Attachment 8

NET-264-03, Revision 1, "Characterization of Boraflex Panel Degradation in the Peach Bottom Unit 2 Spent Fuel Pool Projected to May 2010" (Non-Proprietary Version)

NET 264-03 NP
Non-Proprietary Information Submitted in
Accordance with 10 CFR 2.390

Characterization of Boraflex Panel Degradation in the Peach Bottom Unit 2 Spent Fuel Pool Projected to May 2010

Completed by:

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Review/Approval Record

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1	5/28/09	Matthew C. Harris	[signature]	L. P. Mariani

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1.0 Introduction

This report describes the use of BADGER test data and RACKLIFE projections of average panel loss as a means to project the local degradation in specific Boraflex panels in the future. The characterizations contained herein, allow the three-dimensional effects of non-uniform Boraflex degradation to be equated, from a reactivity standpoint, to an equivalent uniform thinning. This reactivity equivalent thinning can then be modeled in a standard two-dimensional neutron transport code.

This report describes panel characterizations using figures and fits of measured data. The figures and fits provide panel data that can be used in a criticality safety analysis which would be valid for the PB2 and PB3 spent fuel pools up to a projected pool average boron carbide loss of [ ].

1.1 Panel Reactivity Equivalence Methodology

The methodology described below was applied to the Peach Bottom Unit 2 spent fuel racks. For brevity, the description below will generally refer to the racks generically.

As described below, k_{eff} of the spent fuel pool is calculated as a function of various assumed levels of uniform panel thinning. The SCALE[1] code package, specifically Keno V.a, was used to calculate k_{eff} for the racks. For the reactivity equivalence base model, the Boraflex was assumed to be at its nominal thickness and ^{10}B loading. In addition, a conservatively bounding 4.1% width shrinkage was also applied. This bounding shrinkage is based on both analytical analysis and experimental data[2] and has been confirmed by a large number of proprietary laboratory studies and field observations.

Shrinkage of the thickness of Boraflex panels is effectively offset by densification and so need not be accounted for. The effect of axial shrinkage can manifest itself as both end shrinkage and gapping. Measuring the amount of shrinkage-induced gapping is complicated by the fact that local dissolution can increase the apparent size of a gap. Further, BADGER may not detect gaps that are less than 1/3rd inch or smaller. To account for the axial shrinkage with the possibility that some gaps may not have been detected, it is conservatively assumed that every panel has an undetected 4.1% axial shrinkage in the form of 1/3rd inch gaps uniformly distributed up the panel. These assumptions result in a higher than nominal k_{eff}, which conservatively increases the reactivity effects of Boraflex loss.

The Boraflex thickness in the base model was uniformly decreased in 5% increments to calculate the reactivity effects of uniform dissolution. The results were used to develop a relationship between uniform thinning and an increase in k_{eff} for reactivity equivalencing. This is subsequently used to relate uniform thinning and the actual degraded condition of the Boraflex panels.

In the next step, k_{eff} of a [ ] array of fuel storage cells is computed using KENO V.a for a specific set of Boraflex panels, each with a randomly generated non-uniform degradation pattern. The randomly generated degradation patterns are such that there is an equivalency between the loss distribution and RACKLIFE calculated average panel loss. This type of calculation is repeated [ ] times to generate a statistical 1
distribution of k_{eff} values with a mean and a variance.

A verified and validated FORTRAN program is used to create each of the [ ] 1
independent KENO V.a models described above. The algorithms described in Section 3.0 were used to generate the non-uniform distribution of Boraflex for each of the panels in the [ ] KENO V.a model. Therefore, [ ] panels with non-uniform Boraflex distribution are generated for each of the [ ] independent KENO V.a models that are executed. The pattern of non-uniform Boraflex distribution have been developed based on RACKLIFE projections to 2010.

For each of the [ ] KENO cases, a total of 30 million neutrons were tracked over 3000 1
generations. Fifty generations were skipped to ensure convergence of the source distribution. A large number of neutrons was used to ensure that there was adequate sampling of all of the degradation patterns of all [ ] panels in the model. As per standard practice, plots and statistics of the evolution of k_{eff} by generation were inspected and calculated to provide confidence that no sampling instabilities were being encountered.

The Boraflex panels generated for a model were based on a sequence of random numbers, so that each panel model is a random model with an expected value defined by the BADGER measurements plus a random variance. Consequently, the single estimate case described above could be randomly higher or lower than the actual condition of the panel being modeled. Therefore, a total of [ ] independent and randomly distributed cases are created using the Fortran program. These cases resulted in a distribution of calculated reactivity effects. The 95^{th} percentile of this reactivity effects distribution, at 95% confidence, can be used to bound the reactivity effects of non-homogeneously degraded Boraflex panels in the array of cells being considered. In every distribution calculated, the data passed the Anderson-Darling. Cramer-Von-Mises and Kolmogorov-Smirnoff tests for normality; thus, one-sided normal distribution statistical tolerance factors are valid for calculating bounding 95^{th} percentile eigenvalues at 95% confidence.

By randomly sampling these features, a realistic yet conservative projection of the future state of the Boraflex can be generated for criticality analysis. To assure that all features are adequately sampled, [ ] panels are generated [ ] times for a total of [ ] randomly generated Boraflex panels.

The 95/95 level, which bounds the so determined reactivity state, is then used to select a reactivity equivalent level of uniform thinning to serve as input to standard two-dimensional criticality code. The appendices are intended to be stand-alone specifications for panels or panel characterization distributions that can be used in a criticality safety analysis.

1.2 RACKLIFE Model

Historically, the development of RACKLIFE[3] was prompted by the observed in-service deterioration of the neutron absorber material, Boraflex. Boraflex is polydimethyl siloxane (silicone rubber), which serves as a matrix to retain finely divided boron carbide powder. As the material ages in the spent fuel pool environment, the polymer material is converted to amorphous silica as a result of exposure to gamma radiation and the pool water.

RACKLIFE is a Fortran executable program that calculates the loss of boron carbide from Boraflex panels in spent fuel storage racks. The calculation routine is based on first principles to solve a mass balance calculation of silica in the pool from its source (dissolution of the Boraflex matrix), transit into the bulk pool volume and removal via pool cleanup systems.

Calculated results from RACKLIFE simulations include absorbed gamma dose for all panels in the spent fuel pool, and percent boron carbide loss from each panel. Results can be displayed to identify panels with the most severe service histories to facilitate rack management strategies. One of the features of RACKLIFE is the ability to perform future predictive calculations based upon an anticipated refueling and/or ISFSI schedule to estimate the extent of future boron carbide loss.

The details of the Peach Bottom Unit 2 RACKLIFE model, its projection to 2010 and pertinent input are presented in Section 3 of NET-264-02 P, Rev. 2, "Criticality Analysis of the Peach Bottom Spent Fuel Racks for GNF 2 Fuel with Boraflex Panel Degradation Projected to May 2010," dated March 6, 2009.

2.0 RACKLIFE Model Validation and Projections

In this section, the RACKLIFE calculated boron carbide loss levels are compared with actual BADGER measurement of boron carbide loss levels, in order to demonstrate that the RACKLIFE projections of panel degradation are conservative.

RACKLIFE projections of boron carbide loss generated using the PB2 model predict a distribution of loss levels throughout the pool. The algorithm generated boron carbide losses incorporated into the [ ] fuel cell arrays also result in a distribution of loss levels. In what follows below, the consistency between these distributions is demonstrated.

2.1 Comparison of RACKLIFE and BADGER Test Results

Added confidence in the conservatism of RACKLIFE calculated projections of panel degradation was obtained by comparison of RACKLIFE results with in-situ BADGER measurements of panel B^{10} areal density.

The Boraflex panels in the Peach Bottom Unit 2 spent fuel racks were subjected to BADGER testing in early 2006.[4] The results of this test indicated that, on average, the RACKLIFE model provides a conservative estimate of the panel degradation. At the time of the 2006 BADGER test, the projected boron carbide loss for all panels was [ ], with a maximum panel loss of [ ].

For the BADGER test in 2006, a sample of 44 panels were selected for measurement (of which only 38 showed a measureable boron carbide loss). The BADGER test sample was selected with a bias toward panels that had been subjected to a more severe service duty (i.e., higher absorbed gamma dose and longer time since gamma dose sustained, thus resulting in a higher boron carbide loss due to dissolution). Figure 2-1 shows the distribution of panel boron carbide loss (%) at the time of the 2006 BADGER test as calculated by RACKLIFE and as measured by BADGER in 2006. The light blue bars represent all panels in the Peach Bottom Unit 2 spent fuel pool (N = 7329 panels) while the dark blue bars represent the fraction of panels that were selected for the BADGER test. The figure illustrates the conservatism of the BADGER test sample.

Figure 2-1: Comparison of Projected (RACKLIFE) Boron Carbide Loss for All Panels and Test Sample for 2006 BADGER Test

Figure 2-2 shows the BADGER measured percent boron carbide loss versus RACKLIFE calculated boron carbide loss. While there are individual variations for a given panel (due to wrapper plate fit and panel cavity flow) on average, the RACKLIFE projections are conservative relative to the BADGER measurements. For the 44 sample panels measured at Peach Bottom Unit 2 in 2006, the average measured boron carbide loss was [ ] while for the sampled panels, the average boron loss calculated by RACKLIFE was [ ], which is therefore conservative by 2.5%.

[ ]

Figure 2-2: BADGER Measured Versus RACKLIFE Projected Boron Carbide Loss in February 2006

2.2 Projections to 2010

Refueling outages and ISFSI campaigns were modeled in RACKLIFE based upon a schedule provided by Exelon and outlined in Section 3.2 of NET-264-02. The RACKLIFE model was executed out to the year 2010 and the boron carbide losses analyzed. A pseudo-random number generator is then employed to randomly select [ ] panels for input (as uniform thinning) in the [ ] array Monte-Carlo simulation. Figure 2-3 illustrates the favorable comparison of the distributions of panel boron carbide loss in 2010 for the entire pool (yellow bars) and for the [ ] randomly selected panels (blue bars) for the Monte-Carlo simulations.

Figure 2-3: Projected Boron Carbide Loss in 2010 for the Peach Bottom Unit 2 Spent Fuel Pool

3.0 Characterization Distributions

The previous section presented the basis for selection of the panels used to determine projected uniform thinning. Because of the conservatisms in developing the representations, the reactivity penalty due to the gaps and local dissolution in these panels, as computed in a criticality safety analysis will very conservatively bound the actual state of the racks.

This section presents a methodology for developing panel characterizations that are best-estimates of the panels in the spent fuel pool. The methodology depends on an algorithm for sampling features such as end shrinkage, gaps, scallop loss from gap edges, and local dissolution. By randomly sampling these features, a random panel can be defined that is a best-estimate of a panel in the PB2 spent fuel pool with a given RACKLIFE predicted dose and B_4C. (Actually, the algorithm contains some conservatisms in its development and so is only near best-estimate.) The algorithm for the Peach Bottom Unit 2 racks is presented in Appendix A. Appendix B gives the distribution of dose and B_4C loss in the racks in May of 2010; this can be sampled and used as input to the algorithm. Repeated samples from these algorithms can be used to build best-estimate models of the spent fuel pool or a part thereof. Reactivity calculations for a sequence of [ ] such models can be used to develop the probability 1
distribution of reactivity states in the pool. From this distribution, 95% probability at 95% confidence statistical tolerances on the best-estimate reactivity state can be calculated.

In developing the algorithms presented in the appendices, the following observations were noted:

1. Dose alone is not always a robust predictor of Boraflex panel features. The time span over which a panel accumulated its dose is also important. For example, a panel that absorbed a low dose many years ago may have sustained more loss than a panel that received a high dose recently. (Of course, over equal time intervals, the high dose panel will sustain more loss.) The RACKLIFE output for predicted B_4C loss was found to be more than a function of dose alone. The B_4C loss predicted by RACKLIFE accounts for both the effects of dose and time. Comparing the use of explicit time variables (e.g., the time to achieving specific dose levels for a given panel) with the use of predicted B_4C loss showed that neither exhibits a clear advantage in model development. Therefore, the more kinetics-based measure of B_4C loss is used.

2. The coefficient of multiple determination (sometimes called the correlation coefficient, r^2) is a measure of how well model variables explain all of the observed variation in data being modeled. For example, in a regression of observed loss against predicted loss a significant dependence is observed. However, there remain

differences between predicted and observed losses that must be due to other factors unaccounted for in the model. This is clear from a lower than expected value for the adjusted coefficient of multiple determination. The most likely factor unaccounted for is variation from panel cavity to panel cavity of the escape coefficient. The conclusion is that variations in the escape coefficient have a strong effect on the amount of loss that a panel sustains. Because the escape coefficients are not directly measurable, inclusion of this random component is an essential feature of the characterization models.

4.0 Conclusions

In Section 1.0 the panel reactivity equivalency methodology and the RACKLIFE model are described. Sections 2.0 and 3.0 of this report have described models for characterizing the degradation state of Boraflex panels in the PB2 spent fuel pool at the end of 2010. The results of these determinations will subsequently be utilized to conservatively estimate the projected value of k_{eff} for the PB2 spent fuel pool.

Appendix A provides stand-alone analytical algorithmic models for generating random panels that are best estimate representatives of the panels in 2010. Appendix B provides values of boron carbide loss and of absorbed gamma dose for values of Peach Bottom Unit 2 Boraflex panels projected to May 2010.

5.0 References

1. "SCALE-PC: Modular Code System for Performing Criticality Safety Analyses for Licensing Evaluation, Version 5.0," Parts 1 through 3, RSIC Computer Code Collection CCC-725. Oak Ridge National Laboratory: Oak Ridge, Tennessee; May 2004.

2. "Boraflex Test Results and Evaluation," EPRI/TR-101986, prepared by Northeast Technology Corp. for the Electric Power Research Institute; February 1993.

3. "The Boraflex Rack Life Extension Computer Code -- RACKLIFE: Theory and Numerics." EPRI TR-107333. Electric Power Research Institute: Palo Alto, CA; September 1997.

4. "BADGER Test Campaign at Peach Bottom Unit 2," NET-264-01, Rev. 0., Northeast Technology Corp.: Kingston, NY; 21 June 2006.

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Attachment 9

Northeast Technology Corporation Affidavit

NETCO
NORTHEAST TECHNOLOGY CORP

AFFIDAVIT

I, Kenneth O. Lindquist, Director of Northeast Technology Corporation, a wholly-owned subsidiary of Curtiss-Wright Flow Control Company, do hereby affirm and state:

1. I am the President of Northeast Technology Corporation (NETCO) authorized to execute this affidavit on its behalf. I am further authorized to review information submitted to the Nuclear Regulatory Commission (NRC) and apply to the NRC for the withholding of information from disclosure.

2. The information sought to be withheld is contained in the NETCO technical reports, "Criticality Analysis of the Peach Bottom Spent Fuel Racks for GNF-2 Fuel with Boraflex Panel Degradation Projected to May 2010," designated as NET-264-02, Rev 3, and "Characterization of Boraflex Panel Degradation in the Peach Bottom Unit 2 Spent Fuel Pool Projected to May 2010," designated as NET-264-03, Rev 1, and associated Responses for Request for Additional Information. The proprietary information is identified by the use of brackets.

3. In making this application for withholding of proprietary information of which it is the owner, NETCO relies on provisions of NRC regulation 10 CFR 2.390(a)(4). The information for which exemption from disclosure is sought is confidential commercial information.

4. The proprietary information provided by NETCO should be held in confidence by the NRC pursuant to the policy reflected in 10 CFR 2.390(a)(4) because:

    a) The information sought to be withheld in the NETCO technical report (see paragraph 2 above) is and has been held in confidence by NETCO.

    b) This information is of a type that is customarily held in confidence by NETCO, and there is a rational basis for doing so because the information contains methodology, data and supporting information developed by NETCO that could be used by a competitor as a competitive advantage.

    c) This information is being transmitted to the NRC in confidence.

    d) This information sought to be withheld, to the best of my knowledge and belief, is not available in public sources and no public disclosure has been made.

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e) The information sought to be withheld contains NETCO developed methodology, data and supporting information that could be used by a competitor as a competitive advantage, and would result in substantial harm to the competitive position of NETCO. This information would reduce the expenditure of resources and improve his competitive position in the implementation of a similar product. Third party agreements have been established to ensure maintenance of the information in confidence. The development of the methodology, data and supporting information was achieved at a significant cost to NETCO. Public disclosure of this information sought to be withheld is likely to cause substantial harm to NETCO's competitive position and reduce the availability of profit-making opportunities.

5. Initial approval of proprietary treatment of a document is made by the President of NETCO, the person most likely to be familiar with the value and sensitivity of the information and its relation to industry knowledge. Access to such information within NETCO is on a "need to know" basis.

6. Accordingly, NETCO requests that the designated document be withheld from public disclosure pursuant to 10 CFR 2.390 (a) (4).

I declare under penalty of perjury that the foregoing affidavit and statements therein are true and correct to the best of my knowledge, information and belief.

Kenneth O. Lindquist
Director
Northeast Technology Corporation

Date: 5/28/09

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