store the radioactive gases stripped from the reactor coolant.

The accident is defined as an unexpected and uncontrolled release of radioactive xenon and krypton fission product gases and tritium, in the form of tritiated water vapor, stored in a WGDT as a consequence of a failure of a single gas decay tank or associated piping.

Conclusion

In the current analysis, TVA has assumed that the content of the WGDT would include 90.7 curies of tritium from normal operations and additionally would contain 2,320 curies of tritium from the failure of two TPBARs. This yields a total of 2,410.7 curies of tritium released at the time of the postulated tank rupture. The consequences have been analyzed and it has been determined that the 30 day Low Population Zone offsite doses would be substantially below the 10 CFR 100 limits. For the 2-hour Exclusion Area Boundary /Site Boundary offsite dose to be less than the recommendation of NUREG-0800 (0.500 rem), the Xe-133 equivalency will be administratively controlled to ensure that the content of the waste gas decay tank rupture/release will not exceed regulatory requirements.

With the implementation of the prescribed administrative controls, a waste gas decay tank failure will not result in exceeding established requirements. The control room operator doses for a WGDT rupture were calculated to be below the 10 CFR 50 App. A GDC 19 limits of 5 rem gamma, 30 rem beta, and 30 rem thyroid.

2.15.6.3 Loss of Coolant Accident

The radiological consequences of a Loss of Coolant Accident (LOCA) are determined on the basis of the prescriptive assumption that the core cooling is not maintained and that core melting occurs so as to release a large fraction of the core fission-product activity. In addition to the core activity releases of

100 percent of the noble gases and 50 percent of the iodines, it is conservatively assumed that 100 percent of the tritium in the TPBARs is released to the containment. A core maximum value of 1.2 grams of tritium (11,600 Ci) is assumed for each of the TPBARs (maximum loading of 2,304 TPBARs) at the end of the fuel cycle. This yields a total core inventory of 2.68×10^7 Curies.

In modeling the release of tritium to the environment, it is conservatively assumed that the tritium exists solely in the form of tritiated water. This reflects the fact that elemental tritium would relatively quickly exchange with the hydrogen in water to make this a reality (especially considering that the containment is filled with steam and there is ongoing containment spray during the first 2 hours or longer).

Conclusion

Both the containment leakage pathway and the Emergency Core Cooling System (ECCS) leakage pathway contribute to activity releases. The containment leakage pathway releases iodines, noble gases, and tritium to the environment, and the ECCS leakage pathway releases recirculating sump solution to the auxiliary building. It has been determined that the offsite doses due to a LOCA are less than 10 CFR 100 limits. The control room operator doses are less than the 10 CFR 50, Appendix A, GDC 19 limits. The projected offsite doses are only slightly changed from those calculated for operation without TPBARs. (See Table 2.15.6-2.)

2.15.6.4 Main Steam Line Failure Outside of Containment

The steam release arising from a rupture of a main steam line would result in an initial increase in steam flow, which decreases during the accident as the steam pressure falls. The energy removal from the reactor coolant system causes a reduction of coolant temperature and pressure.

Conclusion

In addition failure of two TPBARs was assumed yielding an RCS Tritium level of about 98 µCi/cc. It has been determined that the offsite doses due to a Main Steam Line Break are a small fraction of the 10 CFR 100 limits. The control room operator doses are less than the 10 CFR 50, Appendix A, GDC 19 limits.

2.15.6.5 Steam Generator Tube Failure

The accident examined is the complete severance of a single steam generator tube. The accident is assumed to take place at power with the reactor coolant contaminated with fission products corresponding to continuous operation with a limited amount of defective fuel rods. The accident leads to an increase in contamination of the secondary system due to leakage of radioactive coolant from the reactor coolant system.

Conclusion

In addition, failure of two TPBARs was assumed yielding an RCS Tritium level of about 98 µCi/cc. It has been determined that the offsite doses due to a steam generator tube failure are a small fraction of the 10 CFR 100 limits. The control room operator doses are less than the 10 CFR 50, Appendix A, GDC 19 limits.

2.15.6.6 Fuel Handling Accidents

The accident is defined as dropping of a spent fuel assembly resulting in the rupture of the cladding of all the fuel rods in the assembly despite many administrative controls and physical limitations imposed on fuel handling operations. The analysis considers an FHA occurring in containment with activity passing through the Purge Air Exhaust filters, and an FHA occurring in the fuel handling area of the Auxiliary Building with activity passing through the Auxiliary Building Gas Treatment System filters. The FHA is assumed to occur at 100 hours after shutdown. All the activity is assumed to be released over a two hour period per Safety Guide 25. For the TPC this analysis conservatively assumes that 24 TPBARs are located within the dropped spent fuel assembly and that they rupture and exchange their tritium with the water in the spent fuel pool. Data from Pacific Northwest National Laboratory (Reference 2) indicate that the total tritium activity released from 24 TPBARs into water of <200°F would not exceed 84,890 curies. This analysis assumes that the 84,890 curies of tritium are released to the environment over a two hour period.

Conclusion

An FHA occurring in containment results in the largest off site doses, while an FHA in the fuel handling area of the auxiliary building results in the largest control room exposures. The evaluation of total dose from a fuel handling accident, including the tritium, has demonstrated that the control room operator doses are below the limits of 10 CFR 50, Appendix A, GDC 19 limits. The offsite doses are well within the 10 CFR 100 limits.

2.15.6.7 Rod Ejection Accident (Consequences bounded by 2.15.6.3)

A review was of this analysis was performed. This analysis remains unchanged by the insertion of TPBARs into the reactor core.

Conclusion

Therefore, the consequences of a postulated rod ejection accident remain bounded by the results of the loss-of-coolant accident analysis as discussed in section 2.15.6.3 and well within the 10 CFR 100 limits. The evaluation of a rod ejection accident has demonstrated that the control room operator doses are below the limits of 10 CFR 50, Appendix A, GDC 19 limits.

2.15.6.8 Tritium Lead Test Assembly Accident Releases (Consequences bounded by 2.15.6.3)

The initial test phase of the tritium production program at WBN utilized four lead test assemblies (LTA) containing a total of 32 TPBARs. It was determined that insertion of the LTAs would have an insignificant impact on accident releases. Like the LTAs, the TPBAR assemblies have been designed to withstand Condition I-IV events without failure. One exception to this is the potential damage to 24 TPBARs in a single assembly during a Fuel Handling Accident, resulting in the release of the tritium. Another exception is the Condition IV large break LOCA where cladding temperatures and stresses may cause failures of the TPBAR cladding resulting in the release of the tritium content. The environmental consequences of these releases are discussed in section 2.15.6.6 on Fuel Handling Accidents and in section 2.15.6.3 for the Loss of Coolant Accident.

2.15.6.9 Failure of Small Lines Carrying Primary Coolant Outside Containment

The analysis of the environmental consequences included the offsite and control room operator dose due to ECCS leakage outside containment following a LOCA.

Conclusion

It has been determined that the offsite doses due to post LOCA ECCS leakage into the Auxiliary Building are a small fraction of the 10 CFR 100 limits. The control room operator doses are less than the 10 CFR 50, Appendix A, GDC 19 limits. (See Section 1.5.5, "Control Room Habitability Systems" and Table 2.15.6-2.)

2.15.6.10 References

1. Federal Guidance Report No. 11, "Limiting Values Of Radionuclide Intake And Air Concentration And Dose Conversion Factors For Inhalation, Submersion, And Ingestion", EPA-520/1-88-020, U.S. EPA, Washington, DC.

2. TTQP-1-109 Rev 4, January 2001, "Unclassified TPBAR Releases, Including Tritium", Pacific Northwest National Laboratory, Richland, Washington.

Table 2.15.6-2 Radiological Consequences of a Design Basis LOCA (rem)

	WBN Operations without TPBARs	WBN Operations with 2304 TPBARs	Acceptance Limit
Site Boundary			
Thyroid dose (ICRP-30)			
– Containment leakage	20.25	19.34	
– Recirculation leakage	1.33E-01	1.28E-01	
Total	20.38	19.47	300
Whole body dose (g)			
– Containment leakage	1.60	1.66	
– Recirculation leakage	3.59E-03	3.50E-03	
Total	1.60	1.66	25
TEDE	2.23	2.25	
Low Population Boundary			
Thyroid dose (ICRP-30)			
– Containment leakage	6.87	6.56	
– Recirculation leakage	1.11E-01	1.06E-01	
Total	6.98	6.67	300
Whole body dose (g)			
– Containment leakage	1.32	1.33	
– Recirculation leakage	1.63E-02	1.58E-02	
Total	1.34	1.34	25
TEDE	1.25	1.45	
Control Room			
Thyroid dose (ICRP-30)			
– Containment leakage	2.17	2.08	
– Recirculation leakage	3.22E-02	3.08E-02	
Total	2.21	2.11	30
Whole body dose (g)			
– Containment leakage	8.09E-01	7.96E-01	
– Recirculation leakage	1.23E-03	1.26E-03	
Total	8.10E-01	7.97E-01	5
TEDE	9.49E-01	1.91	
Beta-skin			
– Containment leakage	6.97	6.77	
– Recirculation leakage	1.29E-02	1.40E-02	
Total	6.98	6.78	75

2.17 QUALITY ASSURANCE

2.17.1 Introduction

Chapter 17 of the SRP deals with the Quality Assurance controls applicable during all phases of a facility's life. Section 2.17.2 and 2.17.3 below, describe the Quality Assurance programs which are applicable to aspects of the TPBAR incorporation and use in the Watts Bar Nuclear Plant. TPBARs are being incorporated and used during the Operations Phase, therefore, the applicable portion of the SRP is Chapter 17.2.

Tritium Producing Burnable Absorber Rods (TPBARs) are a basic component as defined by 10 CFR 21. The TPBARs are integral parts of the reactivity control system to keep the reactor core in a safe state, and are therefore, safety-related. In compliance with 10 CFR 21; 10 CFR 50.34(b.6ii); and 10 CFR 50, Appendix A Criterion I; TPBARs are designed, manufactured, and used in accordance with a QA program that complies with the requirements of 10 CFR 50, Appendix B.

After TPBAR irradiation, TVA prepares irradiated TPBARs for transportation. DOE is responsible for transporting the irradiated TPBARs to the Tritium Extraction Facility. As shipper of record, DOE is responsible for furnishing certified transportation packages for TVA's use in preparing the irradiated TPBARs for DOE's shipment. TVA as a package user maintains and implements an NRC-approved quality assurance program complying with 10 CFR Part 71, Subpart H. Section 2.17.4 below describes the Quality Assurance Program applicable to packaging and transportation of radioactive materials.

2.17.2 Quality Assurance During Operations Phase

Activities associated with incorporating use of TPBARs in the Watts Bar Nuclear Plant, are performed in accordance with TVA's NRC accepted QA Program (TVA-NQA-PLN89A) which complies with SRP 17.1 and 17.2 and the Fuel Vendor's NRC Approved Quality Assurance Program which complies with SRP 17.1. Activities include but are not limited to establishing the technical, functional, and quality requirements applicable to TPBARs; reviewing and accepting TPBAR design; integrating TPBAR use into facility and reactor core designs and plant operation; obtaining and accepting for use TPBARs that comply with specified technical, functional, and quality requirements; providing applicable control processes and equipment for pre and post irradiation TPBAR handling; and establishing and maintaining protection of the health and safety of workers and the public.

Since DOE procures TPBAR related engineering, design, procurement, fabrication, and transportation services, TVA performs acceptance reviews of applicable DOE documents used to obtain TPBARs and related services to ensure that adequate and acceptable requirements are being identified to the suppliers. TVA evaluates the DOE suppliers for acceptance and placement on TVA's acceptable suppliers list (ASL). The Quality Assurance Program requirements applicable to DOE suppliers associated with TPBAR design and manufacturing are described in Section 2.17.3 below.

TVA procures nuclear fuel and related design and engineering services from NRC licensed fuel vendors who have established and are implementing NRC approved Quality Assurance Programs that comply with 10 CFR 50, Appendix B. The current nuclear fuel vendor for Watts Bar Nuclear Plant is Westinghouse

Electric Company LLC who provides items and services in accordance with their latest NRC approved Quality Management System (QMS).

2.17.3 Supplier Quality Assurance for TPBAR Design and Fabrication

DOE furnishes TPBARs to TVA for irradiation. DOE procures design, material and service procurements, fabrication, assembly, and delivery to TVA or TVA's Nuclear Fuel Vendor. As such, TVA contractually requires that DOE impose TVA's specified technical, functional, quality, and regulatory requirements (including 10 CFR 21) applicable to the TPBARs on DOE suppliers. Provisions are also included for flowing down the applicable requirements to sub-suppliers.

The same QA Program basis used for the Lead Test Assembly TPBAR design, fabrication, and delivery is applied to production TPBARs. DOE suppliers are required to establish, submit to TVA for review and acceptance, and implement a Quality Assurance Program that complies with the requirements of 10 CFR 50, Appendix B; complies with the methods of ASME NQA-1-1994 Basic and Supplementary Requirements; and complies with regulatory positions C.1, C.2, and C.3 of USNRC Regulatory Guide 1.28, Revision 3.

Use of ASME NQA-1-1994 Basic and Supplementary Requirements and the regulatory positions of Regulatory Guide 1.28, Rev. 3 for TPBAR design, fabrication, and delivery has been previously accepted by the NRC as documented in the NRC Safety Evaluation associated with the Watts Bar License Amendment No. 8 (NRC Letter dated September 15, 1997) for TPBARs supplied as Lead Test Assemblies (LTA).

DOE TPBAR and related service suppliers are evaluated by TVA and placed on TVA's acceptable suppliers list (ASL) in accordance with TVA's NRC accepted QA Program. TVA has evaluated and placed on the TVA ASL both the Pacific Northwest National Laboratory (PNNL) and WesDyne International LLC (WesDyne) as acceptable suppliers supporting incorporation of TPBARs into TVA nuclear facilities.

The Pacific Northwest National Laboratory (PNNL) is an acceptable supplier of TPBAR design, material and service procurements, fabrication, and related services. PNNL activities are performed in accordance with the requirements of the PNNL Tritium Target Qualification Project (TTQP) Quality Assurance Manual which has been reviewed and accepted by TVA as complying with the requirements of 10 CFR Part 50, Appendix B; the methods of ASME NQA-1-1994 Basic and Supplementary Requirements; and regulatory positions C.1, C.2, and C.3 of USNRC Regulatory Guide 1.28, Revision 3.

DOE has entered into a contract with WesDyne International LLC (WesDyne), a wholly owned subsidiary of the Westinghouse Electric Company LLC operating under a separate Board of Directors, to become an acceptable supplier of TPBAR design, material and service procurements, fabrication, and related services. WesDyne is an acceptable supplier of TPBAR material and service procurements, fabrication, and related services. Prior to completing a transfer of TPBAR design responsibilities from PNNL to WesDyne, TVA will evaluate WesDyne's design capabilities. Upon successful completion of the evaluation, WesDyne will be placed on the TVA ASL for TPBAR and related design activities. WesDyne activities are performed in accordance with the requirements of the latest revision of the NRC accepted Westinghouse Electric Company LLC Quality Management System.

2.17.4 Quality Assurance for Packaging and Transportation of Radioactive Material

DOE owns the TPBARs, procures transportation packages and conveyance services, and is the shipper of record. DOE has contracted TVA to prepare irradiated TPBARs for shipment. The TVA activities associated with packaging and transportation of radioactive materials include preparation of irradiated TPBARs for transportation by loading TPBAR consolidation containers into certified transportation packages, loading and securing the transportation packages onto transport vehicles, performing applicable radiation surveys, and preparation of DOE shipping papers. TVA activities are performed in accordance with TVA's NRC-approved Radioactive Material Package Quality Assurance Plan (PQAP), NRC Docket 71-0227, which complies with 10 CFR 71, Subpart H.

In accordance with the NRC approval of TVA's PQAP activities such as package design, fabrication, assembly, testing, and modification are satisfied by TVA obtaining certifications from packaging suppliers that these activities were conducted in accordance with an NRC-approved Quality Assurance Program.

Since DOE procures radioactive material transportation packages and related services, TVA identified to DOE the technical, functional, and quality requirements applicable to the transportation package supplier. The requirements include compliance with and package certification to 10 CFR 71 including an NRC-approved QA program. In addition, the DOE supplier(s) are required to be evaluated by TVA and on TVA's acceptable suppliers list (ASL). TVA performs acceptance reviews of applicable DOE documents used to obtain radioactive material packaging and related services to ensure adequate and acceptable requirements are identified to the package supplier. TVA evaluates package suppliers in accordance with TVA's NRC approved Radioactive Material Package Quality Assurance Plan.

3 PRODUCTION TPBAR EVALUATION

3.1 INTRODUCTION

The TPC Topical Report (Reference 1) evaluated the performance of the getter-barrier type TPBARs in a tritium production core loaded with the maximum number of TPBARs possible (~3344). For the tritium production mission in the Watts Bar Nuclear Plant, TVA has determined that the maximum number of TPBARs to be irradiated in the core is 2304. The number of TPBARs to be irradiated in any given fuel cycle will be determined by the core designer, consistent with power plant operations and tritium production requirements.

The differences between the Production TPBAR and the TPC TPBAR described in the TPC Topical Report (Reference 1) are:

- Variable pellet stack (pencil) lengths
- Length and material specification for the liner have changed
- Use of a spring clip as an alternative to the plenum spring
- Use of spacer tubes as an alternative to upper and lower getter disks and depleted lithium aluminate pellets
- Reduced the number of pencils in a TPBAR
- Modified top and bottom end plug designs

These changes have been made to improve fabrication processes and to enhance performance. Further details are provided in subsequent sections of this report.

Conclusions

The production TPBAR design conditions are within the envelope assumed for the TPC TPBAR design conditions (Reference 1). The comparison given in Table 1-1 shows that the reactor and core parameters for the TPC bound those for Watts Bar (current with TPBARS). The tritium production, mechanical, and thermal performance design conditions for Watts Bar are within the envelope established in Reference 1.

Design changes made for the production TPBARS are a result of TPC TPBAR and LTA testing and analyses (see Section 3.10) to improve the ability to fabricate, enhance tritium production, and minimize the potential for non-performance in a production mode.

3.2 PRODUCTION TPBAR DESIGN

3.2.1 Design Description

The TPBAR internal components are a top plenum spacer tube (may also be referred to as a getter tube), a spring clip or a plenum (compression) spring, pellet stack assemblies ("pencils"), and a bottom spacer tube. A pencil consists of a zirconium alloy liner around which are stacked lithium aluminate absorber pellets that are confined in a getter tube, as illustrated in Figure 3.2-1.

Variable Pellet Stack (Pencil) Lengths

The Production TPBAR design uses thin walled annular lithium aluminate ($LiAlO_2$) pellets assembled into stacks, called pencils, extending over the full or partial length of the active core. A single pencil is typically 12 inches in length. The production TPBAR overall stack length of lithium aluminate pellets enriched in Li-6 will typically range from 126 to 132 inches.

Length of the Liner and Material Specification

The design length of the production core liner has been tailored for compatibility with the new length dimensions for the absorber pellet stack and getter. The specific dimensions for the length of absorber stack containing Li-6 and its offset from the core centerline will be determined by the core designer for compatibility with each future reload core design, therefore small deviations from the dimensions cited in Reference 1 will be required. This flexibility is required to achieve the desired core axial power distribution. Reference 1 specified the liner as "zircaloy-4." For the production design, the liner is specified as a "zirconium alloy," to provide flexibility in obtaining material. The liner function can be met by any zirconium alloy meeting the specification requirements.

Spring Clip

The use of a spring clip as an alternative to the plenum spring uses less internal void volume and increases the factors of safety related to internal gas pressure and pressure stresses. The function of both the spring clip and the plenum spring is to provide an axial restraint of the pencil stack during handling and loading operations prior to irradiation. Neither the compression spring nor the spring clip plays a role during or after irradiation.

The top spacer tube for the production TPBAR design is designed to interface with the spring clip or the plenum spring and the top pencil. Dimensions and tolerances on the getters and liners have been changed to facilitate ease of fabrication. All functional requirements relating to dimensional fit-up are satisfied with the revised dimensions and tolerances.

Nickel Plated Zirconium Alloy Spacer Tubes

Depleted lithium aluminate spacers described in Reference 1 have been replaced with nickel plated zirconium (NPZ) alloy bottom spacer tubes. A NPZ alloy spacer tube is also used for the top spacer tube in the production TPBAR design. These NPZ alloy spacer tubes are preferred structural components and also serve to absorb tritium. Thus, their use allows the option to eliminate the upper and lower getter discs which were used in the LTA for absorbing tritium at the ends of the TPBARs. The NPZ alloy tubular bottom spacer occupies less internal void volume than the depleted lithium aluminate spacer. Consequently, the factors of safety related to internal gas pressure and pressure stresses are improved.

Reduced the Number of Pellet Stacks (Pencils)

The number of pencils in a TPBAR has been reduced from the description in Reference 1 and the LTA. The interfaces between the ends of pencils create small gaps in the absorber material. These interface gaps have a minor effect on the power distribution in adjacent fuel rods. Fewer, but longer pencils reduce the number of interfaces between pencils and are preferred to reduce the effect of power peaks in adjacent fuel rods. The number of pencils has been reduced from a total of 12 to 9 standard length and 2 variable length (total of 11) for the first production core. The variable length pencil stacks are positioned so that the pencil-to-pencil gaps occur at different axial locations in three different TPBARs. The TPBARs are arranged on the baseplate in a manner that minimizes power peaking in adjacent fuel rods.

Modified Top and Bottom End Plug Designs

For closure of the TPBARs, end fittings are welded to each end of the cladding tube. The end fittings for the production TPBARs are manufactured from 316 SS. The top end plug has been modified from the design used in the LTA and Reference 1 designs. The production top end plug design will be compatible with the TPBAR baseplate used by TVA's fuel vendor. The means of attachment of the top end plug to the base plate has been changed from that presented in the TPC topical report, and is described in more detail in Section 3.2.3. Additionally, both the top and bottom end plugs are counter bored to increase the internal void volume and decrease mass. The applied stress concentration, vibration fatigue, and flow induced vibration for the modified end plugs satisfy all of the functional requirements for structural integrity.

Future TPBAR Design Enhancements

The thirty-two (32) TPBARs used in the Lead Test Assembly were, for the most part, fabricated and assembled by hand. Such operations would not support the large scale TPBAR production. The changes described above have been made to both improve fabrication and to enhance performance. At the present time, a number of additional enhancements are anticipated for the TPBAR design. These future enhancements are being contemplated for the purpose of improving TPBAR performance, increasing the uniformity of TPBAR quality, lessening the burden of TPBAR irradiation on the host reactor, facilitating the extraction of tritium from TPBARs and improving the capability for large scale TPBAR production. The future enhancements that are under consideration include the following:

- Long Getter Tubes

  The incorporation of long getter tubes reduces the potential for gaps in the TPBAR absorber which may cause small power peaks in adjacent fuel pins. This design feature removes the need for alternate TPBAR loading patterns and thereby reduces the potential for TPBAR misloading. Advances in fabrication methods will lead to the use of longer pencils, which will improve performance by further reducing the number of pencils and resulting pencil-to-pencil interface gaps in future cores. As fabrication technology matures, steps will be taken to develop full length getters, such that a single pencil will be used, totally eliminating the pencil-to-pencil interfaces.

- Alternate Plating and Coating Specifications

  Alternate plating and coating specifications, which may result in a slightly different product than the current specification, are under consideration as a means to facilitate further improvements in TPBAR performance and provide increased uniformity. The alternate plating and coating specifications offer the potential for increased ease of product inspection, increased margins for mechanical design, and enable TPBAR designs that exhibit enhanced performance. Any alternate plating and coating specification will meet the criteria established for the production TPBARs for chemical compatibility.

- Alternate Stainless Steel Cladding Materials

  The cladding which was used for the LTA, and which will be used for at least the first production core is a special order requiring long lead times to manufacture. For production, the use of more standard cladding material is being investigated, including the use of welded and drawn tubing. Additionally, alternate stainless steel cladding materials offering increased material strength and enhanced corrosion resistance in environments away from the reactor are under consideration for future TPBAR design enhancement. Enhanced corrosion resistance may provide benefits for those TPBARs exposed to extended moist air storage during transportation or at the tritium extraction facility.

- End Plug Design Features

  A number of changes to the end plug features are anticipated to optimize the fabrication, consolidation, and handling of TPBARs. Refinements to the end plug design will likely be incorporated to facilitate the consolidation of irradiated TPBARs in the spent fuel pool and the handling of the TPBARs in the tritium extraction facility.

Conclusions

Design changes made for the production TPBARS are a result of Reference 1 TPBAR and LTA testing and analyses to improve the ability to fabricate and enhance tritium production. A range of pellet column axial lengths is available for the production TPBARS to allow core design flexibility and optimization of core power distribution. Mechanical and material changes have been made to the production TPBAR design to enhance overall performance relative to the Reference 1 TPBAR design. The design changes made to the production TPBAR have been evaluated and determined to meet the functional criteria established by TVA and support the conclusions made by the NRC in the SER related to Reference 1.

Should TVA, in concert with the TPBAR designer, fabricator, and DOE, conclude that enhancements to the TPBAR design are appropriate, all changes will be evaluated in accordance with TVA procedures.

3.2.2 TPBAR Operation

The irradiation design base case for the production TPBAR has been increased from 520 effective full power days (EFPD) for the Reference 1 design to 550 EFPD. The production TPBARs are designed to reside in the reactor core for one fuel cycle for a nominal cycle exposure of 510 EFPD, with a maximum exposure of 550 EFPD. For the Reference 1 design, the expected exposure was 494 EFPD. The capacity factor assumed in the analyses for Reference 1 was 90%. The production TPBAR has been evaluated assuming a 100% capacity factor for the operating cycle. The extended life-time and exposure limits reflect improvements in the TPBAR design.

Conclusions

The extended life-time and greater capacity factor utilized in the production TPBAR design reflect more stringent operation conditions than those analyzed in the Reference 1. With these changes, the production TPBAR design still has adequate margin throughout the operating cycle.

3.2.3 TPBAR Support in the Core Structure

The TPBAR assembly is shown in Figure 3.2-3. It is comprised of a maximum of 24 TPBAR rodlets and the upper structure holddown assembly to which the rodlets are attached. For those locations where TPBAR rodlets are not required, thimble plug rods are used. The TPBAR assembly design is such that the use of source rods with TPBARs on the same upper structure assembly is precluded. The upper structure assembly is basically the same as that used at Watts Bar.

The plate portion of the baseplate has 24 tapped holes for attachment of the TPBAR upper end plugs or thimble plugs. The plate is perforated to provide sufficient flow area for the reactor coolant exiting the fuel assembly top nozzle plenum. The flow holes are symmetric with respect to each quadrant of the baseplate.

The TPBAR upper end plug joint is designed to facilitate harvesting of the TPBAR rodlets. The design consists of the baseplate, crimp sleeve, and threaded stud (upper end plug) as shown in Figure 3.2-4. The baseplate configuration is basically the same as that of the existing Burnable Poison Rod Assembly, with modifications made at the rodlet hole locations. The baseplate thickness is threaded to receive the upper end plug of the TPBAR rod or thimble plug. Crimp sleeves are aligned and welded to the baseplate prior to TPBAR installation. The crimp sleeve consists of an upper thin-wall sleeve and a circular base. The crimp sleeve is welded to the baseplate to prevent removal during the TPBAR installation and removal. Therefore the crimp sleeve remains integral to the baseplate during TPBAR consolidation and eliminates extra loose parts. In addition, the baseplate and handling tool interface remains compatible.

Each TPBAR has an upper end plug that is threaded into and through the baseplate, to which the crimp sleeve is secured. The top portion of the upper end plug is a hex stud to facilitate torqueing and de-torqueing and also serves as the feature to which the sleeve is crimped. The hex stud length is sized for the crimp and torque tool fitups. The upper end plug threads are left-hand such that when the rodlet is removed, conventional right hand torque is used. The threads are designed to minimize the active length and the corresponding stroke used to drive the rodlet out of the baseplate during removal, while ensuring thread structural requirements. Although the thimble plug has a similar design configuration, the length of the hex on the thimble plug terminates just above the crimp sleeve. Therefore, thimble plugs cannot be removed with the TPBAR torque tool and inadvertently mixed with TPBARs during consolidation.

During the consolidation of the TPBAR rods, the rods are de-torqued from the baseplate and removed. A hex socket tool is used to de-torque the rodlet using the hex stud on the rodlet upper end plug as the mating feature. Sufficient torque is applied until the resistance of the crimp is exceeded. The TPBAR is torqued until it is driven out of the baseplate and into the canister.

If the threaded engagement of the rod to the baseplate becomes galled or is incapable of being removed by conventional methods, a backup method of rod removal is required. To enable rod removal in this case, a small hydraulic cutter would be used to sever the upper end plug of the rod from the baseplate. This method would require that all rods that could be de-torqued be removed by the conventional method. Then, the cutter would be delivered onto the rod just below the baseplate. The cutter would sever the upper end plug of the rod at the smallest diameter (a necked down region approximately 1/2" below the baseplate). Severing the upper end plug in this region would not affect the integrity of the rod itself. This method has been successfully utilized in other spent fuel pool applications.

Conclusions

The production baseplate differs from both the Reference 1 baseplate and the current Watts Bar baseplate in the baseplate-to-TPBAR connection design. The TPBAR upper end plug joint is designed to facilitate harvesting of the TPBARs. This requires a modification in the baseplate-to-TPBAR connection. The connection has been bench tested and verified for interface and functional compatibility.

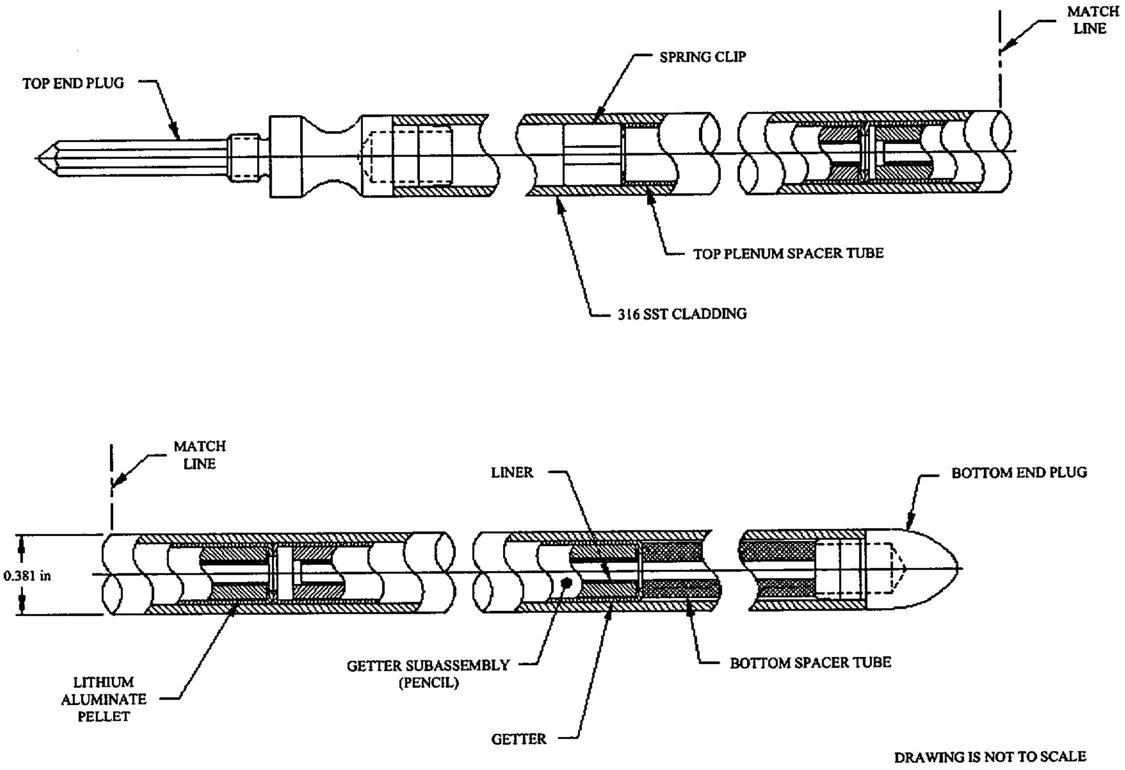


Figure 3.2-1
Longitudinal Cross Section of TPBAR

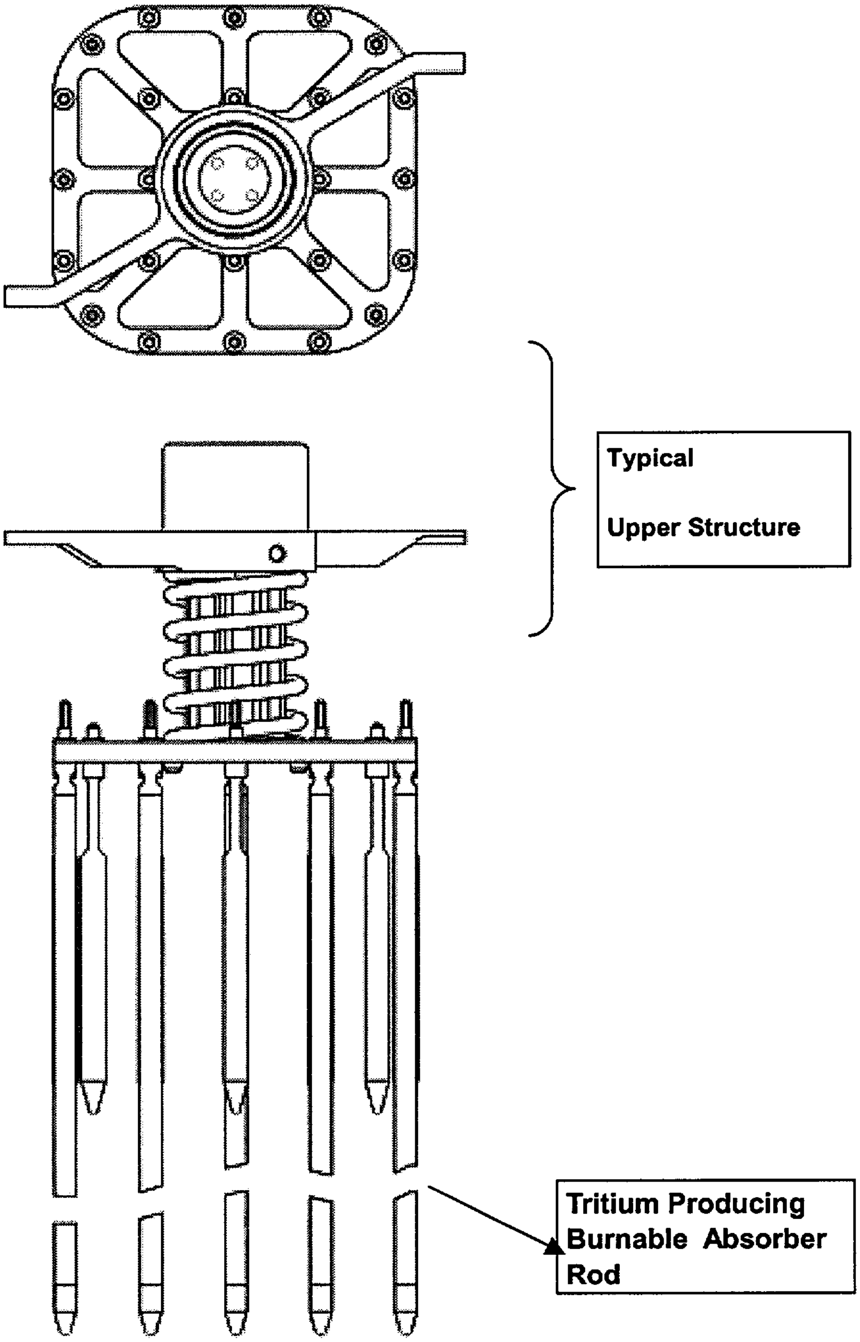


Figure 3.2-3
TPBAR Holddown Assembly

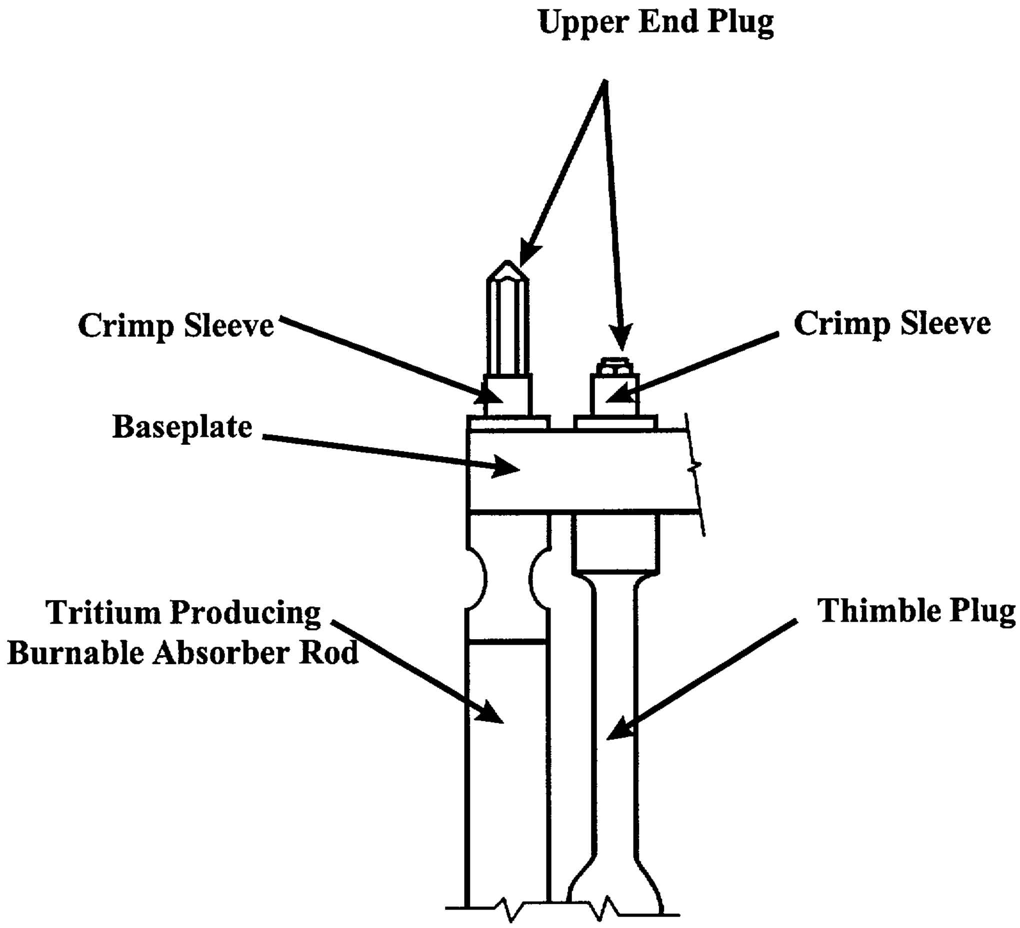


Figure 3.2-4
TPBAR Upper End Plug and Thimble Plug Connections

3.3 DESIGN REQUIREMENTS

The production TPBAR design shall meet the functional requirements listed in Table 3.3-1. These functional requirements are essentially the same as the requirements for the TPC design. The functional requirements for production have been established by TVA. In Reference 1, permeation through the TPBAR cladding was assumed to be <1.0 Ci/TPBAR/year. For the production design, this nominal release rate is unchanged, but is now presented as "less than 1000 Ci/1000 TPBARs/year." This change reflects the statistical understanding that the release from an individual TPBAR may exceed 1.0 Ci/year, but the total release for 1,000 TPBARs will not exceed 1,000 Ci/year. Table 3.3-2 provides a list of TPBAR design requirements and assumptions for the Watts Bar TPC as well as the Reference TPC (Reference 1). Table 3.3-3 compares significant TPBAR parameters for the Watts Bar TPC and the Reference TPC.

Conclusions

The production TPBAR design meets the functional requirements established by TVA. Changes in the design requirements reflect the information gained from the LTA fabrication and operational experiences.

Table 3.3-1 Production TPBAR Functional Requirements

1. The Production Design TPBAR shall produce up to but not exceed 1.2 grams of tritium per rod while exhibiting acceptable materials performance.
2. The in-reactor tritium release rate for intact Production Design TPBARs shall not exceed a core-wide average of 1000 Ci/1000 rods/yr during normal operation and anticipated operational occurrences.
3. The Production Design TPBAR shall not cause adjacent fuel to exceed specified acceptable design limits.
4. The TPBARs shall contribute to reactivity control and power distribution control by use of materials, which supplement the negative reactivity of the boron in the coolant.
5. Safe operating temperatures shall be maintained at all times.
6. Tritium release from TPBARs shall not cause radiological regulatory limits to be exceeded. [System requirements that must be met by the TPBAR design in combination with the reactor system.]
7. TPBAR failures shall not result in unacceptable core performance.
8. The TPBAR components shall be mechanically compatible with each other and the host fuel assembly.
9. The structural integrity of the TPBAR cladding and end plugs shall be sufficient to perform their functions throughout the irradiation cycle.
10. The mechanical integrity of all internal components shall be sufficient to perform their functions throughout the irradiation cycle.
11. The TPBAR cladding shall remain intact during pool storage and post-irradiation handling prior to arrival at the Tritium Extraction Facility.
12. The TPBAR shall be compatible with the host reactor's fuel assembly design, be a removable component within the assembly, and be located as a stationary element in a guide thimble location.
13. Corrosion-related degradation of TPBAR materials and components shall not occur.
14. The Production Design TPBAR shall be capable of being fabricated in accordance with approved requirements.
15. The unirradiated TPBARs and the unirradiated target assembly must be capable of being transported in accordance with approved requirements.
16. The irradiated TPBARs must be capable of being transported.
17. The TPBAR design shall provide for accountability of each TPBAR.
18. After Irradiation, TPBAR assembly waste must be acceptable for waste disposal.

Table 3.3-2 TPBAR Design Requirements and Assumptions***

Subject Item	Reference TPC	Watts Bar TPC
Maximum Tritium Production, g/TPBAR	1.2	1.2
Core Power Density, w/cm^3	108.04	104.33
GVR limit, rod average**	215	215
Rod internal pressure limit, psia at operating temperatures	3200	3200
TPBAR cladding wall temperature limit, °F @2250 psia system pressure	660	663
Max cladding temperature during Conditions I and II, °F	660	683
Bulk boiling temperature in the thimble, °F	652.7	652.7
Maximum cladding structural design temperature, °F	660	663
System pressure, psia	2250	2250
System design pressure, psia	2500	2500
TPBAR life-time, EFPD (nominal without margin)	494	510
Mechanical design life-time, EFPD	520	550
Capacity factor, %	90	100
Tritium release, average, Ci/year	<1.0 per TPBAR	<1000 per 1000 TPBARs

** Gas volume ratio based on theoretical density of lithium aluminate

*** Use ASME Code stress criteria with Westinghouse generic design stresses for core component rods following the procedure in the Mechanical Design Manual for core rod components.

Table 3.3-3 Significant TPBAR Parameters

Subject Item	Reference TPC Data	WBN TPC Data
Maximum Number of TPBARs in core FC/EC	3342/3344	2304 EC
Maximum Number of TPBAR assemblies FC/EC	140	112 EC
Maximum Number of TPBARs per assembly	24	24
TPBAR Geometry & Design		
Cladding OD, in.	0.381	0.381
Cladding ID, in. (before coating)	0.336	0.336
Rod OD tolerance, in.	0.0005	0.0005
Rod length, in.	152.37	152.85
Pellet OD, in.	0.303	0.303
Pellet ID, in.	0.223	0.223
^{6}Li loading, g/in. (enriched pellets)	0.030	0.034 to 0.036
^{6}Li enrichment, at % (enriched pellets)	25.3	28.7-30.4
Enriched pellet stack length, in., Maximum	127.5 FC/128.5 EC	132
Pellet stack off-set down from centerline, in.	0.50/0.25 FC/EC	0.0
Rod back-fill pressure, psia	14.7	14.7
Guide thimble OD, in.	0.474	0.474
Core Power Density, W/cm^3	108.04	104.33
Average fuel rod power, kW/ft	5.68	5.53
TPBAR average rod power, total, kW (with uncertainty)	5.99	6.58
Peak TPBAR power, total, kW (with uncertainties)	8.27	8.16
Average TPBAR power, kW/ft with uncertainties	0.498	0.545
Total uncertainty	1.12	1.125

Notes:

1. Heating rates are for steady state operation
2. Upper limit tolerance ^{6}Li loading assumed, 0.00125 g/in tolerance
3. Total uncertainty is a very conservative bounding value. Consolidation of uncertainties is justified and would reduce the value given above. Future analyses may use a reduced uncertainty, as justified.
4. FC/EC – First Cycle/Equilibrium Cycle.

Table 3.3-3 Significant TPBAR Parameters (cont.)

Tritium Production in First Cycle (FC)/Equilibrium Cycle (EC)		
Subject Item	**ReferenceTPC Data**	**WBN TPC Data**
F_Q	2.5	2.5
$F_{\Delta H}$ with uncertainties TPBAR Fuel	1.46 1.65	1.57 1.65
Overpower for Condition II, fraction of full power	1.187	1.21
Surrounding Fuel Assembly Design		
Core average axial peak thermal flux, n/cm^2/s	0.446E14 BOL 0.528E14 EOL	0.323E14 BOL (EC) 0.362E14 EOL (EC)
Axial peak to average neutron flux ratio (Fz)	1.058 BOL 1.112 EOL	1.123 BOL (EC) 1.115 EOL (EC)
TPBAR Cladding fast neutron flux, >1 MeV, n/cm^2/s	1.06E14 BOL 1.05E14 EOL	1.4E14*
Tritium Production in First Cycle (FC)/Equilibrium Cycle (EC)/(FTC) First Transition Cycle		
Tritium production for mechanical and other design assumptions, g	1.2	1.2
Average tritium produced per rod, g (without uncertainties)	0.856/0.839 FC/EC	0.896 (EC)
Peak tritium produced per rod, g; includes factor for intra-assembly gradient (without uncertainties)	1.089	1.08 (EC)
Amount of tritium produced per cycle, g (without uncertainties)	2860/2805 FC/EC	2065 EC
Rod average GVR	139/137 FC/EC	139
Axial peak GVR in average rod	156/153.8 FC/EC	148
Axial average GVR in peak rod	174	186
Axial peak GVR in peak rod	195	201
Rod average ^{6}Li burnup, %	45.4/44.2 FC/EC	45.3 FTC/39.0 EC

Note: Fluxes given for first cycle are larger than equilibrium cycle fluxes

*Peak TPBAR cladding flux in maximum TPBAR node

3.4 MECHANICAL DESIGN EVALUATION

3.4.1 Tritium Production and Design Life

As noted in Section 3.2.2, the production TPBAR design life for mechanical evaluation has been changed to 550 EFPD from 520 EFPD used for the TPC design. The nominal design life of the core has been increased to 510 EFPD from the TPC value of 494 EFPD. These changes reflect improvement in the TPBAR design and differences in the operating cycle assumptions between Reference 1 and the plant specific assumptions for the TVA reactors to be used in the tritium production mission.

With a 1.2g tritium/rod limitation, the production TPBAR design evaluations show sufficient design margins up to 550 EFPD.

Conclusions

The production TPBAR has been evaluated against the plant specific operating parameters for the TVA reactors and will perform with sufficient design margins throughout the operating cycle under all operating conditions.

3.4.3 Absorber Pellets

Evaluation of neutron radiographs for the LTA TPBARs irradiated in Watts Bar confirmed minor cracking of pellets with no evidence for loss of pellet integrity from irradiation and handling. The neutron radiographs also revealed a slight amount of absorber material missing from the top edge of a few pellets in 7 of the 32 irradiated TPBARs. A qualitatively comparable volume of loose absorber material was observed on the bottom getter disk. The maximum volume of loose material in a single TPBAR was estimated to be less than 0.05 cm^3. The loose material is not significant because:

- During irradiation detached lithium aluminate chips are predicted to operate below their melting point.

- Tritium permeation release to the reactor coolant system from pellet material that has relocated to the bottom uncoated end plug is predicted to be negligible.

- The less than 0.05 cm^3 absorber material observed in the bottom of 7 of the 32 irradiated LTA TPBARs is believed to have been abraded from the edge of the top lithium aluminate pellets during fabrication. Implementation of an improved getter end forming process for the production core TPBARs is expected to reduce the potential for these small chips.

- The small amount of material involved will have a negligible impact on core neutronics and power peaks at pencil-to-pencil gaps.

Conclusions

The absorber pellets have demonstrated physical integrity under reactor operating conditions and pre- and post-irradiation shipping and handling. Improvement in the fabrication process is expected to minimize the cracking of the upper pellet surfaces, thus improving performance in the production mission.

3.4.5 Plenum Spring and Spring Clip

The reference design utilized a 302 SS plenum spring to maintain the internals of the TPBAR in place during shipping and handling. This spring is similar in design to those used in BPRA rods and fuel rods. The production TPBAR has been designed to utilize a zirconium alloy spring clip for the same purpose. The spring clip is also similar to spring clips used in burnable absorber rods. Experimental testing has demonstrated, with high confidence, that the spring clip will provide the restraining force required for pre-irradiation shipping and handling. Neither the plenum spring nor spring clip is required to provide any function during or after irradiation. Sliding of the spring clip along the inner surface of the cladding due to dimensional changes of the pellet stack will not have a negative impact on tritium permeation.

The spring clip occupies less space in the TPBAR than the plenum spring, thus increasing the internal void volume and reducing the internal gas pressure.

Dimensional changes in the plenum spring and spring clip result from thermal expansion and irradiation growth. These phenomena are described in the Materials Properties Handbook (MPH), Reference 2.

Conclusions

The use of a zirconium alloy spring clip in place of the plenum spring reduces the internal gas pressure for the same tritium generation. The spring clip has been designed and tested to provide a restraint to movement of the internal components during pre-irradiation handling and shipping, thus serving the same function as the plenum spring. The spring clip is not required to function during or after irradiation.

3.5 TPBAR PERFORMANCE

As described in Reference 1, the TPBARs were designed such that permeation through the cladding would be less than 1.0 Ci/TPBAR/year. For the production design, this value is reported as "less than 1000 Ci/1000 TPBAR/year." While the value of the permeation is not changed from Reference 1, the new units of reporting emphasize that the release is based on the core average. Thus an individual TPBAR may release more than 1 Ci/year, but the total release for 1000 TPBARs will be less than 1000 Ci/year.

Conclusions

The difference in how permeation from a TPBAR is presented does not impact the total number of curies released. The releases are still bounded by the analyses performed for Reference 1.

3.5.1 TPBAR Performance Modeling

Hydrogen Ingress from the PWR Coolant

Evaluation of hydrogen (protium) ingress into the TPBARs from the coolant as described in the TPC Topical Report assumed that the RCS contained ~35 cm^3/kg STP of hydrogen. This evaluation for the production design assumes that the RCS contains 50 cm^3/kg STP of hydrogen. This higher concentration of hydrogen in the RCS provides a higher driving force for hydrogen ingress, and is therefore a more conservative assumption than used in the TPC topical report. Analysis confirms getter loading and internal rod pressure remain within design limits and the performance of the TPBAR is not adversely affected.

3.5.3 Performance During Abnormal Conditions

During a LBLOCA, those TPBARs which experience conditions of high internal pressure coupled with high cladding temperature will rupture. Burst testing of TPBAR cladding material performed by PNNL conservatively indicates that no more than one pencil worth (~12") of lithium aluminate absorber pellets may be ejected from the TPBAR at the time of the rupture. This loss of pellet material with the leaching of lithium aluminate (at a rate of <3%/day up to 50% of the initial lithium) due to exposure to the RCS coolant has been evaluated and the reactor can still be shutdown and maintained in a safe condition following this event. Further details are provided in Sections 2.15.5.4 and 3.7.3.

3.5.4 Failure Limits

Breach of the TPBAR cladding during Conditions I, II, and III is unlikely. However, in the event a TPBAR fails during reactor operation, two TPBAR failure modes have been evaluated to determine the ability to maintain reactor safety. Should a TPBAR fail during operation, it would most likely be due to a small manufacturing or weld defect, which would allow some reactor coolant to enter the TPBAR and TPBAR gases to escape to the coolant, however there would be no loss of absorber material under these conditions.

In the event of a catastrophic TPBAR failure during reactor operation, all of the lithium is conservatively assumed to be lost immediately to the RCS. Analyses demonstrate the ability to maintain the reactor in a safe condition under both scenarios. See Sections 3.7.3 and 3.8.3.1 for details regarding the effect of pellet leaching on fuel rod performance.

3.6 THERMAL-HYDRAULIC EVALUATION OF TPBARS

An evaluation was performed to determine the effects of the representative reactor core thermal hydraulic conditions on the function and integrity of the TPBARs.

As in the Topical Report, standard Westinghouse procedures were applied to calculate the bypass flow through the fuel assembly guide thimble tubes and the thermal performance of the TPBARs located in the guide thimble tubes.

The Westinghouse methodology was employed to determine for normal operation (Condition I):

- The bypass flow through the fuel assembly guide thimble tubes
- The coolant temperatures in the guide thimble tubes
- TPBAR maximum surface temperatures
- Absence of bulk boiling in the guide thimble coolant flow
- Absence of surface boiling in the guide thimble dashpot

The coolant bulk boiling calculations are performed for the following basic assumptions:

- Thermal core design flow
- Worst-case mechanical TPBAR and guide thimble tubes dimensions and tolerances
- Limiting assembly and TPBAR power generation at the $F_{\Delta H}$, specification limit reduced by 5%.

The $F_{\Delta H}$ specification limit considered is 1.65. For the analyses, this value is reduced by 5 percent because the presence of a TPBAR in the thimble tends to suppress the power in the fuel rods adjacent to it.

Specific evaluation assumptions used in the TPBAR and guide thimble tube evaluation are listed in Table 3.6-2.

Given the conservatism of the input assumption and parameters given above, the evaluation procedure does not require applying additional uncertainties to power, temperature, and pressure which are input at nominal conditions.

Results

TPBARs in the TPC generate higher power than equivalent PYREX burnable absorber rods in the same reactor location, primarily due to the higher (n-α) reaction energy release in ^{6}Li than in ^{10}B. Since the external features of both types of rods are almost identical, the guide thimble tube coolant flow remains unchanged. The results of the thermal-hydraulic evaluation are discussed below with respect to the relevant criteria.

No Bulk Boiling

Requirement: There will be no bulk boiling in the guide thimble tubes.

The maximum bulk coolant temperature in the guide thimble tubes is 652.4°F, which is slightly below the saturation temperature of 652.7°F for a conservative $F_{\Delta H}$ of 1.65 reduced by 5 percent. The maximum cladding surface temperature is 654.4°F.

The TPBAR heat generation (and contribution from the water inside the guide thimble tube) increases the coolant temperature inside the guide thimble by 8°F. The heat transfer from the adjacent fuel rod channels is a major contributor to the coolant temperature inside the guide thimble.

No Surface Boiling In the Dashpot

Requirement: There will be no surface boiling from the core component rod within the dashpot region of the guide thimble tubes.

The calculated rod surface temperature in the dashpot region of ~ 600°F is well below any surface boiling temperatures.

Bypass Flow

Requirement: The sum of the bypass flow through all the different types of guide thimble tubes, core component rods and the instrumentation tubes in the core shall not exceed the limits specified.

The design basis for the core thermal hydraulic design is a core design bypass flow limit of 9.0% of the reactor flow. The design limit for bypass flow through the thimbles is 2%. This bypass flow fraction assumes plugging of open guide thimble tubes and instrument tubes. The evaluation for the TPBAR transition and equilibrium cores showed that this limit was met with margin. These bypass flow calculations were done with assumed loading patterns.

A core bypass flow verification will be performed each cycle as part of the Westinghouse standard reload evaluation.

TPBAR Temperature

Requirement: The maximum temperature of the TPBAR components shall not exceed the melting temperature of component materials during Condition I or Condition II and III events.

Guide thimble inlet and outlet coolant temperatures are used as the boundary conditions with a linear distribution between the top and bottom of the TPBAR. Using this coolant temperature profile and predicted heat inputs from the (n-α) reaction and the gamma heating, rod component temperatures at axial nodes along the TPBAR can be calculated. The nodal component temperatures are then used to predict average gas temperatures at representative burnup steps.

Conclusion

Standard analytical methods used in the nuclear industry were used to evaluate conditions such as bulk boiling during Condition I operation to ensure that an adequate safety margin exists in the thermal-hydraulic design relative to the criteria. These criteria are similar to those that apply to the Westinghouse BPRAs.

The analyses concluded that the operation with TPBARs in the core is compatible with Reference 1 performance capability and with the current Westinghouse fuel products for Watts Bar Unit 1. The TPBARs meet the functional requirements established by TVA.

Table 3.6-2 Evaluation Assumptions

Guide Thimble Tubes Flow Evaluation

1. The fuel assembly coolant temperatures are calculated for a core flow rate reduced by 9.0% bypass flow. This bypass flow rate assumes that the guide thimble tubes contain TPBARs or other core components. Reducing the core flow maximizes the core coolant temperatures and heat transfer into the guide thimble tubes flow.
2. Fabrication tolerances are used to give the worst case for the analysis being performed.
3. Design tolerances were selected to maximize the guide thimble tube gamma heating.
4. The TPBAR power includes the energy deposited in the water flowing through the guide thimble tubes.
5. The plant is operating at the new rated power level of 3459 at 2250 psia, and nominal T_{in} for boiling considerations.
6. For boiling analysis, a long-term, steady-state axial power shape is used.
7. The TPBAR rod is operating adjacent to a rod channel with a hot rod with power ($F_{\Delta H}$) reduced by 5% from the peak design.
8. The thermal condition of the flow channels surrounding the guide thimble tubes is obtained from a representative VIPRE code evaluation.
9. Overpower conditions, that is, 121% power for Watts Bar are used for maximum TPBAR component temperature calculations.
10. Temperature dependent values of thermal conductivity and thermal expansion coefficient are used.
11. One-dimensional, steady-state heat conduction analysis is used in material temperature calculation.
12. A bounding total peaking factor, F_Q, is applied for calculation of maximum material temperature. (This bounding factor bounds the plant specific value for Watts Bar.)

3.7 NUCLEAR DESIGN INTERFACES AND CONDITIONS

3.7.1 Lithium-6 Pellet Loading Tolerance Requirement

The Li-6 loading, in grams/inch, of 0.030 for enriched pellets in the TPC topical report has been revised to a range of 0.028 to 0.040 ±0.00125. The specific value of the Li-6 loading is determined by the TPBAR tritium production requirements and the core design parameters. For Watts Bar, the core designer has selected 0.034 grams/inch for the first and second transition cores, and 0.036 grams/inch for the equilibrium core. The core designer selects the specific value for fabrication based on each core design. The core designer also specifies the axial offset of the TPBAR pellet column.

Conclusions

The change in lithium loading provides needed flexibility to the core designer and does not adversely impact the results of prior safety evaluations. The tritium generated in any individual TPBAR is still limited to 1.2 gm.

3.7.2 Allowable Fuel Peaking Caused by Axial TPBAR Pellet Gaps

As discussed in Reference 1, axial gaps between absorber pellets in a pellet stack or between pellets in adjacent TPBAR pencils can cause increased local power peaking, called spikes, in adjacent fuel rods. In general, the closer a fuel rod is to a TPBAR location, the larger the potential spike. A given fuel rod may be affected by more than one TPBAR gap, depending on its location in the fuel assembly. If gaps from more than one TPBAR contribute to the local peaking increase in a given fuel rod, a reinforcement of the spike occurs as a consequence of the co-located axial gaps. A functional requirement for the production TPBAR is that "the production design TPBAR shall not cause adjacent fuel to exceed specified acceptable design limits." The application of three TPBAR loading configurations in the production design, and the systematic distribution of these three designs within the fuel assembly, provides the core designer with flexibility to control the location of pencil-to-pencil gaps and minimizes the potential for reinforcement of local peaking due to axially co-located gaps. Analyses performed by the plant fuel vendor ensure that the local peaking factors do not exceed acceptable design limits. The production design will use fewer pencils in the TPBAR, thus reducing the number of pencil-to-pencil gaps. Ongoing development of the fabrication process is expected to lead to long getters such that only one pencil will be required, thus eliminating pencil-to-pencil gaps.

Conclusions

This change in the loading configuration for TPBARs provides the core designer with flexibility to minimize the impact of pencil-to-pencil gaps on fuel peaking in adjacent fuel rods. This change has a positive impact on plant operation, when compared with the TPC design.

3.7.3 Interfaces and Operational Impacts

TPBAR Failures during Normal Operation

Should a TPBAR fail during operation, it would most likely be due to a small manufacturing or weld defect, which would allow some reactor coolant to enter the TPBAR and TPBAR gases to escape to the coolant, however there would be no loss of absorber material under these conditions. In the event of a catastrophic failure of the TPBAR cladding, recent test data (see Section 3.8.3.2) suggest that significant leaching of lithium from the TPBAR is possible. Accordingly, the safety implications of TPBAR failures with respect to core reactivity and fuel rod integrity were examined. TPBAR failures are extremely unlikely during normal plant operation due to the high reliability of burnable absorber components. Furthermore, in the unlikely event of a TPBAR failure, the following conclusions can be drawn: (1) the implications on global core reactivity are insignificant, and (2) the local power perturbation caused by the failure of one TPBAR is sufficiently small such that plant operation can continue without challenging normal operation DNBR limits or compromising fuel rod integrity.

Burnable Absorber Reliability

Burnable absorber components have a long history of reliable use in Westinghouse PWRs. Westinghouse cores have primarily employed two burnable absorber designs: the Burnable Poison Rod Assembly (BPRA) and the Wet Annular Burnable Absorber (WABA). More than 200,000 burnable absorbers of both types have been irradiated. Prior to 1981, approximately 30,000 BPRAs were irradiated. Of these, only two failures were identified in burnable absorbers that were irradiated for one cycle (Reference 3). Both of these failures occurred early in the history of burnable absorbers and were caused by slumping of the borosilicate glass and swelling of the rod, causing the rod to stick in the assembly. Neither of the failures resulted in cladding failure. (Based on this experience the material specification for the borosilicate glass was changed and no further problems were encountered with burnable absorber performance.) No burnable absorber failures have been reported since Reference 3 was issued in 1981.

The TPBAR design is similar to the BPRA design in that both employ stainless steel cladding. TPBARs will be used in the reactor core in the same manner as BPRAs and WABAs, i.e., they will be attached to base-plates and placed in the fuel assembly guide thimbles, primarily in fresh fuel assemblies. Like conventional burnable absorbers, TPBARs will produce helium that will increase the TPBAR internal pressure in a manner similar to BPRAs and WABAs. TPBAR irradiation, however, will be limited to one operating cycle (BPRAs and WABAs are occasionally used for more than one cycle). PNNL designed the TPBARs using the Westinghouse burnable absorber design documentation as a guide, which resulted in a design that has margins equal to or greater than the Westinghouse commercial burnable absorber rods. In addition, PNNL has placed more stringent quality control requirements on the TPBARs than the requirements placed on the commercial burnable absorbers. The Department of Energy has awarded the contract to fabricate TPBARs to WesDyne International, a subsidiary of Westinghouse Electric Company. The TPBARs will be manufactured at the Westinghouse Columbia Plant where commercial burnable absorbers are currently manufactured, ensuring that the commercial experience will be applied to the TPBARs.

Because of their similar construction, design margins, and operating environments relative to conventional burnable absorbers, TPBAR reliability is expected to at least equal the reliability of BPRAs and WABAs.

Frequency of TPBAR Failures in a Tritium Production Core

The high reliability of the commercial burnable absorbers and the application of that experience to TPBARs yields a very low expected frequency of TPBAR failures in a Tritium Production Core (TPC). Based on the fact that no cladding failures have been observed in the 200,000 burnable absorbers irradiated, a conservative 95% confidence upper limit for the probability of a TPBAR failure has been determined to be 1.5E-05. A TPC design will have a maximum of approximately 2300 TPBARs. For a TPBAR failure to have safety margin implications, the failure must occur at a high power location at a limiting time in core life. Also, for multiple TPBAR failures to produce more severe power peaking than a single failure, the failures must occur in adjacent or nearly adjacent locations. The frequency of two or more adjacent TPBAR failures is considerably smaller than that for a single failure. The estimate of failure frequency for a single TPBAR in a high power location is 2.9E-03 per year per core, and for multiple adjacent TPBARs in high power locations the estimated failure frequency is 1.2E-07 per year per core. In light of these frequencies, multiple adjacent TPBAR failure scenarios in high power locations are judged to be so improbable that they are not considered credible and further analysis is not warranted. The safety implications of single TPBAR failures are considered below.

Core Reactivity Implications of TPBAR Failures

The global core reactivity effects of a catastrophic TPBAR failure were examined for the TPC designs described in Section 2.4.3. The analyses performed demonstrate that, in terms of global core reactivity, the effect of a TPBAR failure is insignificant. A single TPBAR failure results in a critical boron concentration increase of less than 1 ppm, assuming that all the lithium leaches from the TPBAR. This small reactivity increase is of no consequence with respect to plant operation or shutdown margin and can be easily accommodated by the plant boron system. Failures of more than one TPBAR are not considered credible during normal operation.

DNB Margin Implications of TPBAR Failures

The power distribution effects of a single catastrophic TPBAR failure were examined for the Tritium Production Core designs. To assess the DNB margin implications of such failures, the increase in local power peaking was calculated assuming single TPBAR failures at high power locations in the reactor core and at limiting times in the operating cycle. The results of these evaluations show that single TPBAR failures produce peak fuel rod power increases of 4-6%. The effect of the TPBAR failure is localized and limited to a small number of fuel rods in the immediate vicinity of the failed TPBAR. This local power increase assumes that 100% of the lithium leaches from the TPBAR. This is a very conservative assumption. As Section 3.5.4 discusses, TPBAR failures during normal operation will most likely be due to a small manufacturing or weld defects. Such failures will not result in absorber loss. The peaking factor increases due to such defects will be negligible.

The 4-6% increase represents the expected change in the assembly hot rod power due to the local power perturbation caused by catastrophic failure of the TPBAR cladding and complete leaching. For the TPC designs discussed in Section 2.4.3, the normal operation $F_{\Delta H}$ limit was not exceeded for a single TPBAR failure. While local power peaking is somewhat loading pattern dependent, significantly larger power perturbations (~20-25%) would be required to exceed DNBR safety limits assuming normal operating conditions. Thus, single TPBAR failures in TPC designs will not challenge normal operation DNBR limits, and fuel rod integrity will be maintained.

Operation with Catastrophic TPBAR Failure

In the unlikely occurrence of a catastrophic TPBAR failure, except for very early in the cycle, the increased tritium concentration should be noticed during monitoring of the reactor coolant. Should this occur, plant procedures will be in place to specify the appropriate actions to initiate. The procedures will evaluate conditions and determine appropriate actions such that safety limits would not be exceeded should a moderate frequency event occur. Therefore, power operation could continue without adverse consequences to fuel design limits.

Conclusions

The frequency of TPBAR failures occurring in a Tritium Production Core is small due to the expected high reliability of TPBAR components. In particular, the frequency of experiencing two or more TPBAR failures at limiting core locations is extremely small, so that such scenarios are not considered credible. The safety implications of single TPBAR failures were examined with the following conclusions:

1. the global reactivity increase is very small, less than 1 ppm, and
2. even with the conservative assumption of complete leaching, the local power peaking due to a single TPBAR failure is small enough such that DNBR safety limits will not be challenged assuming normal operation.

Based on the above, the safety implications of TPBAR failures are judged to be sufficiently small such that normal plant operation can continue without challenging DNBR limits or fuel rod integrity.

TPBAR Compatibility with RCS Chemistry

During normal operation, TPBARs release a minimal amount of tritium to the RCS coolant. As described in the TPC topical report, the TPBARs were designed such that permeation through the cladding would be less than 1.0 Ci/TPBAR/year. For the production design, this value is reported as less than 1000 Ci/1000 TPBAR/year. While the value of the nominal release rate is not changed from the TPC topical report, the new units of reporting emphasize that the release is based on the core average. Thus an individual TPBAR may release more than 1 Ci/year, but the total release for 1000 TPBARs will be less than 1000 Ci/year.

Conclusions

This change in the manner in which the permeation is stated does not change the conclusions from Reference 1.

Refueling Operations

The TPBARs will be handled and shipped to the reactor site by methods similar to those applied to burnable absorbers. Prior to shipment to the reactor, the TPBARs are attached to a baseplate, see Figure 3.2-3, and inserted into fuel assemblies at the fuel fabrication facility. Fuel assemblies may be shipped with TPBARs in guide thimble locations in standard shipping containers for fresh fuel, applying standard procedures. Receipt of the TPBAR clusters/fuel assembly combination will follow TVA's standard receiving, unloading and handling procedures for burnable absorber and fuel assemblies. Additionally, TPBARs may also be supplied in suitable containers and relocated into the spent fuel pool utilizing existing procedures and equipment.

During refueling operation, with normal refueling and fuel pool temperatures at approximately 110°F, the tritium release from TPBARs is very low, much less than 1 Ci/TPBAR/year and is not considered to affect any evaluations. Defective TPBARs moved to the fuel pool could continue to release the stored tritium at a slow rate into the pool. To quantify the release of tritium from a breached irradiated TPBAR in the spent fuel pool as a result of mishandling, PNNL conducted laboratory tests with irradiated lithium aluminate absorber pellets in both deionized and borated water to simulate spent fuel pool composition. The rate for leaching tritium from irradiated absorber pellets in simulated PWR spent fuel pool water at 24°C and 93°C demonstrated that if a handling accident resulted in simultaneous breaching of 24 TPBARs (one full baseplate) in the spent fuel pool, the tritium concentration in the pool will remain below the 60 µCi/ml TVA action level at all times following the breach. The 60 µCi/ml spent fuel pool tritium activity action level was established to maintain the refueling floor airborne activity below the 10CFR20 limit for an airborne radioactivity area.

Conclusions

During refueling operations, TPBAR assemblies will be handled in the same manner as burnable poison assemblies. The analyses performed have evaluated the impacts to the spent fuel pool and surrounding area resulting from damage to 24 TPBARs due to a handling accident. The effects have been found to be acceptable. See Section 2.15.6.6, "Fuel Handling Accidents."

On-Site TPBAR Assembly Movement and Handling

Handling, consolidating, and preparation for off-site shipment of TPBARs will be controlled in accordance with the plant's procedures (see Section 1.5.1). Weights and interface dimensions of fuel assemblies containing TPBARs are within design parameters of the existing handling equipment and therefore no new or modified tooling or procedures are required for the movement and handling of fuel assemblies with TPBAR clusters. The tooling and procedures required to relocate burnable poison rod assemblies (BPRA) is sufficient to handle TPBAR clusters between fuel assemblies.

Conclusions

On-site TPBAR assembly movement and handling is similar to processes being used at the plant to move BPRAs.

Off-Site Shipping of TPBAR

After removal from the fuel assemblies, TVA will load TPBARs into a consolidation canister, which will be loaded into a shipping cask. Off-site shipment of TPBARs is not a TVA responsibility and will be executed by DOE or an agency assigned by DOE.

One approach for loading and shipping the TPBAR clusters requires a cask outfitted in a manner similar to that used for the LTA shipment. For a larger number of TPBARs, a shipping cask may be manufactured to receive a consolidation canister capable of holding up to 300 TPBARs. A crane will be used to handle the cask in the facility in accordance with plant procedures and requirements for handling heavy loads in safety related areas.

Conclusions

The process of consolidating TPBARs into a consolidation canister for loading into a shipping cask is a new step and involves new equipment. (See Section 1.5.1.) Analyses have been performed to evaluate the effect of damage to a dropped assembly and a dropped canister. The consequences of these accidents are within regulatory limits..

TPBAR Absorber Material Relocation

An evaluation of the neutron radiographs for the LTA TPBARs irradiated in Watts Bar confirmed that there was minor cracking of pellets with no evidence of loss of pellet integrity from irradiation and handling. The neutron radiographs also revealed a slight amount of absorber material missing from the top edge of a few pellets in 7 of the 32 irradiated TPBARs. A qualitatively comparable volume of loose absorber material was observed on the bottom getter disk. The maximum volume of loose material in a single TPBAR was estimated to be less than 0.05 cm^3. As noted in Section 3.4.3, this loose material does not create a neutronics problem, nor does melting of the loose material occur. Further destructive analysis of the pellets will be performed over the next year. No densification or phase changes of the absorber ceramic over the temperature range of the operating conditions was observed from earlier tests and nothing in the observations of the LTA TPBARs to date would indicate that such effects will be found.

Conclusions

Some minor cracking of pellets was observed and a small amount of pellet material was found to have relocated to the bottom of some of the LTA TPBARs. This material is believed to have been abraded from the edge of the top lithium aluminate pellets during fabrication. Implementation of an improved getter end forming process for the production core TPBARs is expected to reduce the potential for these small chips. As noted in Section 3.4.3, the minimal amount of material involved does not create a problem for reactor operations.

Loss of Coolant Events

During a cold leg break, substantial heat-up of the TPBAR cladding is possible. As discussed in Section 3.8.3.2, cladding breach can occur at LOCA conditions if the cladding temperature and internal pressure of the TPBARs reach limiting values. Consequently, post-LOCA critical boron calculations were performed for the Watts Bar TPC equilibrium cycle which conservatively assumed that all the TPBARs would fail (except for those in low power, low temperature locations on the core periphery) with resultant leaching of 50% of the lithium and loss of 12 inches of $LiAlO_2$ pellets. The calculations demonstrated subcritical margin throughout the cycle. There are several conservatisms in this analysis. First, at the time in life when the margin is at a minimum, TPBAR failures would not be anticipated due to the low internal pressure of the TPBARs. In addition, it is expected that the control rods will insert for a cold leg break due to the low forces on the reactor upper internals, providing additional subcriticality margin. For a hot leg break, although the control rods may not insert, heat-up of the TPBAR cladding is expected to be insignificant with the result that no TPBAR failures (and subsequent loss of lithium) occur.

Conclusions

In conclusion, subcriticality margin is predicted for the Watts Bar TPC designs. Identification of conservative assumptions in the analysis supports the expectation that subcriticality will be maintained post-LOCA. See Section 2.15.5.4 for further discussion of this analysis.

Handling Damage of TPBARs

Calculations performed to support the design of a consolidation container indicate that a TPBAR can survive a drop from a height of ~1.7 feet without significant damage. Calculations also show that a consolidation canister filled with TPBARs (~300) can survive a lateral acceleration limit of 50 g and an axial acceleration of 60 g, thus TPBAR damage will not occur as a result of normal handling and shipping operations.

To quantify the release of tritium from a breached irradiated TPBAR in the spent fuel pool as a result of mishandling, PNNL conducted laboratory tests with irradiated lithium aluminate absorber pellets in both deionized and borated water to simulate spent fuel pool composition. The rate for leaching tritium from irradiated absorber pellets in simulated PWR spent fuel pool water at 24°C and 93°C demonstrated that if a handling accident resulted in simultaneous breaching of 24 TPBARs (one full baseplate) in the spent fuel pool, the tritium concentration in the pool will remain below the 60 TCi/ml TVA action level at all times following the breach. Following such an event, TVA will take the necessary steps to stop the leaching of tritium and return tritium levels in the SFP to normal.

Conclusions

The effects of handling damage have been found to be acceptable from a radiological release and plant operations point of view.

3.8 MATERIALS EVALUATION

3.8.1 Material Specification

The TPC Topical Report description of the liner was a "Zircaloy-4" material. Because the function of the liner can be met by most zirconium alloys, the production TPBAR specification for the liner material has been revised to "a zirconium alloy". Commercial ASTM standards are used for procuring and fabricating the 316 SS cladding and end plugs, the zirconium alloy liner and getter, nickel plating of getters, the plenum spring and spring clip. The applicable standards are summarized in Table 3.8-1.

Conclusions

The change in material specification for the liner from Zircaloy-4 to zirconium alloy provides greater flexibility to the TPBAR fabricator in obtaining liners and has no impact on the function of the liner or its compatibility with other internal materials.

3.8.3.1 Material Compatibilities for Normal and Accident Conditions

Cladding Defects

TPBARs are designed and fabricated to the same high quality standards as fuel rods. Therefore, catastrophic failures of TPBARs during Conditions I, II and III are not expected to occur. Any failures under these conditions are anticipated to be minor fabrication or weld defects, such as pin-hole leaks, with very little likelihood of lithium leaching from the failed rod into the RCS.

Should a TPBAR fail catastrophically during reactor operation, it is conservatively assumed that all lithium is immediately leached from the TPBAR. Even with this assumption, during normal operation, power peaks in adjacent fuel due to such cladding defects will not result in a departure from nucleate boiling (DNB) or fuel failure. TVA has requested that DOE perform additional tests to provide a better understanding of the leach rate and total amount of material that may be leached under these conditions. It is expected that the results of this testing will allow some of the conservatism to be removed from the current assumptions. See Section 3.7.3 for further discussion of failure analyses and the impacts of TPBAR failure.

The lithium from pellet leaching added to the normal lithium content of the RCS has an insignificant effect on the pH.

Both the 302 SS plenum spring and the zirconium alloy spring clip are non-reactive with the other TPBAR components. These components are essentially insoluble in reactor coolant and a negligible amount will dissolve into the coolant in the event of a cladding breach.

3.8.3.2 Material Compatibilities following A Large Break Loss of Coolant Accident

Reference 1 noted that limited lithium leaching would occur from a TPBAR in the event of cladding failure. This conclusion was based on limited published information. PNNL recently performed tests for leaching of irradiated absorber pellets under controlled conditions of water composition and temperature similar to what would be expected in a post-Large Break Loss of Coolant Accident (LBLOCA) environment. The pellets did not dissolve, but lithium leaching from TPBAR-like configurations was observed to occur at a rate of <3%/day. Leaching from pellets approached a maximum level of ~50% of the lithium present at the start of leaching.

During a LBLOCA, those TPBARs which experience conditions of high internal pressure coupled with high cladding temperature will rupture. For accident analyses, it is conservatively assumed that up to

50% of the lithium present at the time of the LBLOCA will eventually be leached from ruptured TPBARs. Based on rupture tests performed by PNNL, it is conservatively assumed that no more than one pencil worth (~12") of lithium aluminate absorber pellets may be ejected from the TPBAR at the time of rupture. Analyses demonstrate that the reactor can be maintained in a safe shutdown condition under these circumstances. TVA has requested that DOE perform additional prototypic testing to confirm the conservative assumption of pellet ejection. See Sections 2.15.5.4 and 3.7.3.

Conclusions

The effects of cladding defects on material compatibilities have been evaluated and found to be of minimal consequence under conditions of normal plant operation and accident conditions.

Table 3.8-1 TPBAR Materials and Assembly Specifications

Component	Applicable Material Specification	Associated ASTM Standards
Pressure Boundary		
316 SS Bar Stock	TTQP-1-075, Alloy Grade UNS S31600	ASTM A831/A831 M-95 and ASTM A484/A484 M-94b
316 SS Top and Bottom End Plugs	TTQP-1-079, TTQP-1-080, and TTQP-1-083	ASTM A831/A831 M-95 and ASTM A484/A484 M-94b
316 SS Seamless Cladding Tubes	TTQP-1-072	ASTM A 771-95
Aluminized Cladding Inner Surface	PNNL-TTQP-1-692	
Absorber Pellets		
Enriched Annular $LiAlO_2$ Pellets	TTQP-1-076	
Getter Tubes and Disks		
Zirconium Alloy Stock Getter Tubes	TTQP-1-073	ASTM B353-95
Zirconium Alloy Getter Disks	TTQP-1-086, TTQP-1-074	ASTM B352-1997
Zirconium Alloy Stock Top and Bottom Spacer Tubes	TTQP-1-073	ASTM B353-95
Nickel Plating	PNNL-TTQP-1-826	ASTM B689-97
Liners		
Liner Tubes	TTQP-1-077	ASTM B353-95
Springs		
Plenum Springs	TTQP-1-078	ASTM A313-95a
Spring Clips	TTQP-1-089	ASTM B352-97
TPBAR Assembly		
Spacer and Pencil Assembly	PNNL-TTQP-1-688	
Target Rod Final Assembly	PNNL-TTQP-1-690	

3.10 POST-IRRADIATION EXAMINATIONS FOR THE LTA TPBARS

Reference 1 identified steps to be taken by the Department of Energy (DOE), Tennessee Valley Authority (TVA), and Pacific Northwest National Laboratory (PNNL) to evaluate performance of the Tritium-Producing Burnable Absorber Rods (TPBARs) after the irradiation of the Lead Test Assemblies (LTAs) in cycle 2 of the Watts Bar Nuclear Power Plant (WBN). Following is a summary of monitoring and evaluation that have been performed.

Summary

Based on monitoring performed during the 18-month irradiation cycle in WBN, the TPBARs performed as expected during irradiation. WBN experienced no difficulties during the cycle attributable to the LTAs. Evaluation of the tritium concentrations in the reactor coolant has concluded that the LTA irradiation met its design goal of releasing less than 6.7 Ci/TPBAR/year. Following irradiation and shipping for post-irradiation examination, the TPBARs were intact and undamaged.

Visual examination of the TPBARs in the WBN spent fuel pool (SFP) showed no visible indications of damage to the rods or unusual amounts of corrosion. The TPBARs were easily removed from their host fuel assemblies and reinserted into shipping arrays, thus indicating no unusual growth, bow, or other physical distortion as a result of irradiation.

Nondestructive examinations (NDE) at Argonne National Laboratory-West confirmed that the cladding of all 32 TPBARs remained intact during irradiation and post-irradiation handling and shipping. Neutron radiography and full-length axial spectral gamma scanning confirmed the physical state of the "pencils" and pellet stacks and the physical integrity of internal components.

Analysis of measured rod gas pressures, void volumes, and gas composition confirmed that the TPBAR internal components functioned as designed; that is, the tritium production was as expected and the tritium was contained in the internal components. This qualitative conclusion will be quantified through the destructive examinations to be performed at PNNL.

In summary, the irradiation was completed without any adverse impacts on reactor operation or on the TPBARs. All LTA expectations were met.

Performance During Irradiation and Storage

During the period of time the TPBARs were resident in the WBN core, TVA performed weekly monitoring of the reactor coolant for tritium concentration. As stated in Reference 1, tritium loss from the TPBARs cannot be specifically measured due to the presence of tritium from other sources in the reactor core. However, an evaluation of the measured tritium concentrations in the reactor coolant concluded that the LTA TPBARs met their design goal of releasing less than 6.7 Ci/TPBAR/year.

In preparation for shutdown of WBN from cycle 2, PNNL requested that TVA take samples of spent fuel pool (SFP) water and measure tritium concentration levels in the SFP prior to and after placing the LTAs in the SFP. This monitoring began two weeks before shutdown, with daily samples taken prior to placing the TPBARs in the SFP and then on a weekly basis for the entire time the TPBARs were in the SFP

(March 1999-September 1999). Monitoring indicated no change in tritium concentration during the time the TPBARs were stored.

Nondestructive Examinations

Nondestructive examinations of the irradiated TPBARs are described in Section 3.10.2 of the TPC topical. This work was performed by Argonne National Laboratory-West on the Idaho National Engineering and Environmental Laboratory (INEEL) site, beginning in September 1999 and was completed in June 2000. The following nondestructive examinations were performed on all 32 TPBARs at ANL-W.

- Visual examination and photography: All TPBARs were examined visually over the full length in at least two orthogonal orientations. Handling scratches, variations in the oxide appearance, and small amounts of crud deposit were observed. No damage to the cladding was observed.

- Rod length, diameter, and bow measurement: Post-irradiation diameters were approximately the same as pre-irradiation; TPBAR lengths increased approximately 0.1 inch during the irradiation, which was less than allowed for in the design; and maximum TPBAR bow was less than 0.5 inch.

- Axial gamma scanning: Axial profiles of activation products in the TPBARs confirmed the axial power profile for the irradiation. Uniform gamma activities among the TPBARs confirmed the relatively flat distribution of power across the LTAs.

- Neutron radiography: All rods were neutron radiographed over their entire length. These radiographs provided a good "picture" of the axial location and physical state of the pencils and the absorber pellet columns. The radiographs confirmed that the internal components maintained their physical integrity during irradiation and post-irradiation shipping and handling. Cracked absorber pellets were observed but they were maintained in position by the getter and liner. No opening of axial gaps between pencils or between pellets was observed.

- Rod puncture: All TPBARs were punctured; void volume and gas pressure were measured; and gas composition was measured. Analysis of the void volumes, gas pressures, and gas compositions confirmed the predicted tritium production, i.e., tritium production derived from these data agreed with the predicted tritium production. Analysis of the gas composition also confirmed that the internal components performed their function of retaining the tritium.

- An insignificant amount of loose absorber material was found at the bottom of some TPBARs; see Section 3.4.3 for a further discussion.

LTA Destructive Examinations and Results

Four of the 32 LTA TBPARs are being destructively examined by PNNL. The objectives of the examinations include confirming the lithium-6 burnup, evaluating the physical condition of the internal components, and evaluating the distribution of retained tritium within the TPBAR components. Small sections are cut from the TPBARs and then the individual components (cladding, getter, pellet, and liner) are separated. Mass spectrometry is used to measure the lithium isotopic ratios in pellet samples. Optical metallography and scanning electron microscopy are used to examine the physical condition of selected components. Assays for tritium, hydrogen, and helium concentrations in selected component samples are performed.

Confirmation of TPBAR integrity during irradiation was obtained from the NDE results. The destructive examination (DE) data will be used to refine design assumptions on TPBAR performance and provide additional benchmark data for design models. The benchmarked design models may be used to support future design modifications and assessments of changing operating conditions on TPBAR performance.

Tritium, hydrogen, helium, and lithium isotopic assays have been performed on samples obtained from the upper two-thirds of the first TPBAR to be destructively examined (June 2001). The balance of the examination work for all four TPBARs is scheduled to be completed by the end of December 2001.

Preliminary analyses of the DE data collected through June 2001 are confirming the in-reactor performance of the TPBARs determined from the NDE data. Measured lithium-6 burnout is consistent with tritium production determined from the NDE data. Overall tritium performance, based on both the NDE and DE data, is consistent with expectations.

3.11 TPBAR SURVEILLANCE

During TPBAR irradiation, periodic review of the reactor coolant activity measurements taken as part of the plant operation will be performed. Specifically, a review of the tritium activity data for tritium concentration in the reactor coolant system will be measured during normal monitoring of the RCS chemistry as described in Section 2.11.3.

Catastrophic failure of one or more TPBARs during operation will result in an evaluation for continued operation. This evaluation will consider the impact of TPBAR failure on fuel assembly power peaking. This evaluation, when required, will be completed within five days of discovery.

Reference 1 stated that a number of irradiated TPBARs would be shipped to a DOE-specified site for additional post-irradiation examinations after the first production cycle. Based on the performance of the LTA TPBARs, TVA does not foresee a need to perform post-irradiation examinations of additional TPBARs following the first production cycle. From the in-reactor data and non-destructive post-irradiation examinations that have been performed on all 32 LTA TPBARs, there do not appear to have been any unusual performance characteristics. Therefore, unless something unusual is observed in the first production cycle that would question TPBAR performance, this additional testing will not be performed. For post refueling outage surveillance, see Section 2.14.2, "Initial Test Program."

Conclusions

A plant surveillance program will be developed by TVA to identify any problems attributable to operation with TPBARs. Unless problems are identified that would require further post-irradiation examinations, TVA does not propose to do additional testing following the first production cycle. There is no impact to personnel or public safety as a result of the elimination of the post-irradiation examinations.

3.12 SUMMARY AND CONCLUSION

The TPBAR as evaluated meets accepted and conservative criteria as a core component in the 17x17 type fuel assemblies inserted in the TVA reactors to be used for tritium production (WBN and SQN-1 and -2). The primary functions of TPBARs located in guide thimble tubes which are not under a CRDM are:

- To absorb neutrons as part of the fuel cycle reactivity control
- To produce and contain tritium

The TPBARs perform their function with acceptable margin to failure during normal operation and in conjunction with design-basis accidents:

- As a core component, the TPBAR does not initiate or increase the severity of an accident but has the potential to affect the radiological consequences of some accidents.
- The consequences of TPBAR cladding failure have been evaluated and can be accommodated by other systems.
- The TPBARs are compatible with 17x17 assemblies operated in a high power density (up-rated) core of the TVA reactors to be used for tritium production. They are attached to specially designed fuel assembly baseplates, are inserted in guide thimbles and are compatible with the fuel assemblies.
- Analysis and comparison with equivalent core component assemblies have shown that the TPBAR will not fail during normal operation and Condition I through IV events, with the exception of a Large Break LOCA and the Fuel Handling Accident. During the Large Break LOCA, TPBARs may fail under conditions of high internal pressure and high cladding temperature.
- The tritium release from TPBARs can be accommodated by the plant systems. The enveloping tritium releases provided as input to the tritium release consequence evaluations are considered conservative.
- TPBARs use materials with known and predictable characteristics in reactor performance and are compatible with the reactor coolant system.
- Detection of excess tritium concentration in the reactor coolant during periodic surveillance will trigger evaluations to ensure safety margins are adequate for continued normal operation or operation during a moderate frequency event.
- All significant consequences of assumed TPBAR failures (without identifying failure mechanism) were considered during normal operation and accident conditions and found to be acceptable.
- The thermal-hydraulic evaluation has shown that TPBARs operate within established thermal-hydraulic criteria.

The evaluation of the production TPBARs incorporates the methodology developed for the TPC TPBARs, including comments raised during the NRC review of the TPC Topical Report, as documented in the TPC Topical Report and the NRC SER.

3.13 REFERENCES

1. NDP-98-181, Revision 1, "Tritium Production Core (TPC)," Unclassified, Non-proprietary version, dated February 8, 1999 by Westinghouse Electric Company.
2. TTQP-7-008, Revision 2, "Material Properties Handbook for the Tritium Target Qualification Project," Pacific Northwest National Laboratory, August 21, 1998.
3. A. Strasser, et al., "Control Rod Materials and Burnable Poisons, An Evaluation of the State of the Art and Needs for Technology Development, July 1980," NP-1974, Edison Power Research Institute, November 1981.

4 PLANT SPECIFIC CONFIRMING CHECKS

The DOE Tritium Production Core Topical Report identified a number of Standard Review Plan items for which a plant specific confirming check was recommended. Table 4-1 summarizes the confirming checks performed for the Watts Bar TPC which resulted in no impact to the plant.

Table 4-1 Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
3.9.1 Special Topics for Mechanical Components	3.9.2	2.3.2	Confirming check recommended for LAR. Response: The pertinent operating parameters (NSSS power, RCS flow, RCS temperatures, steam temperature, feedwater temperature, and steam flow) for the TPC are unchanged from those previously evaluated. Therefore, the existing NSSS design transient curves remain valid.	No Impact
3.9.2 Dynamic Testing & Analysis of Systems, Components & Equipment	3.9.2	2.3.3	Confirming check recommended for LAR. Response: The pertinent operating parameters for the TPC are unchanged from those previously evaluated. The added TPBAR assembly weight, together with the rodlet stiffness, has an insignificant effect on the fuel assembly's dynamic characteristics. The LOCA forces analysis input relative to fuel assembly thimble tube modeling remains bounding for assemblies with or without TPBARs. Therefore, the existing LOCA forces and Flow Induced Vibration evaluations remain applicable.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
3.9.3 ASME Code Class 1, 2 & 3 Components, Component supports, and Core support Structures	3.9.3	2.3.4	Confirming check recommended for LAR, for structural analysis of components. Auxiliary components for spent fuel pit should be reviewed to confirm that design temperatures bound maximum expected temperature. Response: The pertinent operating parameters for the TPC are unchanged from those previously evaluated. The existing NSSS design transient curves remain valid. The existing LOCA forces and Flow Induced Vibration evaluations remain applicable. The existing spent fuel pit design temperatures bound the maximum expected temperatures with the TPC. Therefore, the TPC has no adverse effect on the component (i.e., steam generator, pressurizer, piping and supports, reactor coolant pumps, reactor vessel, and auxiliary heat exchangers, tanks, pumps and valves) structural analyses.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
3.9.4 Control Rod Drive Mechanism Design	3.9.4	2.3.5	Confirming check recommended for LAR. Response: The pertinent operating parameters for the TPC are unchanged from those previously evaluated. The existing NSSS design transient curves remain valid. Therefore, the TPC has no adverse effect on the CRDM.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
3.9.5 Reactor Internals Design	3.9.5	2.3.6	Plant specific evaluation recommended for LAR. Response: The T/H evaluation of the Watts Bar reactor internals demonstrated that the core bypass flow, upper head fluid temperature, hydraulic lift forces, and momentum flux are unaffected by the presence of the TPC. The pertinent operating parameters for the TPC are unchanged from those previously evaluated. The existing NSSS design transient curves remain valid. The existing LOCA forces and Flow Induced Vibration evaluations remain applicable. The gamma heating rates which were used in the current evaluations of the baffle-barrel region, the upper core plate and the neutron pad remain applicable. The gamma heating rates seen by the lower core plate increase for the TPC, but an evaluation showed acceptable margins of safety and fatigue utilization factors for all ligaments under all loading conditions. Therefore, the reactor internals will continue to perform their intended design functions for the TPC.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
3.11 Equipment Qualification	3.11.7.1	2.3.7	Confirming check recommended for LAR. Response: For the Tritium Production Core (TPC) the radiation exposure inside containment after a design basis LOCA was calculated based on a release to the containment atmosphere of 100% of the core inventory of noble gases, 50% of the core inventory of iodine, 1% of the core inventory of solid fission products, and 100% of tritium as determined by the ORIGEN2.1 computer code. Following the same methodology as previously utilized, the resulting doses were determined to be less than those resulting from the previous determinations. Assessments of the mass and energy releases associated with a TPC, for postulated LOCA and secondary system pipe ruptures, demonstrate that they are bounded by the values for a non-tritium- producing core.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
4.6 RCCA Drop Time Evaluation	4.2.3	2.4.5	Confirming check recommended for LAR to verify acceptable results. Response: An analysis performed for the TPC design conditions concluded that the TPC has no effect on the RCCA drop time relative to the uprated WBN core design.	No Impact
5.2.2 Overpressure Protection	5.2.2	2.5.2	Plant-specific evaluation of App. G limit (and potential impact on COMS) recommended for LAR. Response: The pertinent operating parameters for the TPC are unchanged from those previously evaluated. In addition, as discussed in Section 1.5.4, the existing reactor vessel integrity analyses, including the reactor vessel Appendix G limits, remain valid for the TPC. Therefore, the existing COMS analyses and setpoints remain applicable for the Tritium Program.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
5.4.7 Residual Heat Removal System	5.5.7	2.5.4	Plant specific evaluation of the net effect of TPC on RHR System cooling capability is recommended. Response: An analysis has quantified the actual TPC impact on core heat loads at approximately 0.3 MWt. This value represents approximately 1% of the heat load imposed on RHRS during the cooldown period. A review of the RHRS design basis heat load analysis, performed to assess the actual impact of a 1% increase in core decay heat, showed that there is no significant impact on RHRS.	No Impact
6.1.2 Protective Coating Systems	6.1.2	2.6.1	No plant-specific evaluation for LAR if no impact on post-accident EQ conditions for candidate plant. Response: Post-accident EQ conditions for TPC operation will not affect coatings or organic materials.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
6.2.1 Containment Functional Design 6.2.2 Containment Heat Removal Systems	6.2.1 6.2.2	2.6.1 2.6.2 2.6.3 2.6.4	Plant-specific confirmation that core stored energy (and, therefore, M/E releases) do not increase is recommended for LAR. Response: A confirming check has been performed which showed that the key safety analysis parameters (moderator density coefficients and shutdown margin) used in the WBN safety analyses for steamline and feedline break M&E releases bound the TPC design values. In addition, the NSSS performance parameters remain unchanged from those previously evaluated. Therefore, the licensing-basis analyses of record for the high-energy secondary-side line breaks remain valid, and the conclusions with respect to M&E releases and the associated pressure and/or temperature response also remain valid for the TPC. A confirming check of the impact of the TPC on the LOCA M&E releases concluded that the vessel temperatures, core stored energy, core pressure drop, and decay heat model used in the LOCA M&E analyses remain applicable for the TPC. Therefore, the current licensing basis analyses remain applicable. There is no adverse impact due to the TPC on the M&E releases to containment.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
6.3 Emergency Core Cooling System	6.3.2.4 6.3.3.15	2.6.1	Confirm no impact on post accident EQ conditions for candidate plant. Response: The current equipment qualification bounds the expected conditions with the TPBARs.	No Impact
6.5.3 Fission Product Control Systems and Structures	6.5	2.6.1 2.15.6	A plant-specific evaluation is recommended for the LAR. Response: The assumed containment design leakage rates, isolation methods and times will remain the same as specified in each of the plant's design basis and will not impact the calculated doses for a design basis LOCA.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
7.2 Reactor Trip System 7.3 Engineered Safety Features System	7.2 7.3	2.7.2	For LAR, a plant-specific core design will be prepared. If one of the goals is to optimize on fuel usage, safety analysis input parameters could change, requiring a change to the protection system setpoints. Therefore, a review of this area is recommended. Response: As discussed in Section 2.4.3, most of the key safety analyses parameters for the WBN TPC core design remained within the current WBN ranges. The exception was the least negative Doppler-Only Power Coefficient for the Steam Line Break with Coincident Rod Withdrawal at Power. An evaluation of this transient showed that the safety analysis limit did not need to be changed. Nominal plant operating conditions and power peaking factors are unchanged from those previously evaluated. Therefore, no changes are required for the reactor trip setpoints or the engineered safety features actuation setpoints.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
7.4 Safe Shutdown Systems 7.5 Information Systems Important to Safety	7.4 7.5	2.7.3	For the LAR, if the candidate plant employs bottom mounted thermocouples, it is recommended that the process measurement effects for post accident monitoring be revalidated with TPBARs accounted for. If not, no plant-specific evaluation is recommended. Response: WBN has top mounted thermocouples, thus no additional evaluation required for TPC.	No Impact
7.7 Operational Transients/Margin to Trip	7.7	2.7.4	For LAR, a plant-specific evaluation is recommended if: the NSSS performance parameters change, the protection system setpoints change, or the fuel reactivity changes are significant with the TPC. Response: The WBN TPC does not result in changes to the NSSS performance parameters or the protection system setpoints. A comparison of core design reactivities for a typical WBN core design to those for the WBN TPC resulted in the conclusion that there are no significant differences. Therefore, the TPC will not materially affect the plant response for normally expected plant operability transients.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
Ch. 8 Electric Power	3.11 8.3.1.2.3 8.3.1.4.1 8.1.4 8.1.5	2.8	Confirm no impact on post-accident EQ conditions for candidate plant. Response: The safety related electrical equipment that must operate in a hostile environment (both inside and outside containment) has been evaluated against the environmental conditions associated with a TPC. It has been determined that the equipment will continue to perform its intended functions.	No Impact
Ch. 10: Steam and Power Conversion System	10	2.10	No plant-specific evaluation is recommended for the LAR, unless the NSSS performance parameters are modified to accommodate the TPC. Response: The NSSS performance parameters are unchanged from those previously evaluated, therefore there are no impacts on the steam and power conversion systems.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
15.1.1-15.1.4 Decrease in Feedwater Temperature, Increase in Steam Flow, and Inadvertent Opening of a steam Generator Relief or Safety Valve.	15.2.10 15.2.13	2.15.1 2.15.2.5	Confirming check recommended for LAR. If any key input parameters change (as was the case for the reference plant), reanalysis of affected events is recommended. Response: There are no changes to the nominal plant operating conditions (power, coolant temperature, pressure and flow rate) assumed in the existing plant safety analyses. There are no changes to the reactor core thermal hydraulic characteristics or power peaking factors which could affect the core thermal limits. The TPC design has not changed any of the bounding values assumed for the key safety analysis parameters used in the WBN UFSAR analyses for any of these events. Therefore, the WBN safety analysis for each of these events is unaffected by the TPC design.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
15.1.5 Steam System Piping Failures Inside and Outside of Containment	15.4.2.1	2.15.2.5	Confirming check recommended for LAR. Response: There are no changes to the nominal plant operating conditions (power, coolant temperature, pressure and flow rate) assumed in the existing plant safety analyses. There are no changes to the reactor core thermal hydraulic characteristics or power peaking factors which could affect the core thermal limits. The TPC design has not changed any of the bounding values assumed for the key safety analysis parameters used in the WBN UFSAR analyses for any of these events. Therefore, the WBN safety analysis for each of these events is unaffected by the TPC design.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
15.2.1-15.2.5 Loss of External Load, Turbine Trip, Loss of Condenser Vacuum, Closure of Main Steam Isolation Valve, and Steam Pressure Regulator Failure (Closed)	15.2.7	2.15.2.6	Confirming check recommended for LAR. Response: There are no changes to the nominal plant operating conditions (power, coolant temperature, pressure and flow rate) assumed in the existing plant safety analyses. There are no changes to the reactor core thermal hydraulic characteristics or power peaking factors which could affect the core thermal limits. The TPC design has not changed any of the bounding values assumed for the key safety analysis parameters used in the WBN UFSAR analyses for any of these events. Therefore, the WBN safety analysis for each of these events is unaffected by the TPC design	No Impact
15.2.6 Loss of Nonemergency AC Power to the Station Auxiliaries	15.2.9	2.15.2.6		
15.2.7 Loss of Normal Feedwater Flow	15.2.8	2.15.2.6		
15.2.8 Feedwater system Pipe Breaks Inside and Outside of Containment	15.2.2.2	2.15.2.6		
15.3.1-15.3.2 Loss of Forced Reactor Coolant Flow Including Trip of Pump Motor and Flow Controller Malfunctions	15.2.5 15.3.4	2.15.2.7		
15.3.3-15.3.4 Reactor Coolant Pump Rotor Seizure and Reactor Coolant Pump Shaft Break	15.4.4	2.15.2.7.3 2.15.2.7.4 2.15.6.4		
15.4.1 Uncontrolled Control Rod Assembly Withdrawal from a Subcritical or Low Power Startup Condition	15.2.1	2.15.2.8.1		
15.4.2 Uncontrolled Control Rod Assembly Withdrawal at Power	15.2.2	2.15.2.8		
15.4.3 Control Rod Misoperation	15.2.3	2.15.2.8		
15.4.4 Startup of an Inactive Loop or Recirculation Loop at an Incorrect Temperature	15.2.6	2.15.2.8.2		
15.4.6 Chemical and Volume Control System Malfunction that Results in a Decrease in Boron Concentration in the Reactor coolant	15.2.4	2.15.8.2		

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
15.4.7 Inadvertent Loading and Operation of a Fuel Assembly in an Improper Position	15.3.3	2.15.3	Core-specific evaluation recommended for LAR. Response: Inadvertent loadings are prevented by fuel manufacturing and core loading administrative controls. Analysis of inadvertent loading scenarios in the WBN UFSAR and the TPC Topical Report has shown that credible scenarios result in power distribution perturbations that either are small enough such that design limits are met or large enough that detection is likely. Therefore, inadvertent loading scenarios with power distribution perturbations substantial enough to challenge the fuel rod failure limit for this event would be readily detected during routine startup testing.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
15.4.8 Spectrum of Rod Ejection Accidents	15.4.6.3	2.15.2.8.3	Confirming check recommended for LAR. Response: There are no changes to the nominal plant operating conditions (power, coolant temperature, pressure and flow rate) assumed in the existing plant safety analyses. There are no changes to the reactor core thermal hydraulic characteristics or power peaking factors which could affect the core thermal limits. The TPC design has not changed any of the bounding values assumed for the key safety analysis parameters used in the WBN UFSAR analyses for any of these events. Therefore, the WBN safety analysis for each of these events is unaffected by the TPC design.	No Impact

Table 4-1 (cont.) **Summary of Performed Confirming Checks**

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
15.5.1-15.5.2 Inadvertent Operation of ECCS and Chemical and Volume Control System Malfunction that Increases Reactor Coolant Inventory	15.2.14	2.15.2.9	Confirming check recommended for LAR. Response: There are no changes to the nominal plant operating conditions (power, coolant temperature, pressure and flow rate) assumed in the existing plant safety analyses. There are no changes to the reactor core thermal hydraulic characteristics or power peaking factors which could affect the core thermal limits. The TPC design has not changed any of the bounding values assumed for the key safety analysis parameters used in the WBN UFSAR analyses for these events except for the increase in the RWST boron concentration. For the Inadvertent Operation of ECCS event (DNB case) an increase in the boron concentration would result in a decrease in reactor power, hence a decrease in coolant temperature and pressure. The decrease in power and coolant temperature result in a benefit to the DNBR, while a decrease in pressure results in a decrease in DNBR. The opposing DNB trends offset each other, resulting in no impact to the DNB case due to the increase in RWST boron concentration.	No Impact

Table 4-1 (cont.) Summary of Performed Confirming Checks

SRP Chapters & Sections	Affected WBN FSAR Sections	DOE Topical Report Section	Topical Report Recommendation Evaluation Results	Impact Summary for WBN
15.6.1 Inadvertent Opening of a PWR Pressurizer Pressure Relief Valve	15.2.12	2.15.2.10	Confirming check recommended for LAR. Response: There are no changes to the nominal plant operating conditions (power, coolant temperature, pressure and flow rate) assumed in the existing plant safety analyses. There are no changes to the reactor core thermal hydraulic characteristics or power peaking factors which could affect the core thermal limits. The TPC design has not changed any of the bounding values assumed for the key safety analysis parameters used in the WBN UFSAR analyses for any of these events. Therefore, the WBN safety analysis for each of these events is unaffected by the TPC design.	No Impact
15.7.5 Spent Fuel Cask Drop Accidents	3.8.4 9.1.2.6 15.5.6	2.15.1	Confirming check recommended for LAR. Response: The cask handling accidents associated with the production of Tritium involve a Legal Weight Truck (LWT) Cask. Cask handling over the spent fuel pool is prevented by interlocks. In addition, because of an equivalent single-failure-proof crane, cask-drop is not considered to be a credible accident.	No Impact