NRC Request for the Criticality Analysis of the Worst Degraded Storage Cell

NRC Request

Provide a summary of the analysis performed that concluded that the most reactive fuel assembly available could be safely placed in the most degraded cell, without credit for either soluble boron or interim compensatory measures, and Keff would be <1.0.

FPL Response

Summary:

The purpose of this analysis is to provide an assessment of the conservative margin in the Turkey Point Boraflex Management Program. The compensatory actions currently in place add substantial margin to criticality. This analysis was done to demonstrate the conservative nature of our program and shows that the unborated Keff has been maintained < 1.0, even without compensatory actions. The analysis uses the Boraflex panels in the worst degraded storage cell with the highest reactivity fuel assemblies available for storage in Region II of the Unit 3 spent fuel pool (SFP).

The results show:

Keff with the Most Reactive Available Fuel in Most Degraded Cell (unborated)	
Licensing Basis Analysis	Keff = 0.99919
Without Compensatory Measures	Keff = 0.99369
With Compensatory Measures	Keff < 0.80

Nonetheless, the Turkey Point Boraflex Management Program has managed this worst degraded storage cell under administrative control since 2001 with a compensatory measure that provides significant reactivity margin (Keff <0.80, unborated) without crediting any Boraflex in and around the storage cell. This provides significantly more margin to criticality that the current licensing basis analysis.

Analysis:

Worst Degraded Storage Cell Configurations

FPL developed and analyzed two worst degraded storage cell configurations for the Turkey Point Unit 3 spent fuel pool:

- Using worst degraded storage cell in all locations
- A storage cell using worst degraded storage cell, surrounded by the second worst degraded storage cell in all the remaining locations; areal densities in worst

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degraded storage cell modified based on maximum RACKLIFE under-prediction observed and 95/95 statistical model RACKLIFE over-prediction

The worst and second worst storage cells are selected based on the RACKLIFE model predictions. The cells were selected based on the RACKLIFE projection to 9/26/10, the currently scheduled start of the next Turkey Point Unit 3 outage. The selection is based on the cumulative dissolution of the four panels composing each storage cell; therefore, a cell that has one panel with severe dissolution may not be the worst degraded storage cell as the other three panels in that storage cell may not be predicted to have significant dissolution. It should be noted that FPL has performed statistical analyses on the RACKLIFE-BADGER benchmark statistics that show RACKLIFE over-predicts the cumulative panel degradation in a storage cell by at least 10.4% with a 95% probability and 95% confidence level.

The worst degraded storage cell in the Turkey Point Unit 3 spent fuel pool as of 9/26/10 is predicted to be M16, in Region II. Although other storage cells may have one panel with higher dissolution than the panels in cell M16 (e.g., cell R19 had one panel measured to have an areal density less than 0.006 gms-B_{10}/cm^2 in 2004), the cumulative dissolution of all four panels in cell M16 was determined to be the most limiting, having the least amount of remaining Boraflex to control criticality.

The areal densities in the panels in cell M16 are determined using the 95/95 lower confidence limit as-built areal density of 0.015 gms-B_{10}/cm^2 as the initial areal density, combined with the RACKLIFE predicted percentage dissolution of each panel as of 9/26/10. The areal densities in the panels in cell M16 range from 0.00597 to 0.00603 gms-B_{10}/cm^2, as noted in Figure 1 below.

Figure 1 - Areal Densities for Storage Cell M16 on 9/26/10 (as predicted by RACKLIFE)

	0.00597	
0.00599		0.00597
	0.00603	

The second worst degraded storage cell in the Turkey Point Unit 3 spent fuel pool as of 9/26/10 was found to be P16, also in Region II. Same as for cell M16, the areal densities in the panels in cell P16 are determined using the 95/95 lower confidence limit as-built areal density of 0.015 gms-B_{10}/cm^2 as the initial areal density, combined with the RACKLIFE predicted percentage dissolution of each panel as of 9/26/10. The areal densities in the panels in cell P16 range from 0.00601 to 0.00607 gms-B_{10}/cm^2, as noted in Figure 2 below.

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Figure 2 - Areal Densities for Storage Cell P16 on 9/26/10 (as predicted by RACKLIFE)

	0.00605	
0.00601		0.00607
	0.00603	

As previously noted, the first configuration only uses the areal densities from the worst degraded storage cell, as shown in Figure 1.

The second configuration uses the areal densities from the worst and second worst degraded storage cells (Figures 1 and 2), as well as modification of the areal densities in the worst degraded cell to bound the situation of a panel being under-predicted by RACKLIFE. For the second configuration, a single panel in cell M16 was modified to include additional dissolution equal to the maximum RACKLIFE under-prediction from the three BADGER testing campaigns (35.1%). Therefore, one of the panels with areal density of 0.00597 gms-B_{10}/cm^2 was assumed to be degraded by an additional 35.1%. Since the panel had a RACKLIFE predicted dissolution of 60.2%, it was increased to 95.3%, for a areal density of 0.00071 gms-B_{10}/cm^2.

While one panel was assumed to be additionally more degraded than predicted by RACKLIFE, the other three panels in the cell were assumed to be degraded less than predicted by RACKLIFE. As previously noted, RACKLIFE over-predicts the cumulative panel degradation in a storage cell by 10.4%. Therefore, since one of the panels was reduced by 35.1%, the areal densities in the other three panels were increased by a cumulative 45.5% in order to have a representative storage cell conservative to a 95/95 level. The modified areal densities are noted in Figure 3 below.

Figure 3 - Panel Areal Density of Storage Cell M16 on 9/26/10 (modified with statistical model)

	0.00071	
0.00827		0.00824
	0.00831	

Both configurations identified in this section and used in the criticality analysis model are more conservative than a 95/95 representative model. For the first configuration, none of the panels were modified and were taken as predicted by RACKLIFE. For the second configuration, none of the panels in the surrounding cells were modified, and were taken as predicted by RACKLIFE. As mentioned, statistical analyses have shown that RACKLIFE over-predicts panel dissolution in a storage cell by a cumulative 10.4% with a 95% probability and 95% confidence level.

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Most Reactive Fuel Available

The most reactive fuel available in the SFP was selected by searching not only from the inventory currently in the SFP that is eligible for storage in Region II, but also from a review of the past two refueling outages for Unit 3. Four fuel assemblies from the Fall 2007 refueling outage were the closest (most reactive) to the enrichment vs. burnup limits of Technical Specification Table 3.9-1. These four assemblies were at an initial enrichment of 4.0 w/o and a burnup of 32,780 MWD/MTU (a difference of 976 MWD/MTU to the requirements of TS Table 3.9-1) as follows:

Table 1

Batch ID	Cycle	Number of F.A.	w/o U^{235}	Burnup (MWD/MTU)	Region II Burnup Requirement (MWD/MTU)	Delta MWD/MTU
AE	22	4	4.0	32780	31804	976

Although there are only 4 of these assemblies in the Unit 3 SFP, the criticality analysis described in the next section assumes that all fuel assemblies have these characteristics.

Criticality Analysis

A criticality analysis was performed to assess the Keff margin between the current licensing basis analysis and actual conditions of the Boraflex panels in the Turkey Point SFP.

The analysis was performed by Holtec and used the CASMO-4 and MCNP-4a criticality analysis computer codes. The modeling of the Turkey Point SFP using these codes was found to be appropriate in the Turkey Point licensing basis analysis of the Cask Area Rack and the Boraflex Remedy analysis performed for Turkey Point Units 3 and 4 (refer to License Amendments 234 and 229, previously approved by the NRC).

Using the established CASMO-4/MCNP-4a computer models of the Turkey Point fuel and SFP racks, the margin is determined by comparisons using the following steps:

- The initial step is a calculation with these methods that uses all the Boraflex parameters from the licensing basis calculations. This is then used as the reference case (Case 1), which is equivalent to the licensing basis calculation, while being numerically different from it.
- Various calculations are then performed with the same method, but with different parameters that are consistent with the actual situation in the SFP. For each

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calculation, the approximate margin is determined by comparison to the reference case from the initial step described above.

The analysis method used is characterized as follows:

- The CASMO-4 2-D depletion code determines the isotopic composition of the fuel for the given enrichment and burnup.
- The isotopic composition is then used in the MCNP-4a 3-D Monte Carlo calculation modeling the racks with a degraded Boraflex condition.
- The reference case uses the same degraded Boraflex condition of an areal density of 0.006 gms-B_{10}/cm^2 for all Boraflex panels as is used in the current licensing basis analysis. For the cases modeling actual conditions, the same axial distribution is used, but the areal density is varied.
- The purpose of the calculations is to produce a comparison of results from different cases, where all are performed with the CASMO-4/MCNP-4a methodology. For this methodology, the combined effects on reactivity of biases and uncertainties would be essentially identical between all cases. The reactivity difference can therefore be directly determined from the calculated k_{eff} values (k_{calc}), and it is not necessary to specifically quantify reactivity effects of the biases and uncertainty.

Major simplifying and/or conservative assumptions that affect the principal outcome of the calculations presented here, i.e. that affect the reactivity difference to the reference case, are as follows:

- All calculations are performed with uniform assembly specifications to permit simplification of the models. Conservatively, the assembly with the lowest burnup is used.
- Boraflex panels are grouped together by areal density for simplification of the model. Conservatively, panels with an areal density that is much lower than that of the licensing basis calculations are completely ignored and replaced by water. Conservatively, other panels are represented with an areal density that is the lowest in the respective group of panels.

The reference case is modeled using the same degraded Boraflex condition of an areal density of 0.006 gms-B_{10}/cm^2 for all Boraflex panels as is used in the current licensing basis analysis. The reference case also assumes that all storage cells contain a fuel assembly at the limiting Technical Specification allowable enrichment loading of 4.5 weight percent U-235 and at a minimum burnup of 36,746 MWD/MTU.

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Reference Panel Areal Density of Case 1

	0.006	
0.006		0.006
	0.006	

Two calculations are performed (Case 2 and Case 3), both of which use actual but bounding configurations in the SFP with respect to fuel assembly specifications and the Boraflex degradation condition. The parameters for these cases are conservatively modeled as follows:

- All fuel is modeled as the most reactive fuel described in Table 1 of the previous section; at an initial enrichment of 4.0 wt% and a burnup of 32,780 MWD/MTU.
- The model is a 5x5 array. The cell with the panel having the lowest areal density is located at the center of the array.
- Case 2 models the configuration of Figure 3 discussed in the previous section as the storage cell in the center of the 5x5 array. Case 2 conservatively models this storage cell configuration where one panel is assumed missing, and the others all have an areal density equal to the lowest areal density of 0.00824 gms-B_{10}/cm^2. Case 2 also conservatively models the Figure 2 surrounding storage cells in the array with an areal density of 0.006 gms-B_{10}/cm^2. Due to the reflective boundary conditions, this single cell with the different areal densities is present in each 4x4 block of cells.

Panel Areal Density of Case 2

	0.00000	
0.00824		0.00824
	0.00824	

- Case 3 conservatively models all the Boraflex panels in the 5x5 array with an areal density equal to the lowest area density of the panels shown in Figure 1 of the previous section 0.00597 gms-B_{10}/cm^2, and there is no missing panel.

Panel Areal Density of Case 3

	0.00597	
0.00597		0.00597
	0.00597	

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These values represent the lower bound values in term of burnup and Boraflex panel areal density of the actual conditions in the SFP.

Criticality Analysis Results

The results for all cases are listed below, and the results (k_{calc}) of Case 2 and Case 3 are compared to the reference case to estimate the margin. In both cases, the margin is between 0.0055 and 0.0095 delta-k, confirming that both Case 2 and Case 3 represent less reactive conditions than the current licensing basis (Reference Case).

Results of the Comparison of Actual Turkey Point Unit 3 SFP Conditions with the Licensing Basis

Case	k-calc	Delta-k	Equivalent Licensing Basis Resultant Keff
1	0.9976	Reference	0.99919
2	0.9921	-0.0055	0.99369
3	0.9881	-0.0095	0.98969

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Conclusion

The results of the analysis of this hypothetical case show that the most reactive fuel assembly available could be safely placed in the most degraded cell without credit for soluble boron or a compensatory measure and Keff would remain less than 1.0 consistent with the Turkey Point licensing basis analysis. The analysis demonstrates the conservative margin in the Turkey Point Boraflex Management Program which requires action to be taken to preserve reactivity margin well before significant Boraflex degradation can cause the SFP to challenge the Keff limits.

The analysis performed uses conservative assumptions that bound the current degraded condition of the Boraflex panels in the Turkey Point Unit 3 SFP. The analysis considers projected degradation to 9/26/10 to conservatively bound the current condition of the Boraflex. The analysis accounts for the uncertainties in the Boraflex condition assessment tools (RACKLIFE and BADGER) and the as-built areal density in the determination of the condition of the panels in a storage cell with a 95% probability and 95% confidence level consistent with the requirement for the determination of the effect of this degradation on Keff.

The analysis performed uses conservative assumptions for the selection of the most reactive fuel assemblies currently available in the SFP.

The analysis is performed using criticality analysis computer codes suitable for such analysis of the Turkey Point SFP. These computer codes have been established as acceptable tools in the analysis of the current licensing basis for the Turkey Point Cask Area SFP storage racks and were previously NRC approved for the analysis of the Boraflex Remedy (Amendments 234 and 229 for Turkey Point). The analysis was appropriately benchmarked to the current licensing basis analysis for the Boraflex SFP storage racks supporting this assessment. The analysis results show at least a 0.0055 ΔK margin to the current licensing basis analysis for Boraflex dissolution discussed in Turkey Point UFSAR Section 9.5.2.3. As a result, the worst degraded storage cell, with the most reactive fuel available, would be expected to have a Keff = 0.99369 vs. a licensing basis analysis Keff = 0.99919 when flooded with unborated water.

Furthermore, the predicted worst degraded storage cell has been under administrative control since 2001 as part of the storage rack module configured in a checkerboard of stored fuel assemblies interspersed with empty storage cells. This configuration does not credit any Boraflex in any of the storage cells in the rack module. This configuration provides even more reactivity margin to the unborated Keff limit, with a Keff < 0.80 when flooded with unborated water and assuming no Boraflex in any of the panels related to that cell. Keff would even be lower, had FPL assumed the remaining Boraflex in the panels.