Tanya M. Hamilton
Vice President
Harris Nuclear Plant
5413 Shearon Harris Road
New Hill, NC 27562-9300

PROPRIETARY INFORMATION – WITHHOLD UNDER 10 CFR 2.390
UPON REMOVAL OF ATTACHMENT 3, THIS LETTER IS DECONTROLLED

10 CFR 50.90

April 13, 2018
Serial: HNP-18-039

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

Shearon Harris Nuclear Power Plant, Unit 1
Docket No. 50-400/Renewed License No. NPF-63

Subject: Supplement to License Amendment Request Regarding Spent Fuel Storage Pool Criticality Analyses

Ladies and Gentlemen:

By letter dated June 28, 2017 (Agencywide Document Access and Management System (ADAMS) Accession No. ML17193B165), as supplemented by letters dated July 20, 2017, January 18 and February 16, 2018 (ADAMS Accession Nos. ML17201A035, ML18018B974, and ML18047A730, respectively), Duke Energy Progress, LLC (Duke Energy), submitted a License Amendment Request (LAR) proposing changes to the Technical Specifications (TS) for the Shearon Harris Nuclear Power Plant, Unit 1 (HNP). The proposed amendment would modify the TS for fuel storage criticality to account for the use of Metamic neutron absorbing spent fuel pool rack inserts and soluble boron for the purpose of criticality control in the Boiling Water Reactor (BWR) storage racks that currently credit Boraflex.

On March 20, 2018, a public meeting between the Nuclear Regulatory Commission (NRC) and Duke Energy (ADAMS Accession No. ML18081A495) was held to discuss the means in which Duke Energy proposes to integrate the Metamic rack insert coupon testing program into the HNP licensing basis. This supplement, as provided in Attachment 1, outlines Duke Energy's plan to incorporate the program into the licensee-controlled procedure PLP-106, "Technical Specification Equipment List Program and Core Operating Limits Report." Attachment 1 also includes a description of changes incorporated in Revision 2 of Holtec International Report No. HI-2177590, "Licensing Report for Use of DREAM Neutron Absorber Inserts in the Spent Fuel Pools 'A' and 'B' at Shearon Harris NPP." Attachment 2 of this correspondence is the affidavit supporting the request for withholding the proprietary information in Attachment 3 from public disclosure. Attachments 3 and 4 provide the revised proprietary and nonproprietary versions of the Holtec International report. Revision 1 of the report was previously provided as Attachments 4 and 5 of the original submittal, dated June 28, 2017.

The content of this supplemental correspondence does not change the No Significant Hazards Consideration provided in the original submittal.

No regulatory commitments are contained in this letter.

In accordance with 10 CFR 50.91(b), HNP is providing the state of North Carolina with a copy of this supplemental correspondence.

Should you have any questions regarding this submittal, please contact Jeffrey Robertson, HNP Regulatory Affairs Manager, at (919) 362-3137.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on April 13, 2018.

Sincerely,

Tanya M. Hamilton

Attachments:

1. Supplement to License Amendment Request Regarding Spent Fuel Storage Pool Criticality Analyses
2. Affidavit for Withholding of Proprietary Information
3. Holtec International Report No. HI-2177590, "Licensing Report for Use of DREAM Neutron Absorber Inserts in the Spent Fuel Pools 'A' and 'B' at Shearon Harris NPP," Revision 2 (Proprietary)
4. Holtec International Report No. HI-2177590, "Licensing Report for Use of DREAM Neutron Absorber Inserts in the Spent Fuel Pools 'A' and 'B' at Shearon Harris NPP," Revision 2 (Nonproprietary)

cc: J. Zeiler, NRC Sr. Resident Inspector, HNP
W. L. Cox, III, Section Chief N.C. DHSR
M. Barillas, NRC Project Manager, HNP
C. Haney, NRC Regional Administrator, Region II

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cc: J. Zeiler, NRC Sr. Resident Inspector, HNP
W. L. Cox, III, Section Chief N.C. DHSR
M. Barillas, NRC Project Manager, HNP
C. Haney, NRC Regional Administrator, Region II

SERIAL HNP-18-039

ATTACHMENT 1

SUPPLEMENT TO LICENSE AMENDMENT REQUEST REGARDING SPENT FUEL STORAGE POOL CRITICALITY ANALYSES

SHEARON HARRIS NUCLEAR POWER PLANT, UNIT 1

DOCKET NO. 50-400

RENEWED LICENSE NUMBER NPF-63

2 PAGES PLUS COVER

Shearon Harris Nuclear Power Plant, Unit No. 1
Docket No. 50-400 / Renewed License No. NPF/63

Supplement to License Amendment Request Regarding
Spent Fuel Storage Pool Criticality Analyses

By letter dated June 28, 2017 (Agencywide Document Access and Management System (ADAMS) Accession No. ML17193B165), as supplemented by letters dated July 20, 2017, January 18 and February 16, 2018 (ADAMS Accession Nos. ML17201A035, ML18018B974, and ML18047A730, respectively), Duke Energy Progress, LLC (Duke Energy), submitted a License Amendment Request (LAR) proposing changes to the Technical Specifications (TS) for the Shearon Harris Nuclear Power Plant, Unit 1 (HNP). The proposed amendment would modify the TS for fuel storage criticality to account for the use of Metamic neutron absorbing spent fuel pool rack inserts and soluble boron for the purpose of criticality control in the Boiling Water Reactor (BWR) storage racks that currently credit Boraflex.

On March 20, 2018, a public meeting between the Nuclear Regulatory Commission (NRC) and Duke Energy was held to discuss the means in which Duke Energy proposes to integrate the Metamic rack insert coupon testing program into the HNP licensing basis. This supplement outlines Duke Energy’s plan to incorporate the program into the licensee-controlled procedure PLP-106, “Technical Specification Equipment List Program and Core Operating Limits Report.”

Plant Procedure PLP-106 is incorporated by reference into the HNP Final Safety Analysis Report (FSAR) per FSAR Section 1.6, Table 1.6-4, “Procedures, Programs, or Manuals Incorporated by Reference.” As such, PLP-106 is a part of the HNP Current Licensing Basis, therefore subject to the update and reporting requirements of 10 CFR 50.71(e) and change controls of 10 CFR 50.59, “Changes, tests and experiments.”

Per 10 CFR 50.59(a)(1), a change is a modification or addition to, or removal from, the facility or procedures that affects a design function, method of performing or controlling the function, or an evaluation that demonstrates that intended functions will be accomplished. Furthermore, per 10 CFR 50.59(a)(3), a facility is defined as the structures, systems, and components (SSC) that are described in the FSAR, the design and performance requirements for such SSCs described in the FSAR, and the evaluations or methods of evaluations included in the FSAR for such SSCs which demonstrate that their intended function(s) will be accomplished.

Upon issuance of the license amendment for the proposed change, FSAR Section 9.1.2.1.1, “BWR Racks,” will be updated to reflect the crediting of the Metamic rack inserts in the Westinghouse BWR Boraflex racks in Spent Fuel Pools (SFPs) A and B to maintain an acceptable neutron multiplication factor in accordance with the criticality accident requirements of 10 CFR 50.68, “Criticality accident requirements.” The Metamic rack insert coupon monitoring program that will be included in PLP-106 will verify that the inserts continue to provide the criticality control relied upon in the criticality analysis. The purpose of the program is to

characterize certain properties of Metamic in order to provide the data needed to evaluate the ability of Metamic to perform its intended function. The monitoring program will be capable of identifying whether changes to the Metamic are occurring, and if those changes are occurring, that the anticipated characteristics of change can be verified. The program, as outlined in Section 3.6 of Attachment 1 of the original submittal, will demonstrate that the intended function of the rack inserts will be accomplished. A license amendment pursuant to 10 CFR 50.90 would be required prior to implementing a proposed change that would result in a departure from the intent of this program.

In addition, Attachments 3 and 4 of this correspondence contain the proprietary and nonproprietary copies of Revision 2 of Holtec International Report No. HI-2177590, “Licensing Report for Use of DREAM Neutron Absorber Inserts in the Spent Fuel Pools ‘A’ and ‘B’ at Shearon Harris NPP.” Revision 1 of this report, provided as Attachments 4 and 5 of the original submittal, is superseded by Revision 2 as provided in this correspondence. The report was revised to update Chapter 2, “Proposed Modification, Principal Design Criteria & References,” with the latest figure of the insert (Figure 2.1), which was slightly modified to increase the gap between the steel plates (in the top portion of the insert) and to modify the lead-ins on the steel plates. A chamfer was also introduced on a small portion of Metamic at the bottom of the insert (non-active fuel region). All changes described above were made to improve installation and avoid interference issues. These changes did not impact the results of the analyses provided in the prior revision and do not impact the technical or regulatory evaluations provided in the original submittal.

Chapter 3, “Material Considerations,” was revised to reflect the inclusion of information previously redacted that has since been determined to be nonproprietary. Chapter 6 of the report, “Structural/Seismic Considerations,” was revised to update the revision number of the insert calculations package (Reference 6.7.4). These changes are editorial in nature, with no impact to the technical or regulatory evaluations provided in the original submittal.

SERIAL HNP-18-039

ATTACHMENT 2

AFFIDAVIT FOR WITHHOLDING OF PROPRIETARY INFORMATION

SHEARON HARRIS NUCLEAR POWER PLANT, UNIT 1

DOCKET NO. 50-400

RENEWED LICENSE NUMBER NPF-63

5 PAGES PLUS COVER

HOLTEC INTERNATIONAL

Holtec Center, 555 Lincoln Drive West, Marlton, NJ 08053
Telephone (856) 797-0900
Fax (856) 797-0909

Holtec International Document ID 2635003--AFFIDAVIT-03

AFFIDAVIT PURSUANT TO 10 CFR 2.390

I, Debabrata (Debu) Mitra Majumdar, being duly sworn, depose and state as follows:

(1) I have reviewed the information described in paragraph (2) which is sought to be withheld, and am authorized to apply for its withholding.

(2) The information sought to be withheld is information in the following report.

a. HI-2177590, "Licensing Report for Use of DREAM Neutron Absorber Inserts in the Spent Fuel Pools "A" and "B" at Shearon Harris Nuclear Power Plant", Revision 2"

This report contains Holtec Proprietary Information.

(3) In making this application for withholding of proprietary information of which it is the owner, Holtec International relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4) and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10CFR Part 9.17(a)(4), 2.390(a)(4), and 2.390(b)(1) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 4). The material for which exemption from disclosure is here sought is all "confidential commercial information", and some portions also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by Holtec's competitors without license from Holtec International constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

c. Information which reveals cost or price information, production, capacities, budget levels, or commercial strategies of Holtec International, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future Holtec International customer-funded development plans and programs of potential commercial value to Holtec International;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraph 4.b, above.

(5) The information sought to be withheld is being submitted to the NRC in confidence. The information (including that compiled from many sources) is of a sort customarily held in confidence by Holtec International, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by Holtec International. No public disclosure has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary

agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within Holtec International is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his designee), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside Holtec International are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information classified as proprietary was developed and compiled by Holtec International at a significant cost to Holtec International. This information is classified as proprietary because it contains detailed descriptions of analytical approaches and methodologies not available elsewhere. This information would provide other parties, including competitors, with information from Holtec International's technical database and the results of evaluations performed by Holtec International. A substantial effort has been expended by Holtec International to develop this information. Release of this information would improve a competitor's position because it would enable Holtec's competitor to copy our technology and offer it for sale in competition with our company, causing us financial injury.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to Holtec International's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of Holtec International's comprehensive spent fuel storage technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology, and includes development of the expertise to determine and apply the appropriate evaluation process.

The research, development, engineering, and analytical costs comprise a substantial investment of time and money by Holtec International.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

Holtec International's competitive advantage will be lost if its competitors are able to use the results of the Holtec International experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to Holtec International would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive Holtec International of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

AFFIDAVIT PURSUANT TO 10 CFR 2.390

STATE OF NEW JERSEY)
) ss:
COUNTY OF CAMDEN)

Mr. Debabrata (Debu) Mitra Majumdar, being duly sworn, deposes and says:

That he has read the foregoing affidavit and the matters stated therein are true and correct to the best of his knowledge, information, and belief.

Executed at Camden, New Jersey, this 10th day of April, 2018

Debabrata (Debu) Mitra Majumdar, Ph.D.
Corporate Director – Engineering Analysis
Holtec International

Subscribed and sworn before me this 10 day of April, 2018.

MARIA C. MASSI
NOTARY PUBLIC OF NEW JERSEY
My Commission Expires April 25, 2020

SERIAL HNP-18-039

ATTACHMENT 4

HOLTEC INTERNATIONAL REPORT NO. HI-2177590, “LICENSING REPORT FOR USE OF DREAM NEUTRON ABSORBER INSERTS IN THE SPENT FUEL POOLS ‘A’ AND ‘B’ AT SHEARON HARRIS NPP,” REVISION 2 (NONPROPRIETARY)

SHEARON HARRIS NUCLEAR POWER PLANT, UNIT 1

DOCKET NO. 50-400

RENEWED LICENSE NUMBER NPF-63

120 PAGES PLUS COVER

HOLTEC
INTERNATIONAL

Holtec Technology Center, One Holtec Boulevard, Camden, NJ 08104
Telephone (856) 797-0900
Fax (856) 797-0909

LICENSING REPORT FOR USE OF DREAM NEUTRON ABSORBER INSERTS IN THE SPENT FUEL POOLS "A" AND "B" AT SHEARON HARRIS NPP

FOR

DUKE ENERGY

Holtec Report No: HI-2177590

Holtec Project No: 2635

Sponsoring Holtec Division: NPD

Report Class : SAFETY RELATED

SUMMARY OF REVISIONS

Revision 0 – Original Issue

Revision 1 – Editorial/verbiage changes were made to Chapter 4. All changes are marked by revision bars.

Revision 2 – This report is being revised to update the chapter 2 with the latest figure of the insert. The insert design was slightly modified to increase the gap between the steel plates (in the top portion of the insert) and to modify the lead-ins on the steel plates. A chamfer was also introduced on a small portion of Metamic at the bottom of the insert (non-active fuel region). All changes described above were made to improve installation and to avoid interference issues. Chapter 6 was revised to update the revision number of the insert calculation package (revised to update the ASTM spec change from B209 to B221 for the support block and insert block attachment). Chapter 3 was revised to remove certain shaded portions of the text which are publicly available. All changes are marked by revision bars.

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1.0 INTRODUCTION

The Shearon Harris Nuclear Power Plant (HNP), owned and operated by Duke Energy Progress, is located in the extreme southwest corner of Wake County, North Carolina, and the southeast corner of Chatham County, North Carolina. The design of HNP incorporates the use of three spent fuel pools and one new fuel pool, as well as a cask loading pool. All of these pools are connected by a fuel transfer canal system. Spent fuel storage is provided by the New Fuel Storage Pool (Pool A) and the three spent fuel pools commonly referred to as Pool B, C, and D. The four pools are licensed to include 3404 PWR storage cells and 4628 BWR storage cells for a total storage capacity of 8032 fuel assemblies.

There is one Westinghouse design for spent BWR fuel storage. The limiting design in Pools A and B is such that the k_{eff} for the racks will not exceed 0.95 with the spent fuel pool flooded with unborated water. With this limit on assembly reactivity, all fuel assemblies located in Brunswick Steam Electric Plant (BSEP or BNP) Unit 1 through reload 5 and all fuel assemblies located in BSEP Unit 2 through reload 6 are conservatively bounded and may be stored at HNP. The BWR design for all four pools do not require or contain flux traps, since subcriticality of all fuel is ensured by considering storage of fuel with the highest reactivity. BWR storage locations do not have a lead-in, since the fuel nozzle design facilitates insertion into the storage cell.

Since the installation of the BWR Boraflex spent fuel racks in Pools A and B, significant industry experience has indicated that the Boraflex degrades at a higher rate than originally anticipated. This degradation leads to a reduction of the ability of Boraflex to hold down reactivity sufficiently to ensure safe storage of fuel. NRC Generic Letter (GL 96-04) was issued in June 1996 informing power plants of concerns with the use of Boraflex material in spent fuel racks. The result of the degradation was acknowledged in the HNP supplemental response to GL 96-04 on April 25, 2005 to the NRC. The response details the actions taken and the coupon monitoring program and silica monitoring of the fuel pools. The Boraflex degradation phenomenon does not impact other BWR spent fuel storage racks at HNP that use Boral for reactivity suppression.

Due to the degradation of the neutron absorbing materials in these racks that is credited in the HNP Technical Specifications, and the inability to relocate this fuel because of insufficient storage capacity, Duke Energy Progress, Inc., is seeking to install Rack Inserts into three (3) Westinghouse BWR Boraflex Racks in Spent Fuel Pool (SFP) A and five (5) in SFP B. Pools A and B are located at the south end of the Fuel Handling Building and provide storage for new PWR and spent PWR and BWR fuel assemblies using a combination of various rack modules sizes.

The fuel rack enhancement program proposed by this application intends to rely on Metamic™ inserts, designed and supplied by Holtec International, for reactivity control. Crediting Metamic™ as the neutron absorber provides a robust means of ensuring that the current inventory of stored irradiated fuel can be accommodated without losing spent fuel storage locations and while maintaining an acceptable neutron multiplication factor. The Boraflex panels will remain in place providing additional (not credited) neutron absorption.

The Holtec inserts are known as DREAM™ inserts. DREAM™ is an acronym for Device for Reactivity Mitigation. This is a fully developed product and Holtec has the capability to mass-produce them efficiently. The use of similar inserts, supplied by Holtec to Florida Power and Light, has been reviewed and approved by the USNRC [1.7]. The method for storage cell criticality control enhancement proposed in this license amendment request is disclosed in several U.S. Patents [1.1-1.5].

The proposed rack enhancement program does not require any physical modifications to the existing storage rack arrays, other than insertion of the DREAM™ inserts into the storage cells. This report documents the design and analyses performed to demonstrate that the DREAM™ inserts in the existing racks will meet all governing requirements of the applicable codes and standards; in particular the "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications" [1.6]. The aspects of the proposed rack enhancement program that are to

be implemented via this request to amend the station's operating license are described in the following paragraphs, and in the balance of this report.

Sections 2 and 3 of this report provide a brief abstract of the design and material information for the existing racks and a detailed description of the new DREAM™ inserts. Section 4 provides a summary of the methods and results of criticality evaluations performed for the existing racks with the DREAM™ inserts. Section 5 and 6 provide summary of the methodology and acceptance criteria used for the thermal and structural qualifications.

All computer programs utilized to perform the analyses documented in this report are benchmarked and verified. Holtec International has utilized these programs in numerous license applications over the past decade.

The analyses presented herein demonstrate that when the existing fuel storage racks at HNP Pools A and B are equipped with DREAM™ inserts, the resulting modules possess wide margins of safety with respect to all the nuclear subcriticality considerations specified in the OT Position Paper [1.6].

1.1 References

[1.1] Metamic™ U.S. Patent # 5,965,829 entitled "Radiation Absorbing Refractory Composition and Method of Manufacture" Dr. Kevin Anderson, Thomas G. Haynes III, & Edward Oschmann, issued Oct. 12, 1999

[1.2] Metamic™ U.S. Patent # 6,042,779 entitled "Extrusion Fabrication Process for Discontinuous Carbide Particulate Metal and Super Hypereutectic Al/Si Alloys" Thomas G. Haynes III and Edward Oschmann, issued March 28, 2000.

[1.3] Metamic™ U.S. Patent # 6,332,906 entitled "Aluminum - Silicon Alloy Formed by Powder" Thomas G. Haynes III and Dr. Kevin Anderson, issued Dec. 25, 2001.

[1.4] Metamic™ U.S. Patent Application 09/433773 entitled "High Surface Area Metal Matrix Composite Radiation Absorbing Product" Thomas G. Haynes III and Goldie Oliver, filed May 1, 2002.

[1.5] U.S. Patent # 8,681,924B2 entitled "Singe-Plate Neutron Absorbing Apparatus and Method of Manufacturing the Same", Evan Rosenbaum, Thomas G. Haynes and Krishna P. Singh, March 25, 2014.

[1.6] USNRC, "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications, April 14, 1978, and Addendum dated January 18, 1979.

[1.7] Turkey Point Plant, Units 3 and 4 – Issuance of Amendments Regarding Spend Fuel Pool Boraflex Remedy," USNRC Letter from B. Mozafari to J.A. Stall, dated 17 July 2007.

2.0 PROPOSED MODIFICATION, PRINCIPAL DESIGN CRITERIA & REFERENCES

2.1 Introduction

As noted in Section 1, Duke Energy Progress, Inc. is seeking to install Rack Inserts into three (3) BWR Westinghouse Boraflex Racks in Spent Fuel Pool (SFP) A and five (5) in SFP B. Pools A and B are located at the south end of the Fuel Handling Building and provide storage for new PWR and spent PWR and BWR fuel assemblies using a combination of various rack modules. Each rack is a freestanding module, made primarily of austenitic stainless steel, and containing an array of interconnected storage cells. Nominal data for the Westinghouse BWR rack modules is presented in Table 2.1.

The rack enhancement proposed by this license amendment seeks to equip certain storage cells with Holtec DREAM inserts made of the neutron absorber Metamic™. This rack enhancement is designed to compensate for the ongoing loss in neutron attenuation capability of the originally installed Boraflex material. Details of the DREAM™ insert design are provided in Section 2.5.

2.2 Summary of Principal Design Criteria

The key design criteria for spent fuel storage racks are set forth in the USNRC memorandum entitled "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications" [2.7]. The "OT Position Paper" remains applicable for re-evaluation of the existing racks to consider the addition of the DREAM™ inserts. The individual sections of this report address the specific design bases derived from the above-mentioned "OT Position Paper".

The design bases for the racks with DREAM™ inserts are summarized in the following:

a. Rack Module Configuration: The rack modules remain freestanding during a seismic event.

b. Kinematic Stability: Each freestanding module must be kinematically stable (resist tipping or overturning) under the plant's design basis seismic events.

c. Structural Compliance: All primary stresses in the rack modules must satisfy the limits in Section III Subsection NF of the ASME B&PV Code.

The DREAM™ inserts to be installed in the rack modules are non-structural components. Nevertheless, to ensure that they will continue to perform their intended function under all service conditions, the following requirement is imposed:

The allowable load for buckling is limited to 2/3 of the critical buckling load for conservatism and to ensure embedded margin in the design.

The above structural integrity requirement on the DREAM inserts is derived from Holtec International's fuel rack design practice; it is not a prescribed requirement in the NRC or Code documents applicable to this project. Additionally, it is noted that this acceptance criterion is conservative in some respects, since failure of certain insert welds does not necessarily compromise the design function of the insert.

d. Criticality Compliance:

The objective of the criticality analysis is to ensure that the effective neutron multiplication factor (k_{eff}) is less than or equal to 0.95 with the pool flooded with borated water, and that it is less than 1.0 under the assumed accident of the loss of soluble boron in the pool water, i.e. assuming unborated water in the spent fuel pool, all for 95% probability at a 95% confidence level.

e. Thermal Compliance: The objective of the thermal analysis is to demonstrate that the Westinghouse-supplied BWR spent fuel storage racks (SFSRs) in Shearon Harris spent fuel

pools (SFPs) A & B will continue to meet the thermal-hydraulic requirements for safe storage of spent fuel following installation of Holtec-supplied DREAM inserts.

The foregoing design bases are further articulated in Sections 4, 5 and 6 of this licensing report.

2.3 Applicable Codes and Standards

The following codes, standards and practices are used as applicable for the design, construction, and assembly of DREAM™ inserts. Because DREAM™ inserts do not perform a structural function, only the criticality safety related codes and standards cited hereunder are germane to the evaluations and analyses presented in this report. Additional specific references related to detailed analyses are also provided, as appropriate.

[2.1] ASTM C750 - Standard Specification for Nuclear-Grade Boron Carbide Powder.

[2.2] ASTM C992 - Standard Specification for Boron-Based Neutron Absorbing Material Systems for Use in Nuclear Spent Fuel Storage Racks.

[2.3] ANSI N45.2.1 - Cleaning of Fluid Systems and Associated Components during Construction Phase of Nuclear Power Plants - 1973 (R.G. 1.37).

[2.4] ANSI N45.2.2 - Packaging, Shipping, Receiving, Storage and Handling of Items for Nuclear Power Plants - 1972 (R.G. 1.38).

[2.5] ASME NQA-1 – Quality Assurance Program Requirements for Nuclear Facilities.

[2.6] ASME NQA-2 – Quality Assurance Requirements for Nuclear Power Plants.

[2.7] "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications," dated April 14, 1978, and the modifications to this document of January 18, 1979.

[2.8] ANSI/ANS 8.1 - Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors.

[2.9] ANSI/ANS 8.17 - Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors.

[2.10] 10CFR21 - Reporting of Defects and Non-compliance.

[2.11] 10CFR50 Appendix B - Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.

[2.12] 10CFR50.68 "Criticality Accident Requirements".

2.4 Quality Assurance Program

The governing quality assurance requirements for design and fabrication of the spent fuel storage equipment are stated in 10CFR50 Appendix B. Holtec's Nuclear Quality Assurance program complies with this regulation and is designed to provide a system for the design, analysis and licensing of customized components, such as the DREAM™ inserts, in accordance with the applicable codes, specifications, and regulatory requirements.

In recognition of the central role of the neutron absorber in maintaining subcriticality, Holtec International utilizes appropriately rigorous technical and quality assurance criteria and acceptance protocols to ensure satisfactory neutron absorber performance over the service life of the inserts.

Holtec International's Q.A. program ensures that the neutron absorber material will be manufactured under the control and surveillance of a Quality Assurance/Quality Control Program that conforms to the requirements of 10CFR50 Appendix B, "Quality Assurance Criteria for Nuclear Power Plants". Consistent with its role in reactivity control, all neutron absorbing material in the Holtec products is categorized as Safety Related (SR). SR manufactured items, as required by Holtec's NRC-approved Quality Assurance program, must be produced to essentially preclude the potential of an error in the procurement of constituent materials and the manufacturing processes. Accordingly, material and manufacturing control processes must be established to eliminate the incidence of errors, and inspection steps are implemented to serve as an independent set of barriers to ensure that all critical characteristics defined for the material by Holtec's design team are met in the manufactured product.

All major steps in the manufacture of Metamic™ are governed by formalized procedures. Raw materials (Al-6061 and B_4C) used to make Metamic are obtained from qualified suppliers and overcheck analyses are performed to confirm the claims of the materials vendors. Separate mass spectroscopic determination of the fraction of the boron-10 nuclide in the boron is performed for each lot of B_4C. Each batch mixture of B_4C and Al-6061 is chemically analyzed to assure a composition that conforms to the design specification for the weight percentage of B_4C. Permanent records of these analyses with unique identification numbers are maintained in the Holtec QA files. Each completed Metamic™ panel has a unique identification number that permits traceability to the material lot numbers of the constituent powders. Once the powders are thoroughly mixed, there is no known mechanism that might cause re-segregation of the powders. After the isostatic pressing and sintering, the ingots are extruded and cleaned by glass-beading. At this point, visual inspection confirms the removal of foreign particles from the surface of the extrusion piece. The extrusion piece is then rolled to a specified thickness and dimensions are confirmed with a precision jig. Random samples from the rolled panels are measured by neutron attenuation to confirm the proper B^{10} areal density and to qualify the homogeneity achieved in the fabrication process. As a qualified process, further neutron attenuation testing of the finished product is not required.

The Quality Assurance system enforced on the manufacturer's shop floor shall provide for all controls necessary to fulfill all quality assurance requirements. The final inspection and acceptance criteria of the manufactured DREAM™ inserts focus on the insert's dimensions, bow, twist, profile, cleanliness, and identifying markings.

2.5 DREAM™ Insert Mechanical Design

The design objective for DREAM™ inserts is to provide a neutron absorber having material composition and dimensions suitable for co-residence with fuel in a storage cell, and that can be easily inserted and relocated within the storage racks. Further, neutron absorption properties of the insert must be sufficient to eliminate reliance on the existing Boraflex. A major goal of the

program to eliminate reliance on Boraflex is to allow the use of every storage cell within the Westinghouse BWR Racks.

DREAM™ inserts are designed for insertion in any Westinghouse BWR Rack storage cell subsequent to placing a fuel assembly in that cell. Each insert consists of a Metamic™ panel attached to an aluminum upper "block" used to provide a robust attachment for handling purposes. Table 2.2 provides some basic data on the DREAM™ insert design, which is shown in Figure 2.1.

An installed DREAM insert blankets two of the four walls of the host storage cell. The insert's upper aluminum block is equipped with interfaces for lifting and handling by an appropriate custom-designed tool. Different tools are used to manipulate fuel assemblies and DREAM™ inserts. The position of the aluminum block at the top of the fuel assembly will be visually evident and it provides confirmation of the orientation of the DREAM™ insert within each cell.

The design of the insert ensures that, when seated, the active fuel region is shadowed by Metamic™. The dimensional differences between a fuel assembly (5.787 inches square) and the inside dimension of a storage rack cell (nominally 6.05 inches square) provide a sufficient gap (0.263 inches) for the DREAM™ insert to be inserted. The bottom edge of the Metamic™ panel on each insert is skew cut and beveled to ensure that the insert will readily slide into this gap and not snag on any fuel assembly components.

Table 2.1 MODULE DATA FOR EXISTING WESTINGHOUSE BWR RACKS[1]	
Storage cell inside nominal dimension	6.05 in
Cell wall thickness	0.075 in
Cell pitch	6.25 in
Storage cell height	169 in
Poison material	Boraflex

1 All dimensions are nominal values.

Table 2.2

DREAM™ INSERT PHYSICAL PARAMETERS

Maximum Width of DREAM™ Insert	[redacted]
Minimum Length of DREAM™ Insert	[redacted]
Nominal Thickness of Metamic™ Panel	[redacted]
Metamic™ Panel Minimum B_4C Loading	[redacted]
Approximate Weight of DREAM™ Insert	[redacted]

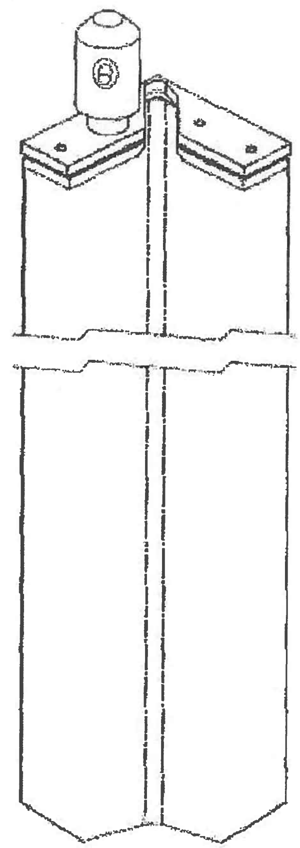


Figure 2.1: DREAM™ INSERT

3.0 MATERIAL CONSIDERATIONS

3.1 Introduction

A primary consideration in design of the DREAM™ insert proposed in this amendment request is that materials introduced into the pool water be of proven durability and compatible with the fuel pool environment. This section summarizes the considerations that provide assurance that the DREAM™ inserts installed in HNP Pool A and B Westinghouse BWR Racks will perform their intended function for the design life of the fuel racks.

3.2 Materials Used in the DREAM™ Insert

The Metamic™ neutron absorber material is the principal material for manufacturing the insert. Metamic™ itself is comprised of aluminum alloy 6061 and boron carbide (B_4C). All other components of the insert are manufactured from aluminum alloys, which are chemically compatible with Metamic.

3.3 Neutron Absorbing Material

The Metamic™ neutron absorber material is manufactured by the Orrvilon division of Holtec International in Ohio. As discussed below, Metamic™ has been subjected to rigorous tests by various organizations, including Holtec International, and has been approved by the USNRC for use in wet storage (i.e., fuel pool) applications.

Metamic™ was developed in the mid-1990s by the Reynolds Metals Company [1.1-1.3], with the technical support of EPRI [3.1, 3.2, 3.4], for spent fuel reactivity control in dry and wet storage applications. Development efforts had the explicit objective of eliminating the performance frailties of aluminum cermet type of absorbers then reported in the industry. Metallurgically, Metamic™ is a metal matrix composite (MMC) consisting of a matrix of 6061 aluminum alloy (325 mesh or better) reinforced with Type 1 ASTM C-750 boron carbide. The high performance and reliability of Metamic™ derives from the small B4C particle size and the uniformity of its distribution. [redacted]

[redacted]

Because Metamic™ is a homogenous, fully dense material there is no capillary path through which spent fuel pool water can penetrate the panels and chemically react with the internal Al-B_4C matrix to generate hydrogen. Thus, the potential for swelling and or blistering is eliminated and any degradation of Metamic can only occur at the surface of the panel. Since boron carbide is completely inert chemically, it is not subject to any leaching process. Any surface loss of B_4C would be far too small to be detectable or to be of significance.

To determine its physical stability and performance characteristics, Metamic™ was subjected to an extensive array of tests sponsored by the Electric Power Research Institute (EPRI). These tests evaluated the functional performance of the material at elevated temperatures (up to 900°F) and radiation levels (1E+11 rads gamma). The results of these tests are documented in an EPRI report [3.1] and indicate that Metamic™ maintains its physical and neutron absorption properties with little variation in these properties from the unirradiated state. The main conclusions provided in this EPRI report, which endorsed the use of Metamic™ for dry and wet storage applications on a generic basis, are summarized below:

- The metal matrix configuration produced by the powder metallurgy process ensures that its (i.e., Metamic™) density is essentially equal to the theoretical density.

- The physical and neutronic properties of Metamic™ are essentially unaltered by exposure to elevated temperatures (750° F - 900° F).
- Accelerated corrosion test conditions do not cause any detectable change in the neutron attenuation characteristics.

Additional technical information on Metamic™ available in the literature includes measurements of boron carbide particle distribution in Metamic™ panels [3.2], which showed extremely small particle-to-particle distance and near-perfect homogeneity, a report by California Consolidated Technology [3.3] characterizing Metamic™ with high B_4C concentrations and test data published by the Northeast Technology Corporation [3.4]. The USNRC has previously approved Metamic™ for use in both wet storage and dry storage applications. The use of Metamic in a similar insert design, supplied by Holtec to Florida Power and Light, has been reviewed and approved by the USNRC [1.7].

Metamic™ has also been subjected to performance assessment tests by Holtec International since 2001 [3.5, 3.6]. This multi-year experimental study simulated the limiting environmental conditions experienced during wet and dry storage. No anomalous material behavior was observed in any of the tests. These Holtec tests essentially confirmed earlier EPRI work and the other industry reports cited with regard to Metamic's suitability as a neutron absorber in fuel storage applications. These tests also confirmed the effectiveness of a glass beading technique for removal of impurities (surface contamination) after the extrusion process and Metamic's™ ability to resist degradation over time (as demonstrated by accelerated corrosion testing).

3.4 Compatibility with Environment

Typically, DREAM™ inserts installed at HNP pools will experience an environment of heated demineralized water. Usual bulk water temperatures will be between 80°F and 150°F. Because both constituents of Metamic™ (the Al 6061 alloy and boron carbide) are known to maintain physical and chemical stability, and Metamic™ has no internal porosity (i.e., panels are fabricated at essentially 100% of the theoretical density) there is no known mechanism for Metamic's degradation in the HNP spent fuel pools. Further, over many years, it has been shown that galvanic corrosion of aluminum and aluminum alloys in contact with other metals (i.e., zircaloy or stainless steel) does not occur in water [3.1, 3.2, 3.4].

3.5 Potential for Abrasion

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

	[redacted]	
	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted]

[redacted]

3.6 References

[3.1] "Qualification of METAMIC for Spent-Fuel Storage Applications", Report 1003137, EPRI, Palo Alto, CA, October 2001.

[3.2] "METAMIC Neutron Shielding", by K. Anderson, T. Haynes, and R. Kazmier, EPRI Boraflex Conference, November 19-20 (1998).

[3.3] "METAMIC 6061 + 40% boron Carbide Metal Matrix Composite Test Program for NAC International, Inc.", California Consolidated Technology, Inc. (2001).

[3.4] "METAMIC" Qualification Program for Nuclear Fuel Storage Applications, Final Test Results", Report NET 152-03, Prepared for Reynolds Metal Company, Inc. by Northeast Technology Corporation.

[3.5] "Use of METAMIC® in Fuel Pool Applications," Holtec Information Report No. HI-2022871, Revision 1 (2002).

[3.6] "Sourcebook for Metamic™ Performance Assessment" by Dr. Stanley Turner, Holtec Report No. HI-2043215 (2004).

[3.7] "Qualification of Metamic™ for Use as a Neutron Poison Material", Holtec Report No. HI-2033129 (2004).

4. CRITICALITY SAFETY ANALYSIS

4.1 Introduction and Summary

This report documents the spent fuel pool (SFP) criticality calculations performed for Duke Energy for the Harris site Pool A and B. The Harris SFP is designed for storage of Pressurized Water Reactor (PWR) fuel, but also contains storage racks designed for Boiling Water Reactors (BWR) fuel. The Harris SFP therefore also contains permanently discharged fuel previously shipped from the Brunswick Unit 1 and 2 BWR's. The purpose of this analysis is to qualify the BWR BORAFLEX™ storage racks designed by Westinghouse in both Pool A and B using Holtec Metamic inserts.

Criticality control in the BWR BORAFLEX™ storage racks DOES rely on the following:

- Administrative Restrictions:
  - *Restriction 1*

    The BWR fuel designs allowed in the Harris Pool A and Pool B BWRBORAFLEX™ storage racks are limited to the GE3, GE4, GE5, GE6 and GE7 fuel designs.
  - *Restriction 2*

    The orientation of the Metamic inserts in Harris Pool A and Pool B BWR BORAFLEX™ storage racks are limited to the orientation shown in Figure 4.1.1 and Figure 4.1.2.
  - *Restriction 3*

    No fuel shall be stored in the storage cell at the northeast corner of the BWR BORAFLEX™ storage racks nearest the interface with the PWR BORAFLEX™ storage racks on the north and east side in Pool A.
- Soluble boron for normal and accident conditions in accordance with 10CFR50.68(b)(4).
- Holtec Metamic inserts.

Criticality control in the BWR BORAFLEX™ storage racks DOES NOT rely on:

- Residual amount of BORAFLEX™.
- Burnup or residual Gadolinium (Gd).

4.1.1 Special Considerations

The criticality analysis presented in this report is unique in several ways from other BWR SFP criticality analyses. Additionally, the Metamic inserts used for criticality control have not been used for BWR fuel previously. Thus, the following special considerations exist:

- Two SFP's are being considered, Pool A and Pool B.
- SFP A has two rack designs, one for PWR fuel and one for BWR fuel.
- SFP B has three rack designs, one for PWR fuel and two for BWR fuel.
- The PWR racks in both Pool A and Pool B are of the flux trap design and were originally Boraflex racks, however, no credit is taken for the Boraflex in the PWR racks.
- The BWR racks in Pool B are both Region 2 style high density racks. One type is the Boraflex design (the same design as Pool A and thus intended to be controlled with Metamic inserts and therefore are bounded by the calculations in this analysis) and the other type is the Holtec Boral design. The Holtec Boral racks were designed to be dimensionally equivalent to the Boraflex design with the exception of using Boral instead of Boraflex. Thus, the Boral racks have a much lower reactivity than the Boraflex racks (the case for both the original Boraflex credit and now with credit for Metamic inserts).
- Since the SFP's contain PWR fuel (Harris is a PWR site), soluble boron credit is taken and established by the PWR analysis of record [4.11].
- The BWR fuel is from another site and was transferred to Harris and therefore the population of fuel is old and static. Additionally, BWR fuel movement is unlikely and not a normal part of plant operations.
- Most BWR fuel is channeled, though some BWR fuel has been de-channeled.
- All BWR fuel has significant burnup and extended cooling time.
- The Holtec Metamic insert design, while new for use with BWR fuel, is not an entirely new design.
- The Metamic insert rests in the storage rack and is not mechanically fixed to the rack cell.
- The BWR fuel does not need to be removed prior to Metamic insert installation and the Metamic inserts must be removed prior to BWR fuel movement.
- This analysis is specific only to the BWR Boraflex racks with Boraflex credit removal and Metamic insert credit established.
- Three Administrative Restrictions are put in place via this criticality analysis to control various SFP operation parameters.

The special considerations listed above, as well as the various design parameters of the SFP and various storage racks, result in several unique approaches with respect to the criticality analysis.

Unique approaches for normal conditions:

- A missing insert is required for the design basis model because the Metamic inserts must be removed prior to BWR fuel movement.
- The normal condition soluble boron requirement, if needed, is already established by the PWR fuel analysis. Thus, any normal condition soluble boron calculations are performed with the

limit amount. No interpolation is required as long as the limit requirement demonstrates regulatory compliance.

- The Metamic insert orientation requirement was selected to ensure additional safety margin will exist. This margin is not credited in the analysis but the analysis considers that the Metamic insert panel was NOT *always* positioned between the BWR Boraflex racks and the PWR racks. Thus, the analysis already considers the bounding Metamic insert orientation for the interface of the BWR Boraflex racks and the PWR racks while the as-installed configuration will always be bounded by the analysis condition.
- Rack to rack interfaces are evaluated in a conservative manner by considering minimum rack to rack gaps over both Pool A and Pool B. Thus, whichever rack to rack gaps from both pools are bounding (smallest gap) and are applied to the interface calculations so that both pools are bounded by the interface evaluations.
- The interface evaluation is only applicable to the BWR Boraflex racks with Metamic inserts. The other rack designs are not qualified by this analysis.
- The analysis considers only fresh BWR fuel. An Administrative Restriction is applied via this analysis to ensure that the fuel in Pool A and Pool B is bounded by the analysis. No fuel movement is required to meet this Administrative Restriction. The purpose of the Administrative Restriction is therefore to ensure consistency with an already established requirement and to ensure that no changes are necessary for the soluble boron requirements established by another analysis.

Unique approaches for accident conditions:

- The Metamic inserts have a specific orientation controlled by an Administrative Restriction. The purpose of the orientation requirement is to maintain the Metamic inserts in a conservative configuration (the analysis considers the worst case) that is always bounded by this analysis. As a result of the orientation requirement a new accident condition is created if the Metamic inserts are not in the controlled orientation. While this is unlikely since the orientation of the insert will be administratively controlled through various plant operating controls, and the Metamic insert orientation is easily observable from above, the possibility remains that the Metamic insert, or more than one Metamic insert, could be orientated incorrectly. Thus, a new accident condition must be considered for multiple mis-oriented Metamic inserts. This accident is only important relative to the situation where an insert is already removed for the purpose of fuel movement. Thus, in that case, if the inserts around that location are mis-oriented, then that configuration would be an accident configuration.
- The Metamic insert orientation requirement was also selected for conservatism with respect to the mislocated fuel assembly accidents. The orientation thus ensures that NO Metamic insert panel is between the mislocated fuel assembly and the BWR fuel.
- For the mislocated fuel assembly accident, the PWR 17x17 fuel design is used. The PWR fuel is used because of the following conservatisms:
    - o The BWR fuel population is static and does not move.
    - o The BWR fuel is all spent and has a low reactivity.
    - o This PWR fuel may be fresh and thus have a high reactivity.
    - o The PWR fuel considered in the mislocated fuel assembly accident is treated as 5.0 wt% U-235, fresh and with no absorbers. Thus, while this is not possible since fresh 17x17 PWR fuel with a maximum enrichment will always have burnable absorbers, the

mislocated accident calculations are very conservative.
- o There are locations where the BWR fuel, if considered in place of the PWR fuel, could fit in locations where PWR fuel cannot fit. However, the accident cases considered bound all those locations. In one such case, the PWR fuel is made to fit where it normally could not by making small adjustments to the rack to rack gaps.

- In general, the accident calculations considered are performed using Pool A configurations. The Pool A configurations bound the Pool B configurations for the following reasons:
  - o The rack to rack gaps bound both pools.
  - o The BWR Boral racks, which are only in Pool B, are a much lower reactivity rack and thus they do not impact the reactivity of the BWR Boraflex racks.
  - o The BWR Boral racks in Pool B might reduce the reactivity effect of the various mislocated accidents and thus it is conservative to neglect them.
  - o The Metamic insert orientation is controlled such that the analysis considers the worst case for the accident scenarios. Thus, the analysis calculations bound both pools.
  - o Therefore, every accident considered is applicable to both Pool A and Pool B, or, covers every possibility for Pool A and Pool B.
- The accident condition soluble boron requirement is already established by the PWR fuel analysis. Thus, all accident condition calculations are performed with both pure water and the soluble boron limiting requirement. No interpolation is required as long as the limit requirement demonstrates regulatory compliance. Furthermore, in some cases accident scenarios may be more reactive at 0 ppm but another variation may be more reactive at the soluble boron requirement. Thus, the most reactive variation should be selected from the highest reactivity with soluble boron.
- The analysis considers only fresh BWR fuel. An Administrative Restriction is applied via this analysis to ensure that the fuel in Pool A and Pool B is bounded by the analysis. No fuel movement is required to meet this Administrative Restriction. However, the accident analysis therefore requires special consideration for the unrealistic possibility that the most reactive BWR fuel design, the GE13, is accidently placed in Pool A or Pool B BWR Boraflex racks. This accident scenario is technically a misload accident. The misload accident is performed in a very conservative manner to demonstrate the significant level of conservatisms which exists in the analysis. The GE13 fuel assembly is modeled as 5.0 wt% U-235 fresh while the GE13 actually is spent fuel that originally had a maximum enrichment of 4.2% U-235. The misload calculations also consider the fresh GE13 in every location, and also include the missing insert required for normal conditions. The results of those calculations show that even with that level of conservatism the results could have been used for normal conditions but are not to avoid potential changes to the TS requirements for soluble boron.

The specific details of the special considerations discussed above are provided in greater detail the sections below.

4.2 Methodology

4.2.1 General Approach

In general, the analysis approach is to be as conservative as possible and whenever possible. Additionally, the analysis is performed in a manner such that the results are below the regulatory

limit with a 95% probability at a 95% confidence level. The calculations are performed using either the worst case bounding approach or the statistical analysis approach with respect to the various calculation parameters. The approach considered for each parameter is discussed below.

4.2.2 Computer Codes and Cross Section Libraries

4.2.2.1 MCNP5-1.51

MCNP5-1.51 [4.1] is used for the criticality analyses. MCNP5-1.51 is a three-dimensional Monte Carlo code developed at the Los Alamos National Laboratory. MCNP was selected because it has a long history of successful use in fuel storage criticality analyses and has all of the necessary features for the analysis to be performed for Harris Pool A and B. MCNP5-1.51 calculations use continuous energy cross-section data predominantly based on ENDF/B-VII [4.2]. The default ENDF/B-VII cross sections are adjusted for temperature dependence using the appropriate continuous energy cross-section data processed with NJOY 99.396 code using ENDF/B-VII library [4.3, 4.4].

The convergence of a Monte Carlo criticality problem is sensitive to the following parameters: (1) number of histories per cycle, (2) the number of cycles skipped before averaging, (3) the total number of cycles and (4) the initial source distribution. All MCNP5-1.51 calculations are performed with a minimum of 12,000 histories per cycle, a minimum of 400 skipped cycles before averaging, and a minimum of 800 cycles that are accumulated. The initial source is specified the fueled regions (assemblies) and confirmed to converge. It is a well-known fact [4.5] that k_{eff} (eigenvalue), which is an integral quantity, converges much faster than the fission source spatial distribution (eigenfunction). However, a convergence of the spatial source distribution is important for estimating local quantities, such as pin power. To assist users in assessing the convergence of the fission source spatial distribution, MCNP5 computes a quantity called the Shannon entropy of the fission source distribution, H_{src} [4.1]. The Shannon entropy [4.5] is a well- known concept from information theory that has been shown to be an effective diagnostic measure for characterizing convergence and provides a single number for each cycle to help characterize convergence of the fission source distribution. It has been found that the Shannon entropy converges to a single steady-state value as the source distribution approaches stationarity. Therefore, the convergence of the power iteration process is ensured using the Shannon entropy, as implemented in MCNP5 [4.1]. Since the eigenvalue (k_{eff}) converges faster than the fission source distribution, the convergence of the k_{eff} is assured by the convergence of the source distribution. The Shannon entropy convergence has been checked for each calculation.

4.2.2.2 MCNP5-1.51 Validation

Benchmarking of MCNP5-1.51 for criticality calculations is documented in [4.6]. The benchmarking is based on the guidance in [4.7], and includes calculations for a total of 562 critical experiments with fresh UO_2 fuel, fresh MOX fuel, and fuel with simulated actinide composition of spent fuel (HTC experiments [4.6]). The benchmarking area of applicability is presented in Table 4.2.1. The results of the benchmarking calculations for the full set of all 562 experiments are presented in Table 4.2.2 along with trending analysis. The statistical treatment used to determine those values considered the variance of the population about the mean and used appropriate confidence factors and trend

analysis.

Trend analyses are also performed in [4.6], and the significant trends determined for various subsets and parameters are presented in Table 4.2.2. In order to determine the maximum bias that is applicable to the calculations in this report, the trend equations from [4.6] are evaluated for the specific parameters of the current analyses in Table 4.2.3. The results presented in Table 4.2.3 show the maximum bias and bias uncertainty associated with the benchmark subsets. This maximum bias and bias uncertainty is applied to all analysis calculations to determine k_{eff}.

4.2.3 Analysis Methods

The overall analysis method considers a bounding analysis approach for the fuel, Metamic inserts and various storage rack models. The analysis models consider 12 inches of water above and below the active length of the fuel, thus the rack baseplate and other materials are modeled as water. This approach is acceptable because for fresh fuel the maximum reactivity is in the center of the fuel active length, not at the top or bottom. These bounding approaches and storage rack models are summarized below:

Bounding Fuel Designs and Fuel Assembly Parameters:

- Each design basis analysis calculation considers fresh fuel with a uniform enrichment equal to the initial maximum planar average enrichment (IMPAE) plus the enrichment tolerance. The same bounding enrichment is considered along the entire active length for each fuel pin [4.8]. No Gd is included. Lower enriched blankets are neglected. Therefore, there is no axial or radial variation in fuel along the entire active length. This bounding approach provides analysis simplicity and margin since the fuel has significant burnup and cooling time and thus inherent negative reactivity. See Section 4.2.3.1.1.
- The bounding fuel assembly parameters are considered. This bounding approach provides analysis simplicity and margin since the fuel assembly parameter tolerance uncertainties are treated as a bias, not an uncertainty. See Section 4.2.3.1.2.

Bounding Storage Rack Parameters:

- The bounding rack design parameters are considered. This bounding approach provides analysis simplicity and margin since the rack design parameter tolerance uncertainties are treated as a bias, not an uncertainty. See Section 4.2.3.2.
- The BORAFLEX™ is replaced by water. This bounding approach provides analysis simplicity and margin since the remaining BORAFLEX™ has negative reactivity that is not credited.
- Each Metamic insert within a particular rack is administratively controlled to be installed with the same orientation (see Figure 4.1.1 and Figure 4.1.2), however, the storage cell in the center of the array is modeled with a missing Metamic insert. The center location is left with no Metamic insert because the Metamic insert design requires removal of the Metamic insert in order move a fuel assembly. Thus, after all locations have Metamic inserts installed, if a fuel assembly is to be moved, the Metamic insert must first be removed. Therefore the analysis considers a Metamic insert removed in the design basis model for both normal conditions and accident conditions.
- For the misload accident, the missing insert location is also used for the misloaded fuel

assembly location. This bounding approach provides analysis simplicity and margin since the worst case location for a missing insert is considered for both normal and accident conditions.

Bounding Metamic Insert Parameters:

- The bounding thickness, width and B-10 loading for the Metamic inserts is considered. Additionally, a slot along the entire length in the bend region is included in the model. This bounding approach provides analysis simplicity and margin since the reactivity effect of the insert design parameters are treated as an analysis bias rather than an uncertainty. Furthermore, the Metamic in the insert bend region that is not slotted (i.e. that remains after slotting) is ignored and modeled as water. See Section 4.2.3.3.

Bounding SFP Moderator Temperature:

- The bounding SFP moderator temperature and density are used for all design basis calculations. The calculations include NJOY corrected cross sections and $S(\alpha,\beta)$ cards. This bounding approach provides analysis simplicity and margin since the reactivity effect of the SFP reduction in temperature accident is treated for all normal and accident conditions, rather than as an additional accident condition. See Section 4.2.3.4.

Bounding Radial Positioning of Fuel assembly and Insert Location

- The radial position of the fuel assembly and Metamic insert in the storage cell, as well as the presence or lack of the fuel assembly channel, is considered in a bounding fashion. This bounding approach provides analysis simplicity and margin since the reactivity effect of the radial location of the Metamic insert, fuel assembly along with the presence or lack of a channel is treated as an analysis bias rather than an uncertainty. See Section 4.2.3.5.

Various fuel, rack and Metamic insert models are used in the analysis. The base model used for the analysis calculations in Section 4.2.3 consider the following MCNP5-1.51 rack model (with additional variations for the various evaluations described in each subsection):

- 11x11 array of storage cells with the BORAFLEX™ replaced by water.
- Cell geometry along the exterior considers a simple cell wall.
- Adjacent to the exterior cell wall is a water gap with a thickness equal to half the BWR BORAFLEX™ rack to BWR BORAFLEX™ rack gap.
- Periodic boundary conditions are considered along the water gap, thus creating a laterally infinite array.
- All Metamic inserts have the orientations shown in Figure 4.1.1 and 4.1.2.
- The center location of the 11x11 array does not include any Metamic insert.
- The Metamic inserts are located between the fuel assembly and cell corner and have a bounding (assumed minimum) loading, width and thickness.
- The storage rack design parameters are nominal values.
- The SFP moderator is at 39.2 °F.
- All materials in the model have the same temperature as the SFP moderator.

Additional details and analysis methodology discussions are provided below.

4.2.3.1 Bounding Fuel Design and Fuel Assembly Parameters

The Harris SFP contains various GE BWR fuel designs (i.e. GE3, GE4, GE5, GE6, GE7, GE8, GE9, GE10, and GE13), of which a subset (i.e. GE3, GE4, GE5, GE6 and GE7) is selected for potential storage in the Pool A and B BWR BORAFLEX™ racks. The most reactive of that subset of fuel designs and that fuel designs bounding design parameters are determined below.

4.2.3.1.1 Bounding Fuel Design

For normal conditions, the GE7 fuel design is expected to be the design basis assembly. The GE7 fuel design is expected to be more reactive than the GE3, GE4, GE5 and GE6 fuel designs and is therefore used to bound those lower reactivity fuel designs and qualify the GE3 through GE7 fuel designs for storage in the Pool A and B BWR BORAFLEX™ racks. Note that the GE5 and GE6 are essentially the same and therefore the GE6 is used to evaluate both.

Since there is a restriction on which fuel designs can be stored in the Pool A and B BWR BORAFLEX™ racks, an administrative requirement will control which fuel designs are allowed in the Pool A and B BWR BORAFLEX™ racks. Therefore, consideration is taken for the potential misload accident where a fuel design not qualified for storage in the Pool A and B BWR BORAFLEX™ racks is accidently loaded in a Pool A or B BWR BORAFLEX™ storage cell location. Note that this is highly unlikely since the movement of BWR fuel is uncommon and all non-qualified fuel designs have been removed from Pool A and B. However, for the purpose of this analysis, the accident condition is considered. Therefore, since the GE13 is expected to be the most reactive of all fuel designs, the GE13 is used as the misload accident fuel design [4.8].

The bounding fuel design evaluation calculates the maximum reactivity of each fuel design using the 11x11 rack model discussed in Section 4.2.3 (with the center cell Metamic insert missing) and the following generic fuel design parameters unless otherwise noted:

- IMPAE including the enrichment tolerance, unless otherwise stated.
- Dimension parameters are nominal values.
- The fuel assembly is cell centered.
- The fuel channel present.

The following cases are evaluated:

- Case 4.2.3.1.1.1: GE3 with maximum IMPAE + enrichment tolerance.
- Case 4.2.3.1.1.2: GE4 with maximum IMPAE + enrichment tolerance.
- Case 4.2.3.1.1.3: GE6 with maximum IMPAE + enrichment tolerance.
- Case 4.2.3.1.1.4: GE7 with maximum IMPAE + enrichment tolerance.
- Case 4.2.3.1.1.5: GE13 with maximum IMPAE + enrichment tolerance.

4.2.3.1.2 Bounding Fuel Design Parameters

The bounding fuel design parameters are determined using the same 11x11 rack model as discussed in Section 4.2.3 (with the center cell Metamic insert missing) with the exception for variations in fuel assembly parameters. For the fuel assembly parameter evaluations, each fuel assembly in the model has the tolerance applied at the same time.

Note that the fuel density increase and fuel pellet diameter increase cases are not considered since it is a well-known effect that maximum parameter values will increase reactivity (considering that the pellet to clad gap is not flooded in the model). Therefore, the reference case below (and all tolerance cases) includes the maximum fuel pellet density and maximum fuel pellet outer diameter.

The following BWR fuel tolerances [4.8] are considered for the bounding fuel design for nominal conditions (expected to be the GE7):

- Case 4.2.3.1.2.1: Reference case. All tolerance parameters nominal (except fuel pellet diameter and density which are maximum).
- Case 4.2.3.1.2.2: Minimum cladding thickness.
- Case 4.2.3.1.2.3: Maximum cladding thickness.
- Case 4.2.3.1.2.4: Minimum fuel rod pitch.
- Case 4.2.3.1.2.5: Maximum fuel rod pitch.
- Case 4.2.3.1.2.6: Minimum fuel channel thickness.
- Case 4.2.3.1.2.7: Maximum fuel channel thickness.
- Case 4.2.3.1.2.8: Minimum water rod thickness.
- Case 4.2.3.1.2.9: Maximum water rod thickness.
- Case 4.2.3.1.2.10: Pin specific enrichment for the IMPAE considered in Case 4.2.3.1.1.4.

Note that the fuel rod pitch tolerance calculations were increased and decreased by applying a 2 σ approach using the following equation:

Tolerance = pitch +/- 2*(tolerance)/sqrt(number of fuel rods)

The reactivity effect of each tolerance is determined from:

$$\text{delta-}k_{calc} = (k_{calc2} - k_{calc1}) \pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$$

where $\pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$ is called the 95/95 uncertainty.

The results are then used to determine the bounding fuel assembly parameters for use in all design basis calculations.

Case 4.2.3.1.2.10 is evaluated to show that using the IMPAE is acceptable.

4.2.3.2 Bounding BWR BORAFLEX™ Rack Parameters

The bounding BWR BORAFLEX™ rack parameters are determined using the same 11x11 rack model as discussed in Section 4.2.3 (with the center cell Metamic insert missing) with GE7 fuel with nominal fuel design parameters and with the exception for variations in BWR BORAFLEX™ rack

parameters.

The following tolerances are considered:

- Case 4.2.3.2.1: Reference case. All storage rack parameters nominal.
- Case 4.2.3.2.2: Minimum storage cell inner diameter.
- Case 4.2.3.2.3: Maximum storage cell inner diameter.
- Case 4.2.3.2.4: Minimum storage cell wall thickness.
- Case 4.2.3.2.5: Maximum storage cell wall thickness.
- Case 4.2.3.2.6: Minimum storage cell pitch.

The reactivity effect of each tolerance is determined from:

$\text{delta-}k_{calc} = (k_{calc2} - k_{calc1}) \pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$

where $\pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$ is called the 95/95 uncertainty.

Note that there is no maximum storage cell pitch tolerance.

The results are then used to determine the bounding BWR BORAFLEX^{TM} rack parameters for use in all design basis calculations.

4.2.3.3 Bounding Metamic Insert Parameters

The bounding Metamic insert design parameters are determined using the same 11x11 rack model as discussed in Section 4.2.3 (with the center cell Metamic insert missing) with GE7 fuel with nominal fuel design parameters and with the exception for variations in Metamic insert design parameters. Additionally, since it is expected that the position of the insert relative to the fuel will have an impact on reactivity (see Section 4.2.3.5), the Metamic insert position in the calculations in this section is adjacent to the storage cell corner. Therefore, the results of the calculations with various Metamic insert design parameter changes will resolve the reactivity impact of the Metamic insert design parameters and not the slight changes in relative distance to the fuel assembly.

The following tolerances are considered:

- Case 4.2.3.3.1: Reference case. Minimum B_4C wt%, nominal insert thickness and width (nominal loading at minimum B_4C wt%). Metamic insert position is adjacent to the storage cell corner.
- Case 4.2.3.3.2: Same as Case 4.2.3.3.1, but with alternative missing insert location along rack edge, in center location. Minimum B_4C wt%, nominal insert thickness and width (nominal loading at minimum B_4C wt%).
- Case 4.2.3.3.3: Same as Case 4.2.3.3.1, but with alternative missing insert location along rack edge, in corner location. Minimum B_4C wt%, nominal insert thickness and width (nominal loading at minimum B_4C wt%).
- Case 4.2.3.3.4: Same as Case 4.2.3.3.1, but with minimum B_4C wt%, maximum thickness and width (maximum loading at minimum B_4C wt%).

- Case 4.2.3.3.5: Same as Case 4.2.3.3.1, but with minimum B_4C wt%, minimum thickness and width (minimum loading at minimum B_4C wt%).
- Case 4.2.3.3.6: Coupon testing measurement uncertainty. Same as Case 4.2.3.3.1, but with minimum B_4C wt% – 5%, minimum thickness and width (minimum loading at minimum B_4C wt% – 5%).

The reactivity effect of each tolerance is determined from:

$$\text{delta-}k_{calc} = (k_{calc2} - k_{calc1}) \pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$$

where $\pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$ is called the 95/95 uncertainty.

Case 4.2.3.3.2 and Case 4.2.3.3.3 are included to show that the missing Metamic insert in the center location is the bounding configuration.

Case 4.2.3.3.6 is provided for the coupon measurement uncertainty and the results of those calculations are not included in the design basis model. Rather, the results for Case 4.2.3.3.6 is statistically combined with the other analysis uncertainties to determine k_{eff}.

The results for Case 4.2.3.3.4 and Case 4.2.3.3.5 are evaluated to determine the bounding Metamic insert design parameters for use in all design basis calculations.

4.2.3.4 Reactivity Effect of Spent Fuel Pool Water Temperature

The criticality analysis should be performed at the most reactive temperature and density [4.9]. Additionally there may be temperature-dependent cross section effects in MCNP5-1.51 that need to be considered. In general, both density and cross section effects are not necessarily the same for all storage rack scenarios, since configurations with strong neutron absorbers typically show a higher reactivity at lower water temperature, while configurations without such neutron absorbers typically show a higher reactivity at a higher water temperature. For the Harris Pool A and B BWR BORAFLEX™ storage racks with Metamic inserts, the maximum reactivity condition therefore is expected to be the minimum SFP water temperature and maximum density.

Additionally, the standard cross section temperature in MCNP5-1.51 is 300 K. Cross sections are also available at other temperatures, however not usually at the desired temperature for SFP criticality analysis. MCNP5-1.51 has the ability to automatically adjust the cross sections to the specified temperature when using the TMP card. Additionally, MCNP5-1.51 has the ability to make a molecular energy adjustment for select materials (such as water) by using the $S(\alpha,\beta)$ card. The $S(\alpha,\beta)$ card is provided for certain fixed temperatures which are not always applicable to SFP criticality analysis. Rather, there are limited temperature options, i.e. 300 K and 350 K, etc. Additionally, MCNP5-1.51 does not have the ability to adjust the $S(\alpha,\beta)$ card for temperatures as it does for the TMP card discussed above. Therefore, the cross sections and $S(\alpha,\beta)$ card are adjusted using NJOY [4.3, 4.4], and these adjusted cross sections use a temperature that is reasonably close to the SFP specific values. This approach is acceptable because the system is poisoned and the reactivity trend is well known.

The Harris SFP have a normal water temperature operating range of 85 to 105 °F [4.8].

Temperatures above and below this range are considered accidents. However, for conservatism, the design basis model will consider the bounding temperature.

Studies are performed to demonstrate the reactivity effect of the moderator temperature and density over the range 39.2 °F through 212 °F using temperature adjusted cross sections and S(α,β) cards. The bounding temperature is determined using the same 11x11 rack model as discussed in Section 4.2.3 (with the center cell Metamic insert missing) with GE7 fuel (GE7 with IMPAE at 4.0 wt% U-235 and nominal fuel design parameters) and with the exception for variations temperature. The following studies are performed:

- Case 4.2.3.4.1: Reference case. Temperature of 39.2 °F (NJOY cross sections are 39.2 °F). Same model as discussed in Section 4.2.3.1.1.
- Case 4.2.3.4.2. Minimum nominal temperature 85 °F (NJOY cross sections are 69 °F).
- Case 4.2.3.4.3. Maximum nominal temperature 105 °F (NJOY cross sections are 149 °F).
- Case 4.2.3.4.4. Maximum possible temperature 212 °F (NJOY cross sections are 212 °F).

The reactivity effect of each tolerance is determined from:

delta-$k_{calc} = (k_{calc2} - k_{calc1}) \pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$

where $\pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$ is called the 95/95 uncertainty.

All design basis calculations consider the bounding moderator temperature and density using temperature adjusted cross sections and S(α,β) cards. Note that void formation is not considered credible [4.8].

4.2.3.5 Reactivity Effect of Fuel Assembly Channel and Radial Positioning of Fuel Assembly and Metamic Insert

The reactivity effect off the fuel assembly with and without the channel should be considered coincidently with the radial position of the fuel and Metamic insert. The fuel assembly can be in the following main radial locations: cell centered, centered between the insert and opposite corner, and eccentrically positioned towards all four corners. Additionally, the two main positions for the fuel in the 11x11 array are all fuel towards the center location and all fuel away from the center location. The Metamic insert can be in the following main positions: adjacent to the cell corner and as far from the cell corner as possible while adjacent to the fuel assembly. Note that the incorrect orientation of an insert is considered an accident condition and is therefore discussed in Section 4.2.5.8. The presence or lack of a channel impacts the physical distance for the various radial locations for Metamic inserts and fuel assembly. The dominant reactivity effect from these parameters is expected to be the radial position of the fuel assembly. The bounding radial location for fuel and insert, along with presence or absence of the fuel channel, is evaluated using the same 11x11 rack model as discussed in Section 4.2.3 (with the center cell Metamic insert missing) with GE7 fuel (GE7 with IMPAE at 4.0 wt% U-235 and nominal fuel design parameters) and with the exception for the variations described below:

Fuel Assembly Cell Centered, Fuel Channel Present:

- Case 4.2.3.5.1: Reference case. Metamic inserts are between fuel assembly and cell corner.
- Case 4.2.3.5.2: Metamic inserts are adjacent to the cell corner.
- Case 4.2.3.5.3: Metamic inserts are adjacent to the fuel assembly.

Fuel Assembly Cell Centered, Fuel Channel Missing:

- Case 4.2.3.5.4: Metamic inserts are centered between fuel assembly and cell corner.
- Case 4.2.3.5.5: Metamic inserts are adjacent to the cell corner.
- Case 4.2.3.5.6: Metamic inserts are adjacent to the fuel assembly.

Fuel Assembly Positioned Towards Rack Center, Fuel Channel Present:

- Case 4.2.3.5.7: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is centered in rack cell.
- Case 4.2.3.5.8: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is eccentric in rack cell.

Fuel Assembly Positioned Towards Rack Center, Fuel Channel Missing:

- Case 4.2.3.5.9: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is centered in rack cell.
- Case 4.2.3.5.10: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is centered in rack cell.

Fuel Assembly Positioned Away From Rack Center, Fuel Channel Present:

- Case 4.2.3.5.11: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is centered in rack cell.
- Case 4.2.3.5.12: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is eccentric in rack cell.

Fuel Assembly Positioned Away From Rack Center, Fuel Channel Missing:

- Case 4.2.3.5.13: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is centered in rack cell.
- Case 4.2.3.5.14: Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is eccentric in rack cell.

The reactivity effect of each tolerance is determined from:

$$\text{delta-}k_{calc} = (k_{calc2} - k_{calc1}) \pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$$

where $\pm 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)}$ is called the 95/95 uncertainty.

The maximum reactivity case is used for all design basis calculations.

4.2.3.6 Design Basis Model

The design basis model contains various bounding parameters that are determined from the results of the studies discussed in:

- Section 4.2.3.1 for the bounding fuel design (expected to be GE7 for normal conditions and GE13 for the misload accident)
- Section 4.2.3.2 for the bounding BWR BORAFLEX™ storage rack parameters
- Section 4.2.3.3 for the bounding Metamic insert parameters (expected to be minimum)
- Section 4.2.3.4 for the bounding SFP moderator temperature and density (expected to be 39.2 °F)
- Section 4.2.3.5 for the bounding radial position of the fuel assembly in the storage rack cell, the Metamic insert and the presence or lack of a fuel assembly channel.

The results of those studies are all considered in the design basis model for simplicity and margin.

Additionally, as discussed in Section 4.2.3 the design basis model considers:

- 11x11 array of storage cells with the BORAFLEX™ replaced by water.
- The 11x11 storage rack model replaces the cell geometry along the exterior with a simple cell wall.
- Adjacent to the exterior cell wall is water with a thickness equal to half the rack to rack gap.
- Periodic boundary conditions are considered along the water gap, thus creating a laterally infinite array.
- The center location of the 11x11 array does not include any insert.
- All materials in the model have the same temperature as the SFP moderator.

The design basis model described above is used for the following calculations:

- Case 4.2.3.6.1: Design basis model maximum k_{calc} with GE7 fuel with design IMPAE 3.282 wt% U-235.
- Case 4.2.3.6.2: Design basis model except with nominal fuel rod cladding thickness.
- Case 4.2.3.6.3: Design basis model except with nominal fuel rod pitch.
- Case 4.2.3.6.4: Design basis model except with nominal storage rack cell pitch.
- Case 4.2.3.6.5: Design basis model except with maximum Metamic thickness and width.
- Case 4.2.3.6.6: Design basis model with 500 ppm soluble boron.

The design basis model is presented in Figure 4.2.1.

4.2.3.6.1 Model Simplifications

While the fuel and rack models used in the analyses are very detailed, they still contain a number of modeling simplifications. The following is a list of those simplifications:

- The 11x11 storage rack model replaces the formed cells along the exterior with the poison pocket and sheathing with a simple cell wall. Adjacent to the exterior cell wall is water with a thickness equal to half the rack to rack gap. Periodic boundary conditions are considered along the water gap, thus creating a laterally infinite array. This is acceptable for cells in the center of the racks, where the effect of any lateral neutron leakage would be negligible. This is conservative for cells on the periphery of the racks, specifically on the periphery of the pool, since it conservatively neglects the lateral leakage in those areas which will reduce reactivity.
- Dishing and chamfering of the fuel pellets is neglected, i.e. the fuel is always modeled as solid cylinder inside the cladding. This is acceptable since the amount of fuel is maintained, and the water-to-fuel ratio and the principal location of the fuel remain unchanged.
- Minor parts of the fuel and rack construction are neglected and replaced by water. Those include grid straps and minor structural rack components.
- The residual B-10 amount in the BORAFLEX™ in the racks is neglected in the analyses. The BORAFLEX™ is replaced by water in the MCNP5-1.51 model. This is appropriate because as the absorber material degrades, the polymer and silica substrate which hold the B4C are removed together with the B4C and replaced by the water in the SPF.
- All fuel cladding material is modeled as pure zirconium, while the actual fuel cladding consists of one of several zirconium alloys. This is acceptable since the model neglects the trace elements in the alloy which may provide additional neutron absorption.

4.2.3.7 Storage Rack Interfaces

The Harris site Pool A and B BWR BORAFLEX™ storage racks have the following rack to rack interfaces:

Pool A

- BWR BORAFLEX™ to PWR BORAFLEX™
- BWR BORAFLEX™ to BWR BORAFLEX™

Pool B

- BWR BORAFLEX™ to PWR BORAFLEX™
- BWR BORAFLEX™ to BWR BORAL
- BWR BORAFLEX™ to BWR BORAFLEX™

For both Pool A and B, the design basis model described in Section 4.2.3.6 considers the minimum BWR BORAFLEX™ storage rack to rack gap and therefore bounds all BWR BORAFLEX™ storage rack to storage rack interfaces for Pool A and Pool B.

For the non BWR BORAFLEX™ storage rack to storage rack interfaces, the interface conditions are evaluated using the interface assumption: *the interface does not result in a more reactive condition than the infinite array calculations*. This is because the geometry and material conditions (of the racks) is assumed to create a physical configuration that does not allow for neutron coupling between racks. Since the more reactive condition (infinite arrays) is considered for the

determination of k_{eff}, *regulatory compliance is determined by the validation of the infinite array calculations and not the interface calculations.* Rather, *the interface qualification is determined by demonstration that the basic assumption is valid.*

The interface assumption validation for the rack to rack interfaces is complicated by the fact that for any given reactivity calculations, the reactivity determined (i.e. k_{calc}) is necessarily the maximum reactivity at any single point in the calculation model, no matter how large or small the model. For example, if there are two racks in a spent fuel pool where Rack A is a high reactivity rack with a k_{eff} of 0.99 and Rack B is a low reactivity rack with a k_{eff} of 0.97 (where k_{eff} is from the infinite array calculations at the 95/95 level to meet regulatory requirements), and an interface calculation is performed with Rack A very far from Rack B (far enough to preclude any neutron coupling), the resulting calculated reactivity (k_{calc}) will necessarily be due to Rack A. This example calculation does not provide any useful information whatsoever about the reactivity of Rack B or about the interface between Rack A and Rack B and therefore cannot be used to validate the interface assumption. For the interface calculation, if the calculation is performed by placing Rack A very close to Rack B and the result of the calculation is that the interface k_{calc} is less than the infinite array k_{calc} for the loading pattern in Rack A, then the interface calculation has determined that the interface assumption for Rack A only is validated. If the k_{calc} of the interface calculation is higher than the infinite array calculations for the loading pattern in Rack A then no determination can be made about which rack has the higher reactivity and the interface assumption has not been validated. Therefore, because of this complication, various approaches have been developed to validate the interface assumption for such cases. The approach selected for the Harris Pool A and B BWR BORAFLEX™ storage rack interfaces is discussed below.

Note that the interface evaluation presented in this analysis is used to qualify the BWR BORAFLEX™ storage racks with Metamic inserts only. The BWR BORAL storage racks and PWR BORAFLEX™ storage racks are qualified under separate analysis [4.11, 4.12], respectively. Additionally, note that:

- In [4.10] depletion calculations were performed to generate the 17x17 PWR spent fuel isotopic compositions for use in the interface and accident evaluations. Those same isotopic compositions are used in this analysis. The spent PWR fuel isotopic compositions are not recalculated, therefore the methodology for their determination is referred to in [4.10].
- The PWR BORAFLEX™ storage racks do not credit residual BORAFLEX™ and may contain either a checkerboard of fresh and empty cells or spent fuel in a uniform loading pattern [4.11].
- The BWR BORAL racks credit BORAL and consider fresh BWR fuel only [4.12]. The BWR BORAL racks have the same BWR fuel design restrictions that are imposed on the BWR BORAFLEX™ racks (i.e. the GE7 is the design basis fuel assembly).
- The BWR BORAL storage rack contains 90% of the minimum B-10 and has the minimum thickness (see Table 4.5.2).
- For the interface calculations, the BWR BORAL storage racks and the BWR BORAFLEX™ storage rack are fully loaded with fresh GE7 fuel at the design IMPAE and consider that same fuel design parameters as determined for the BWR BORAFLEX™ storage rack with Metamic inserts bounding design basis model (see Case 4.2.3.6.1).

- The 17x17 fuel design which is fully characterized in Table 4.5.1.a is considered bounding of the other PWR fuel designs at Harris [4.11]. Note that the PWR BORAFLEX™ storage rack design parameters, as well as the fuel design parameters, are treated at nominal values.

The interface assumption for the BWR BORAFLEX™ storage rack with Metamic inserts is validated using the following approach:

- A single storage rack model with reflective boundary conditions along the half rack to rack water gap is developed for the three storage rack designs.
- The reactivity of the infinite array for each rack design is evaluated to determine if additional calculations are needed.
    - The bounding BWR BORAFLEX™ storage rack model, i.e. Case 4.2.3.6.1, is evaluated since this is the model which shows compliance with the regulatory requirements.
    - The evaluation of the BWR BORAL storage racks with GE7 fresh fuel and PWR BORAFLEX™ storage racks with both fresh and spent 17x17 fuel will determine if the reactivity of those configurations is significantly lower than the BWR BORAFLEX™ storage racks with Metamic inserts.
        - For the PWR BORAFLEX™ storage rack infinite array model with spent fuel, it is necessary to perform additional full pool interface calculations since the burnup requirements were determined in another analysis [4.11]. The full pool interface calculations require that the PWR fuel reactivity that is essentially the same as the reactivity of the BWR BORAFLEX™ storage rack with Metamic inserts. Therefore, the evaluation of the PWR BORAFLEX™ storage rack infinite array model is evaluated at a burnup which yields the appropriate infinite array reactivity. The same burnup will then be used in the full pool interface calculations. See Section 4.5.1 for a description of the PWR spent fuel isotopics.
- Full pool models are developed to create interface models that are used to calculate the reactivity of the various interfaces.
- The interface assumption is then validated by evaluating the reactivity of the full pool interface model(s). The requirement is that the reactivity of the full pool interface model must be no greater than the reactivity of the BWR BORAFLEX™ storage rack with Metamic inserts.

The following interface assumption criteria cases are evaluated:

- Case 4.2.3.7.1: BWR BORAFLEX™ storage rack infinite array. Same as design basis model (Case 4.2.3.6.1).
- Case 4.2.3.7.2: BWR BORAL storage rack infinite array. Fuel is centered in storage rack. See Figure 4.2.2.
- Case 4.2.3.7.3: PWR BORAFLEX™ storage rack infinite array with a uniform loading of spent PWR with an initial enrichment of 5.0 wt% U-235 fuel at a burnup which yields essentially the same reactivity as Case 4.2.3.7.1. Fuel is centered in storage rack. See Figure 4.2.3.

- Case 4.2.3.7.4: PWR BORAFLEX™ storage rack infinite array with a checkerboard of empty and fresh PWR with an enrichment of 5.0 wt% U-235. Fuel is centered in storage rack. See Figure 4.2.4.

The interface evaluations are performed, if needed, for the various rack to rack interfaces using full pool models for Harris Pool A. Note that the BWR BORAL racks are essentially identical to the BWR BORAFLEX ™ racks with the exception of the neutron absorber. Therefore, it is expected that the reactivity of the BWR BORAL racks will be bounded (significantly lower reactivity) by the reactivity of the BWR BORAFLEX ™ racks. Since the rack designs are essentially identical, and the same fuel storage restrictions apply to both storage rack designs, it is expected that additional interface calculations for the BWR BORAFLEX ™ storage rack to BWR BORAL storage rack interface will not be necessary because the design basis BWR BORAFLEX ™ model (Case 4.2.3.6.1) bounds both rack designs. Furthermore, since Pool A and B contain PWR BORAFLEX ™ storage racks, but Pool A does not contain BWR BORAL storage racks, only Pool A full pool interface calculations will be necessary.

The full pool model (Pool A only) interface cases are:

- Case 4.2.3.7.5: BWR BORAFLEX™ storage racks are the same as Case 4.2.3.6.1 (bounding design basis configuration). The PWR BORAFLEX™ storage rack contain a uniform loading of spent PWR with an initial enrichment of 5.0 wt% U-235 fuel and the same burnup as Case 2.3.7.3. The PWR fuel is positioned eccentrically towards the BWR BORAFLEX™ storage racks. See Figure 4.2.5.
- Case 4.2.3.7.6: Same as Case 4.2.3.7.5 except that the PWR fuel is cell centered.
- Case 4.2.3.7.7: The model is the same as Case 4.2.3.7.5 except that the PWR BORAFLEX™ storage rack contain a checkerboard of empty and fresh PWR with an enrichment of 5.0 wt% U-235.
- Case 4.2.3.7.8: Same as Case 4.2.3.7.7 except that the PWR fuel is cell centered.
- Case 4.2.3.7.9: Same as Case 4.2.3.7.5 except the BWR fuel is eccentrically positioned towards the PWR fuel.
- Case 4.2.3.7.10: Same as Case 4.2.3.7.9 except the PWR fuel is cell centered.
- Case 4.2.3.7.11: Same as Case 4.2.3.7.7 except the BWR fuel is eccentrically positioned towards the PWR fuel.
- Case 4.2.3.7.12: Same as Case 4.2.3.7.11 except the PWR fuel is cell centered.
- Case 4.2.3.7.13: Same as Case 4.2.3.7.5 except there is no PWR fuel in the PWR racks.
- Case 4.2.3.7.14: Same as Case 4.2.3.7.13 except the BWR fuel is eccentrically positioned towards the PWR racks.

Note that the rack to rack gaps are considered in a conservative manner. The absolute minimum gaps allowed by the rack baseplate extensions are considered [4.8], with this minimum distance being measured from exterior rack wall to exterior rack wall (i.e. not from exterior sheathing to exterior sheathing). Additionally, there are minor differences in the gaps between racks for the full pool model (Case 4.2.3.7.5 through Case 4.2.3.7.14) when compared to the infinite array cases models (Case 4.2.3.7.1 through Case 4.2.3.7.4). For the infinite array models (Case 4.2.3.7.1 through Case 4.2.3.7.4), the periodic boundary conditions along the half water gap defines the rack

to rack gaps. The full pool model is more complex and therefore the model ensures that the gaps remain conservative (i.e. as small as possible) by making them smaller in some cases. Furthermore, the large gap in Pool A between the rows of PWR BORAFLEX™ storage racks is modeled as a large gap, as installed and described in [4.8].

4.2.4 Fuel Movement, Reconstitution etc

The Harris SFP is essentially a repository for spent BWR fuel. Therefore, typical SFP activities such as BWR fuel movement, reconstitution, channeling/dechanning efforts are not normal activities for the BWR fuel. In the case where BWR fuel is moved, the various dropped accident and misload activities are covered by the accident conditions in Section 4.2.5. Fuel activities related to the PWR fuel are also addressed considering the accident conditions (see Section 4.2.5).

4.2.5 Accident Conditions

There are various potential accident conditions that must be evaluated. The credible accidents to be evaluated are:

- The effect of SFP temperature exceeding the normal range.
- A dropped fuel assembly:
- A misloaded fuel assembly (a fuel assembly in the wrong location within the storage rack)
- A mislocated fuel assembly (a fuel assembly in the wrong location outside the storage rack).
- Rack movement due to seismic activity.
- Mis-orientation of Metamic inserts.

As discussed previously in Section 4.2.3.7, the 17x17 5.0 wt% fuel design is considered for the interface and accident analysis. This fuel design is considered bounding of the other 15x15 PWR fuel designs at Harris [4.11] and therefore no separate calculations are performed. The 17x17 fuel design is fully characterized in Table 4.5.1.

For each accident condition considered, an additional calculation is performed with a soluble boron concentration of 1000 ppm. From the full set of accident conditions, the most reactive case is determined from the highest reactivity at 1000 ppm soluble boron.

4.2.5.1 Temperature and Water Density Effects

The SFP water temperature accident conditions for consideration are the decrease and increase in SFP water temperature below and above the nominal SFP temperature range of 85 to 105 °F. The decrease and increase in temperature is evaluated in Section 4.2.3.4. The increase in temperature accident that leads to boiling in the Harris SFP A and B is not considered credible (see Section 5.0).

4.2.5.2 Dropped Assembly – Horizontal

For the case in which a fuel assembly is assumed to be dropped on top of a rack, the fuel assembly will come to rest horizontally on top of the rack with a minimum separation distance from the active fuel region of more than 12 inches [4.8], which is sufficient to preclude neutron coupling (i.e., an effectively infinite separation). Consequently, the horizontal fuel assembly drop accident will not result in a significant increase in reactivity. Furthermore, any reactivity increase would be small compared to the reactivity increase created by the misloading of a fresh assembly discussed in one of the following sections. The horizontal drop is therefore bounded by this misloading accident and no separate calculation is performed for this drop accident.

4.2.5.3 Dropped Assembly – Vertical into a Storage Cell

It is also possible to vertically drop an assembly into a location that might be occupied by another assembly with a Metamic insert or that might be empty. Such a vertical impact would at most cause a small compression of the stored assembly, if present, or result in a small deformation of the baseplate for an empty cell. The damage to the Metamic insert would be minimal due to the necessary presence of the fuel assembly which would absorb majority of the drop accident deformation. These deformations could potentially increase reactivity. However, the reactivity increase would be small compared to the reactivity increase created by the misload of a fresh assembly discussed in one of the following sections. The vertical drop is therefore bounded by this misload accident and no separate calculation is performed for this drop accident.

4.2.5.4 Misloaded Fresh Fuel Assembly

As discussed in Section 4.1, an administrative requirement to restrict the fuel assembly designs allowed in Pool A and B will preclude the presence of the higher reactivity designs GE8, GE9, GE10 and GE13. However, it is possible that one of those restricted fuel assembly designs could be accidently placed in the BWR BORAFLEX^{TM} racks in Pool A and B. Therefore, the follow multiple misload accident condition is evaluated:

- Case 4.2.5.4.1: Same model as Case 4.2.3.6.1 except the GE7 fuel assembly in every location is replaced by a fresh 5.0 wt% U-235 GE13 fuel assembly. The GE13 fuel in the model considers nominal design parameters and is channeled and include the following assumptions apply: no part length rods (considered the more reactive lattice [4.11]) or axial blankets and the axial length increased to 150 inches. Note that the enrichment of the fresh GE13 fuel assembly is increased to 5.0 wt% U-235 whereas the actual IMPAE is less than 4.2 wt% U-235. Note that this configuration is very conservative and bounds all possible multiple misload configurations. Thus, studies are not performed with the GE13 to determine the bounding fuel design parameters. The SFP moderator has 0 ppm soluble boron.
- Case 4.2.5.4.2: Same model as Case 4.2.5.4.1 except that the SFP moderator has 1000 ppm soluble boron.

The misload accident calculations are performed with models that also cover the unlikely scenario of multiple misloaded GE13 fuel assemblies.

4.2.5.5 Mislocated Fresh Fuel Assembly

The possibility exists that a BWR or PWR fuel assembly could be accidently mislocated outside of the BWR BORAFLEX™ racks in either Pool A or B. The three bounding cases are the fresh GE13 (similar to the misload accident discussed in Section 4.2.5.4), the fresh PWR fuel assembly and the spent PWR fuel assembly. Of those three cases the fresh 17x17 PWR assembly with no burnable absorbers is the bounding mislocated accident scenario due to the larger size and actual physical presence of the fresh PWR fuel in the SFP (the GE13 fuel is all spent and administratively restricted from Pool A and B).

The Harris SFP A and B layout was examined to determine possible worst case locations for a mislocated fresh PWR fuel assembly adjacent to the BWR BORAFLEX™ storage racks. The worst possible locations would be in locations where the mislocated fuel assembly would be face adjacent to two or more fuel assemblies in storage racks with no poison between them. The worst case locations are shown in Figure 4.2.6. This location, although not physically possible, bounds all other possible configurations because the mislocated fuel may be face adjacent, with no neutron absorber between them, to up to three fuel assemblies (one BWR and up to two PWR assemblies in the racks). Therefore, this scenario, although not physically possible, is evaluated and no other mislocated cases are required.

The base case model for the mislocated fuel assembly considers the following:

- The model is a full pool model (see Figure 4.2.6) with minimum rack to rack gaps considered along with a water reflector on the exterior of the rack. The water reflector is acceptable because the reactivity in the model is dominated either in the center of the BWR BORAFLEX™ rack or in the location of the mislocated PWR fuel assembly. Thus, the geometry at the exterior of the racks along the pool wall is of no concern.
- The fresh GE7 BWR fuel is eccentrically positioned toward the center BWR BORAFLEX™ rack center (i.e. the bounding configuration for normal conditions). All BWR fuel and BORAFLEX™ rack parameters are considered in the bounding manner, as concluded in Section 4.2.3.6, including that the central location does not include a Metamic insert. All Metamic inserts have the orientation shown in Figure 4.1.1.
- The PWR fuel is a uniform loading of spent fuel and the PWR fuel is cell centered.
- The gap between the PWR racks where the PWR fuel assembly is mislocated is widened slightly (by allowing the surface which defines the rack exterior to cut off most of the external sheathing). This is done to allow the mislocated fuel to just fit in the gap.
- The mislocated fresh 5.0 wt% U-235 17x17 PWR fuel assembly is face adjacent and at its closest approach to the BWR fuel.
- The SFP moderator has 0 ppm soluble boron.

The following cases are therefore considered with variations to the above base case as noted:

- Case 4.2.5.5.1: Same as base case.
- Case 4.2.5.5.2: Same as Case 4.2.5.5.1 except the SFP moderator has 1000 ppm soluble boron.

- Case 4.2.5.5.3: Same as Case 4.2.5.5.1 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
- Case 4.2.5.5.4: Same as Case 4.2.5.5.3 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.5: Same as Case 4.2.5.5.1 except the BWR fuel is eccentrically positioned toward the mislocated PWR fuel.
- Case 4.2.5.5.6: Same as Case 4.2.5.5.5 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.7: Same as Case 4.2.5.5.5 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
- Case 4.2.5.5.8: Same as Case 4.2.5.5.7 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.9: Same as Case 4.2.5.5.1 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.10: Same as Case 4.2.5.5.9 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.11: Same as Case 4.2.5.5.3 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.12: Same as Case 4.2.5.5.11 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.13: Same as Case 4.2.5.5.5 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.14: Same as Case 4.2.5.5.13 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.15: Same as Case 4.2.5.5.7 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.16: Same as Case 4.2.5.5.15 except the SFP moderator has 1000 ppm soluble boron.

<u>Administrative Restriction 3 Variations</u>

As discussed in Section 4.1, Administrative Restriction 3 requires that:

- No fuel shall be stored in the storage cell at the northeast corner of the BWR BORAFLEX™ storage racks nearest the interface with the PWR BORAFLEX™ storage racks on the north and east side in Pool A.

Therefore, to determine the reactivity effect of Restriction 3, the more bounding mislocated accident conditions discussed in Cases 4.2.5.5.1 through 4.2.5.5.16 above are modified to remove the BWR fuel assembly in the model. The following cases are evaluated:

- Case 4.2.5.5.17: Same as Case 4.2.5.5.1 except the corner BWR fuel assembly is removed.
- Case 4.2.5.5.18: Same as Case 4.2.5.5.17 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.19: Same as Case 4.2.5.5.17 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
- Case 4.2.5.5.20: Same as Case 4.2.5.5.19 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.21: Same as Case 4.2.5.5.17 except the BWR fuel is eccentrically positioned toward the mislocated PWR fuel.
- Case 4.2.5.5.22: Same as Case 4.2.5.5.21 except the SFP moderator has 1000 ppm soluble boron.

- Case 4.2.5.5.23: Same as Case 4.2.5.5.21 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
- Case 4.2.5.5.24: Same as Case 4.2.5.5.23 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.25: Same as Case 4.2.5.5.17 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.26: Same as Case 4.2.5.5.25 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.27: Same as Case 4.2.5.5.19 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.28: Same as Case 4.2.5.5.27 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.29: Same as Case 4.2.5.5.21 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.30: Same as Case 4.2.5.5.29 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.5.31: Same as Case 4.2.5.5.23 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX™ racks.
- Case 4.2.5.5.32: Same as Case 4.2.5.5.31 except the SFP moderator has 1000 ppm soluble boron.

Additional Mislocated Accident Cases

The two sets of mislocated accident cases above, i.e. Case 4.2.5.5.1 through Case 4.2.5.5.32, considered a water reflector on the outside of the storage racks in the full pool model. This assumption is acceptable because the mislocated fuel assembly is in the center of the storage racks. Additional calculations are performed for the same configurations as Case 4.2.5.5.1 through Case 4.2.5.5.32 except with a concrete wall surrounding the SFP. Additionally, an alternative mislocated accident fuel assembly location, i.e. between the SFP wall and BWR rack is also provided to demonstrate that the bounding configuration is provided in Case 4.2.5.5.1 through Case 4.2.5.5.32.

The concrete wall is assumed to have the bounding material composition described in [4.15] and a thickness of 40 cm (an infinite reflector for concrete). The pool liner is neglected. The descriptions of these cases is presented in Appendix 4.B.

4.2.5.6 Rack Movement

During seismic activity the storage racks may move. Since Pool A only credits the Metamic inserts (i.e. Pool B has BWR BORAL racks) only Pool A is considered for this accident. The following evaluations are performed:

The base case model for the rack movement accident considers the following:

- The model is a full pool model (similar to Figure 4.2.6) which considers nearly closed rack to rack gaps along with a water reflector on the exterior of the rack. The water reflector is acceptable because the reactivity in the model is dominated either in the center of the BWR BORAFLEX™ rack or in the location in the center of the model where the PWR racks are adjacent to two sides of the BWR racks. Thus, the geometry at the exterior of the racks along the pool wall is of no concern.

- The fresh GE7 BWR fuel is eccentrically positioned toward the center BWR BORAFLEX™ rack center (i.e. the bounding configuration for normal conditions). All BWR fuel and BORAFLEX™ rack parameters are considered in the bounding manner, as concluded in Section 4.2.3.6, including that the central location does not include a Metamic insert. All Metamic inserts have the orientation shown in Figure 4.1.1.
- The PWR fuel is a uniform loading of spent fuel and the PWR fuel is cell centered.
- All gaps are reduced so that the racks are closer than possible due to the baseplate extensions.
- The SFP moderator has 0 ppm soluble boron.

The following cases are therefore considered with variations to the above base case as noted:

- Case 4.2.5.6.1: Same as base case.
- Case 4.2.5.6.2: Same as Case 4.2.5.6.1 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.6.3: Same as Case 4.2.5.6.1 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
- Case 4.2.5.6.4: Same as Case 4.2.5.6.3 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.6.5: Same as Case 4.2.5.6.1 except the BWR fuel is eccentrically positioned toward the location where two PWR racks are adjacent to the BWR rack.
- Case 4.2.5.6.6: Same as Case 4.2.5.6.5 except the SFP moderator has 1000 ppm soluble boron.
- Case 4.2.5.6.7: Same as Case 4.2.5.6.5 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
- Case 4.2.5.6.8: Same as Case 4.2.5.6.7 except the SFP moderator has 1000 ppm soluble boron.

4.2.5.7 Missing Metamic Inserts

As discussed in Section 4.2.3.6, the design basis models consider the missing Metamic insert already, in conjunction with the misload accident (see Section 4.2.5.4). Therefore, no further evaluations are required.

4.2.5.8 Mis-orientation of Metamic Inserts

As discussed in Section 4.1, the orientation of the Metamic inserts is controlled by an administrative requirement. Therefore, the accident condition of mis-oriented inserts should be evaluated. For the mis-orientation accident, the Metamic inserts are present in all storage rack locations, however, one or more are not oriented as shown in Figures 4.1.1 and 4.1.2. In general, since the Metamic inserts are not missing, but mis-oriented, the worst configuration is where there is a 2x2 array with four fuel assembly to fuel assembly gaps with no Metamic panel; however, this configuration still has the four inserts albeit in a different configuration. For simplicity and conservatism, the mis-orientation accident is covered by the more reactive configuration with four missing inserts adjacent to the missing insert in the central location of the design basis model (Case 4.2.3.6.1). In this configuration, the fuel assembly in the center of the model (which has no Metamic insert) is face adjacent to four other locations with no Metamic insert. Each of those four other locations which are missing Metamic inserts also therefore have a fuel assembly face adjacent to another

fuel assembly with no Metamic insert between them. See Figure 4.2.7. The following cases are evaluated:

- Case 4.2.5.8.1: The model is the same as Case 4.2.3.6.1 except that the center location, and the four locations which are face adjacent to the center location have no Metamic insert. The SFP has 0 ppm soluble boron.
- Case 4.2.5.8.2: The model is the same as Case 4.2.5.8.1 except that the SFP has 1000 ppm soluble boron.

4.2.5.9 Calculations to Determine k_{eff} Values

The calculation of the maximum k_{eff} for both normal and accident conditions for the BWR BORAFLEX™ storage racks in the Harris Pool A and B includes the following conservative biases within the design basis model:

- Bounding fuel assembly parameters
- Bounding storage rack parameters
- Bounding Metamic insert design parameters
- Bounding radial positioning of the Metamic insert and fuel assembly

Therefore, the calculated reactivity is conservatively biased. The maximum k_{eff} is determined using the following equation:

$k_{eff} = k_{calc}$ + uncertainty + bias

where k_{calc} includes:

- Maximum reactivity normal case k_{calc} or,
- Maximum reactivity accident case.

where uncertainty includes:

- Coupon Measurement uncertainty
- MCNP5-1.51 bias uncertainty (95% probability at a 95% confidence level)
- MCNP5-1.51 calculations statistics (95% probability at a 95% confidence level, 2σ)

and the bias includes

- MCNP5-1.51 bias
- 1% NRC Administrative Margin

Note that each uncertainty is statistically combined with other uncertainties, while biases are added together in order to determine k_{eff}. The approach used here takes credit for soluble boron under normal conditions (see Section 4.3). Under this approach, the limiting condition is the non-borated

condition, which needs to be shown to result in a maximum k_{eff} of less than 1.0 at the 95/95 level. Note that for the cases with credit for soluble boron, where the regulatory limit is 0.95, no specific target k_{eff} is defined, rather a soluble boron concentration is selected and the k_{eff} is shown to meet the regulatory limit.

4.2.5.10 Margin Evaluation

The criticality analysis methodology conservatively includes biases in the design basis model for simplicity and margin. The following is a summary of the approach:

- Bounding fuel assembly parameters treated as a bias rather than as an uncertainty.
- Bounding storage rack parameters treated as a bias rather than as an uncertainty.
- Bounding Metamic insert design parameters treated as a bias.
- Bounding radial positioning of the Metamic insert and fuel assembly treated as a bias.
- Planar average enrichment versus pin specific enrichments (Section 4.2.3.5.3) treated as a bias (see Case 4.2.3.1.2.10).

Additionally a 1% bias is applied to bias the results of the analysis for the NRC to use as administrative margin.

4.3 Acceptance Criteria

Codes, standard, and regulations or pertinent sections thereof that are applicable to these analyses include the following:

- Code of Federal Regulations, Title 10, Part 50, Appendix A, General Design Criterion 62, "Prevention of Criticality in Fuel Storage and Handling."

- Code of Federal Regulations, Title 10, Part 50, Section 68, "Criticality Accident Requirements"

- USNRC Standard Review Plan, NUREG-0800, Section 9.1.1, Criticality Safety of Fresh and Spent Fuel Storage and Handling, Rev. 3 – March 2007.

- L. Kopp, "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," NRC Memorandum from L. Kopp to T. Collins, August 19, 1998.

- ANSI ANS-8.17-1984, Criticality Safety Criteria for the Handling, Storage and Transportation of LWR Fuel Outside Reactors.

- USNRC, NUREG/CR-6698, Guide for Validation of Nuclear Criticality Safety Calculational Methodology, January 2001.

- DSS-ISG-2010-01, Revision 0, Staff Guidance Regarding the Nuclear Criticality Safety Analysis for Spent Fuel Pools.

Consistent with the requirements in 10CFR50.68(b)(4), the objective of this analysis is to ensure that the effective neutron multiplication factor (k_{eff}) is less than or equal to 0.95 with the pool flooded with borated water, and that it is less than 1.0 under the assumed accident of the loss of soluble boron in the pool water, i.e. assuming unborated water in the spent fuel pool, all for 95% probability at a 95% confidence level.

4.4 Assumptions

The analyses apply a number of assumptions, either for conservatism or to simplify the calculation approach. Each assumption is appropriately discussed and justified in the text. Important aspects of applying those assumptions are as follows:

- Bounding or sufficiently conservative inputs and assumptions are used essentially throughout the entire analyses, and in most cases, studies are presented to show that the selected inputs and parameters are in fact conservative or bounding.
- An evaluation is performed to estimate the overall margins of the analyses. This evaluation includes considerations for potential non-conservatisms throughout the analyses, to ensure those are covered by the margin.

4.5 Input Data

4.5.1 Fuel Assembly Designs

The BWR and PWR fuel assembly data used in the analysis is presented in Table 4.5.1a and Table 4.5.1b. The GE7 pin map is provided in [4.14].

All BWR fuel is modeled as fresh fuel with no Gd, while the PWR fuel is both fresh (no reactivity control devices) and spent.

The GE13 is modeled with no axial blankets, no part length rods, and the axial length increased to 150 inches.

For the PWR fuel, only the 17x17 design is considered since this design bounds the 15x15 design [4.11]. All 17x17 spent fuel isotopic compositions are taken directly from [4.10], with the exception of the lumped fission products [4.10] which were removed.

For all fuel designs, the fuel assembly is explicitly modeled in terms of fuel pin, cladding, water holes and channels (BWR fuel) and guide tubes (PWR fuel). The water holes, channels and guide tubes are all considered to be the same length as the fuel.

4.5.2 Storage Rack Designs

The storage rack designs data used in the analysis is presented in Table 4.5.2.

The MCNP5-1.51 storage rack models consider the axial height of the rack beginning at the top of the rack baseplate. The baseplate itself is not considered, and everything below the bottom of the fuel is replaced by water. The storage rack height however extends above the active length of the fuel to its full height. This is done because the various fuel designs considered in this analysis have various axial lengths and therefore for those cases where various rack designs exist in the same model the axial variation is considered. This approach is not expected to have any impact on the results of the analysis since only fresh fuel is considered with no axial variations and therefore the maximum reactivity will be in the center of the fuel assembly. Note that the BWR racks and PWR racks baseplate tops are at different heights and this difference is also considered.

4.5.2.1 BWR BORAFLEX™ Spent Fuel Storage Racks

The BWR BORAFLEX™ spent fuel storage racks are located in both Pool A (three 11x11 racks) and Pool B (five 11x11 racks) and were designed by Westinghouse. These racks contain 968 storage spaces that are the focus of this analysis. The BORAFLEX™ used in the design has known degradation issues and it is assumed to be completely gone for this analysis and is replaced by water in the MCNP5-1.51 models. The storage racks are composed of an 11x11 array of stainless steel boxes, joined at the corners in an egg-crate structure such that there are two cell types, one that is fabricated and one that is formed. The original BORAFLEX™ material was fixed to the fabricated cell wall exterior with sheathing.

As discussed in Section 4.2, various BWR BORAFLEX™ rack models are considered for the various evaluations.

4.5.2.2 PWR BORAFLEX™ Storage Racks

The PWR BORAFLEX™ storage racks were designed by Westinghouse and are located in both Pool A (six 6x10 racks) and Pool B (five 6x10, six 7x10 and one 6x8 racks). These racks are qualified (with soluble boron credit) to contain both fresh (in a checkerboard of fresh and empty cells) and spent fuel (in a uniform loading pattern) [4.11]. As discussed in Section 4.5.2.1 the BORAFLEX™ used in the design has known degradation issues and it is assumed to be completely gone for this analysis and is replaced by water in the MCNP5-1.51 models. The various storage racks are low density flux trap style racks. This geometry is explicitly modeled.

4.5.2.3 BWR BORAL Storage Racks

The BWR BORAL racks were designed by Holtec International and are located only in Pool B (twelve 11x11 racks). These storage racks credit the BORAL, do not take credit for soluble boron and are qualified to store the same GE fuel designs considered in this analysis for the BWR BORAFLEX™ storage racks [4.12]. The analysis in [4.12] considered the GE7 as the design basis analysis and therefore the current analysis considers the BWR BORAL racks fully loaded with GE7 fuel.

The various storage racks are composed of arrays of stainless steel boxes, joined at the corners in an egg-crate structure such that there are two cell types, one that is fabricated and one that is

formed. This geometry is explicitly modeled. Each storage rack has a Boral panel fixed along the exterior [4.12].

4.5.2.4Rack to Rack Gaps

In Pool A there are both BWR BORAFLEX™ and PWR BORAFLEX™ storage racks and in Pool B there are BWR BORAFLEX™, PWR BORAFLEX™ and BWR BORAL storage racks. The gaps between these racks vary from pool to pool and within each pool for the various rack types. Therefore, minimum rack spacing values were determined for use in the accident and interface calculations. These values are presented in Table 4.5.3 and are applicable to both pools.

4.5.3 Metamic Insert Design

The Metamic insert design parameters are presented in Table 4.5.4. The Metamic insert is fabricated using a single extruded sheet of Metamic which is rolled to the desired thickness. The Metamic sheet is then trimmed to the desired dimensions and the slots are cut for bending using a waterjet. The insert is heated prior to each bend, including bending of top of the insert for mounting of the head piece and a full length continuous bend. Following the final bend, the insert is placed in a flattening fixture, and allowed to cool. It may be necessary to perform multiple flattening iterations to meet the desired flatness requirements. The final step of fabrication is to machine and install the insert head piece. All Metamic insert design parameters are then verified using the appropriate QA processes.

4.5.4 Material Composition

The material compositions for the various MCNP models are presented in Table 4.5.5.

4.6 <u>Computer Codes</u>

See Section 4.2.2.

4.7 <u>Analysis</u>

As discussed in Section 4.2, the analysis is performed using a combination of bounding analysis parameters and statistical uncertainties. The use of bounding analysis parameters allows for simplicity and inclusion of analysis margin in the results. The following analysis parameters are treated in a bounding manner:

- Fuel assembly manufacturing parameters.

- Storage rack manufacturing parameters.
- Metamic insert manufacturing parameters.
- SFP moderator temperature.
- Radial positioning of fuel assembly, Metamic insert location, and presence of fuel assembly channel.
- 11x11 array used in design basis model includes a missing insert in center location.

Additional discussions are provided below.

4.7.1 Bounding Fuel Design and Fuel Assembly Parameters

As discussed in Section 4.2.3.1.1 and 4.2.3.1.2, the analysis performs evaluations to determine the most reactive fuel design and fuel design parameters for use as the design basis assembly.

4.7.1.1 Bounding Fuel Design

As discussed in Section 4.1, the following BWR GE fuel designs are permitted for storage in the Harris Pool A and B BWR BORAFLEX™ storage racks: GE3, GE4, GE5, GE6 and GE7. Additionally, for accident conditions, all administratively non-permitted designs, i.e. the GE8, GE9, GE10 and GE13, are evaluated to determine the bounding fuel assembly for the accident analysis. For simplicity and analysis margin, the GE13 is selected as the bounding accident fuel design with a conservative IMPAE of 5.0 wt% U-235. Thus, further evaluations of the administratively non-permitted fuel designs are not required since the GE13, while already the fuel design with the highest IMPAE, is evaluated with the conservative IMPAE of 5.0 wt% U-235.

As discussed in Section 4.2.3.1.1, evaluations are performed and the results are presented in Appendix 4.A, Table 4.A.1. The GE fuel designs evaluated are fully characterized in Table 4.5.1.a and Table 4.5.1.b.

4.7.1.2 Bounding Fuel Design Parameters

As discussed in Section 4.2.3.1.2, evaluations are performed for the bounding fuel design, the GE7, and the accident case fuel design, the GE13. The results of the evaluations for the bounding fuel design parameters is presented in Appendix 4.A, Table 4.A.2. The results show that the bounding GE7 fuel design parameters are:

- Maximum fuel rod density and pellet OD.
- Minimum fuel rod clad thickness.
- Maximum fuel rod pitch.

The water rod and channel thickness have minimal impact. Therefore, for calculations with those parameters nominal dimensions are used.

Therefore, for all design basis calculations the bounding set of fuel assembly parameters is used. This is conservative and provides analysis margin because the reactivity effect of the fuel assembly parameters is treated as a bias rather than an analysis uncertainty.

Note that the results for the pin specific enrichment cases, Case 4.2.3.1.2.10, show that it is acceptable to use the IMPAE rather than pin specific enrichments.

4.7.2 Bounding BWR BORAFLEX™ Storage Rack Parameters

As discussed in Section 4.2.3.2, the BWR BORAFLEX™ storage rack parameters were evaluated to determine the bounding set for use in the design basis model. The results of the evaluations are presented in Appendix 4.A, Table 4.A.3. The results presented in Appendix 4.A, Table 4.A.3 show that the bounding BWR BORAFLEX™ storage rack parameters are:

- Minimum storage cell pitch.

Note that the storage cell inner diameter and cell wall thickness had minimal impact. Therefore those parameters are treated as nominal.

Therefore, for all design basis calculations the bounding set of BWR BORAFLEX™ storage rack parameters is used. This is conservative and provides analysis margin because the reactivity effect of the BWR BORAFLEX™ storage rack parameters is treated as a bias rather than an analysis uncertainty.

4.7.3 Bounding Metamic Insert Parameters

As discussed in Section 4.2.3.3, the Metamic insert parameters were evaluated to determine the bounding set for use in the design basis model. The results of the evaluations are presented in Appendix 4.A, Table 4.A.4. The results presented in Appendix 4.A, Table 4.A.4 show that the bounding Metamic insert parameters are:

- Missing insert in the center location.
- Minimum Metamic loading, thickness and width.

Therefore, for all design basis calculations the bounding set of Metamic insert parameters is used. This is conservative and provides analysis margin because the reactivity effect of the Metamic insert parameters is treated as a bias rather than an analysis uncertainty.

Note that the results presented in Appendix 4.A, Table 4.A.4 also provide the statistical uncertainty calculations for the coupon measurement uncertainty (Case 4.2.3.3.6).

4.7.4 Reactivity Effect of SFP Water Temperature

As discussed in Section 4.2.3.4, the reactivity effect of SFP water temperature and density is evaluated so that the bounding values can be used in the design basis mode. The results of the evaluations are presented in Appendix 4.A, Table 4.A.5. The results presented in Appendix 4.A,

Table 4.A.5 show that the bounding temperature (and corresponding density) are the minimum temperature and maximum density. Therefore, these values are used in the design basis model.

4.7.5 Reactivity Effect of Fuel Assembly Channel and Radial Positioning of Fuel Assembly and Metamic Insert

As discussed in Section 4.2.3.5, the reactivity effect of the fuel and Metamic insert radial location, in conjunction with the presence or not of the fuel channel is evaluated to determine the bounding configuration for use in the design basis model. The results of the evaluations are presented in Appendix 4.A, Table 4.A.6. The results presented in Appendix 4.A, Table 4.A.6 show that the bounding radial configurations are:

- No fuel assembly channel present
- Metamic insert adjacent to the storage cell corner.
- All fuel eccentrically positioned towards the center of the storage rack.
- Fuel assembly in the central storage rack location positioned in the center of the storage cell.

Therefore, all design basis calculations for normal conditions include the bounding configuration. This is conservative and provides analysis margin because the reactivity effect of the radial position of the fuel and Metamic insert is treated as a bias rather than an analysis uncertainty.

4.7.6 Design Basis Model

As discussed in Section 4.2.3.6, various evaluations have been performed to determine the bounding set of parameters for the design basis modal. The results of these evaluations have been discussed in the previous sections. Based on the results of those evaluations, the design basis calculations for normal conditions have been performed. The results of the design basis calculations for normal conditions are presented in Appendix 4.A, Table 4.A.7. The design basis models consist of the following parameters:

- Bounding fuel assembly parameters
- Bounding storage rack parameters
- Bounding Metamic insert design parameters
- Bounding radial positioning of the Metamic insert and fuel assembly
- Missing Metamic insert in most reactive location (center of rack array).

The results of the design basis model calculations are used to determine k_{eff} (see Section 4.7.9).

4.7.7 Storage Rack Interfaces

As discussed in Section 4.2.3.7, the Harris Pool A and B storage rack interfaces are evaluated to determine if the design basis model is bounding by validating the interface assumption. The results of the interface calculations are presented in Appendix 4.A, Table 4.A.8. The results of the calculations show that the interface assumption is validated.

4.7.8 Accident Conditions

As discussed in Section 4.2.5, the following accident conditions have been evaluated:

- The effect of SFP temperature exceeding the normal range.
- A dropped fuel assembly:
- A misloaded fuel assembly (a fuel assembly in the wrong location within the storage rack)
- A mislocated fuel assembly (a fuel assembly in the wrong location outside the storage rack).
- Rack movement due to seismic activity.
- Mis-orientation of Metamic inserts.
- Soluble boron dilution accident.

The results of the accident condition evaluations are presented in Appendix 4.A, Table 4.A.9. The maximum reactivity case is used to determine k_{eff} for accident conditions (see Section 4.7.9).

The results of the additional mislocated fuel assembly accident cases, as discussed in Section 4.2.5.5, are presented in Appendix 4.B, Tables 4.B.1 through 4.B.3. A summary of the maximum reactivity cases from all of the mislocated fuel assembly cases is presented in Appendix 4.B, Table 4.B.4. The results presented in Appendix 4.B show that the bounding configuration, i.e. the mislocated fuel assembly in the center of the SFP, was selected. The results also show that using a water reflector for those cases is acceptable.

4.7.9 Calculation of the Maximum k_{eff}

As discussed in Section 4.2.5.9, the maximum k_{eff} for both normal and accident conditions is determined for both pure water and borated water. The results of the k_{eff} calculations are presented in Table 4.7.1.

4.7.10 Margin Evaluation

The criticality analysis methodology that is used in this report is described in detail in Section 4.2. The methodology allows for the use of both nominal and bounding parameters for the design basis calculations, and also performs various studies that quantify potential conservatisms and non-conservatisms. The reactivity effect of various analysis methods is presented in Table 4.7.2. As it can be seen from Table 4.7.2, the primary conservatisms are the use of planar average enrichment, bounding Metamic insert parameters and the eccentric positioning of the fuel in the storage cell (with no fuel channel present). Smaller impacts are associated with the fuel design and storage rack manufacturing parameters. In summary, the analysis methodology contains significantly conservative approaches which yield substantial margin.

4.8 Conclusion

The criticality calculations for the Harris SFP Pool A and B have been performed for the BWR BORAFLEX™ storage racks without credit for the degraded BORAFLEX™ and with credit for

Metamic inserts. The objective of the analysis is to demonstrate that the effective neutron multiplication factor (k_{eff}) is less than 1.0 with the pool flooded with un-borated water and that k_{eff} is less than or equal to 0.95 with the pool flooded with borated water. The maximum k_{eff} includes a margin for uncertainty in reactivity calculations including manufacturing tolerances and is shown to be less than the regulatory limit with a 95% probability at a 95% confidence level as presented in Table 4.7.1. Reactivity effects of abnormal and accident conditions have also been evaluated to assure that under all credible abnormal and accident conditions, the maximum k_{eff} will not exceed the regulatory limit of 0.95 with credit for soluble boron.

4.9 References

[4.1] "MCNP - A General Monte Carlo N-Particle Transport Code, Version 5," Los Alamos National Laboratory, LA-UR-03-1987 (2003, Revised 2/1/2008).

[4.2] ENDF/B-VII.0 Evaluated Nuclear Data Library, Release December 15, 2006.

[4.3] NJOY99.0, Code System for Producing Pointwise and Multigroup Neutron and Photon Cross Section from ENDF/B Data, PSR-480, March 2000, ORNL.

[4.4] HI-2156450, "MCNP5 Temperature Dependent Library Construction with NJOY", latest revision, Holtec International.

[4.5] F. Brown, A Review of Monte Carlo Criticality Calculations – Convergence, Bias, Statistics, 2009 International Conference on Mathematics, Computational Methods and Reactor Physics, Saratoga Springs, NY, 2009.

[4.6] "Nuclear Group Computer Code Benchmark Calculations", Holtec Report HI-2104790 Rev. 3.

[4.7] Guide for Validation of Nuclear Criticality Safety Calculational Methodology, NUREG/CR- 6698, January 2001.

[4.8] Brunswick Nuclear Plant Calculation 0B21-0203, "Supplemental Information to Support Criticality Analysis Removing Credit for Boraflex in BWR Spent Fuel Storage Racks at HNP," Latest Revision.

[4.9] DSG-ISG-2010-01, Staff Guidance Regarding the Nuclear Criticality Safety Analysis for Spent Fuel Pools, Revision 0.

[4.10] HI-2104763, current revision, "Criticality Analysis for Harris Spent Fuel Pool A/B BWR Boraflex Racks Without Credit for Boraflex".

[4.11] Framatome ANP, Inc. Document 77-5069740-NP-00, Dated August 2005, "Shearon Harris Criticality Evaluation".

[4.12] HI-2115044, current revision, "Criticality Analysis for Harris Spent Fuel Pool B BWR Boral Racks".

[4.13] Deleted.

[4.14] Email from Patrick Washington (Duke Energy) to Patrick Washington, dated August 2, 2016, subject "HNP BWR Rack Inserts – GE 7x7 Fuel Pin Map".

[4.15] EPRI Report 3002003073, "Sensitivity Analysis for Spent Fuel Pool Criticality," 2014.

Table 4.2.1
Summary of the Area of Applicability of the MCNP5-1.51 Benchmark

Parameter	Design Application	Benchmarks	Validated
Fissionable Material	^{235}U, ^{239}Pu, ^{241}Pu	^{235}U, ^{239}Pu, ^{241}Pu	^{235}U, ^{239}Pu, ^{241}Pu
Isotopic Composition			
$^{235}U/U$	< 5.0wt%	1.57 – 10%	< 10wt%
Pu/(U+Pu)	n/a	1.104 - 20 %	< 20wt%
Physical Form	UO_2	UO_2, MOX	UO_2, MOX
Fuel Density (g/cm^3)	10.31 – 10.63	6.1 – 10.4	6.1 – 10.7[1]
Moderator Material (coolant)	H	H	H
Physical Form	H_2O	H_2O	H_2O
Density (g/cm^3)	around 1.0 g/cm^3	around 1.0 g/cm^3	around 1.0 g/cm^3
Reflector Material	H	H	H
Physical Form	H_2O	H_2O	H_2O
Density (g/cm^3)	around 1.0 g/cm^3	around 1.0 g/cm^3	around 1.0 g/cm^3
Interstitial Reflector Material			
Plate	Steel	Steel or Lead	Steel or Lead
Absorber Material			
Soluble	None, Boron (0 – 1000 ppm)	None, Boron (15 - 2550 ppm) or Gadolinium (48 – 197 ppm)	None, Boron (0 - 2550 ppm) or Gadolinium (48 to 197 ppm)
Rods	n/a	B_4C, Pyrex®, Vicor®, Steel or B-Al	Boron
Separating Material			
Plate	Water, Boral	Water, B-SS, Boral, Boroflex, Zircaloy or Cadmium	Water, B-SS, Boral, Boroflex, Zircaloy or Cadmium
Geometry			
Lattice type	Square	Square, Triangle	Square, Triangle
Lattice Pitch (cm)	1.44 – 1.87 (BWR) 1.26 (PWR)	0.7 to 4.318	0.7 to 4.318
Neutron Energy	Thermal spectrum	Thermal spectrum	Thermal spectrum

[1] See Table 2.3 in [4.7].

Table 4.2.2
MCNP5-1.51 Benchmarking Bias and Bias Uncertainty and Trending Analysis
[4.6]

Experiment Description	No. of exp.	Bias	Bias Uncertainty	Normality χ^2 ($P_d(\chi^2;d)$)	Linear Correlation	Residuals Normality, ($P_d(\chi^2;d)$)
All experiments	562	0.0001	0.0072 **(0.0111)**	165.89 (0.0%)	None	-
All except those with Gadolinium, Cadmium and Lead[2]	389	0.0004	0.0061	35.50 (19%)	None	-
All with Fresh Water	311	0.0008	0.0062	33.43 (26.90%)	None	0.19%
All with Borated Water	78	-0.0004	0.0054	4.54 (21%)	Density k(x) = 1.0654 + (-6.428E-03)*x	33% (Significant)
Fresh UO2 Fuel with Fresh Water	178	0.0011	0.0054 (0.0042)	18.24 (1.09%)	EALF k(x) = 1.0001 + (5.349E-03)*x	44% (Significant)
Fresh UO2 Fuel with Borated	53	-0.0007	0.0046 (0.0078)	9.73 (2.22%)	None	-
HTC + MOX Fuel with Fresh Water	133	-0.0003	0.0083	3.78 (80%)	EALF k(x) = 0.9981 + (1.024E-02)*x	25% (Significant)
					Pu Enrichment k(x) = 0.9986 + (5.552E-04)*x	12% (Significant)
HTC + MOX Fuel with Borated Water	25	0.0016	0.0092	1.19 (75%)	Rod-OD k(x) = 0.9904 + (1.125E-02)*x	31% (Significant)
					Density k(x) = 1.0754 + (-7.198E-03)*x	21% (Significant)

[2] Note: Critical experiments with Gadolinium, Cadmium and Lead were excluded from all subsequent subsets.

Table 4.2.3
Summary of MCNP5-1.51 Benchmarking Bias and Bias Uncertainty Significant Trending Analysis

Experiment Description	Linear Correlation	Analysis Parameter Value[3]	Analysis Parameter Trend Bias	Analysis Parameter Trend Bias Uncertainty	[4.6] Trend Table
All with Borated Water	Density $k(x) = 1.0654 + (-6.428E-03)*x$ (g/cm^3)	10.6312 g/cm^3 (max)	-0.0029	0.0087	D.3-14
Fresh UO2 Fuel with Fresh Water	EALF $k(x) = 1.0001 + (5.349E-03)*x$ (eV)	0.22 eV (min)	0.0013	0,0053	D.3-16
HTC + MOX Fuel with Fresh Water	EALF $k(x) = 0.9981 + (1.024E-02)*x$	0.22 eV (min)	0.0000	0.0081	
	Pu Enrichment $k(x) = 0.9986 + (5.552E-04)*x$ (wt%)	0 % (min)	-0.0014	0.0081	
HTC + MOX Fuel with Borated Water	Rod-OD $k(x) = 0.9904 + (1.125E-02)*x$ (cm)	0.95 cm (min)	0.0011	0.0108	
	Density $k(x) = 1.0754 + (-7.198E-03)*x$ (g/cm^3)	10.6312 g/cm^3 (max)	**-0.0011**	**0.0124**	

Table 4.5.1.a
Specification of the Fuel Assembly Parameters [4.8]

Fuel Assembly Design	GE 3	GE 4	GE5 and GE6	GE7	GE 13	17x17
Fuel Assembly Overall Length, Inches	176.16	176.16	176.16	176.16	n/a	n/a
Distance from Bottom of Fuel Assembly to Beginning of Active Length, Inches	7.585	7.385	7.385	7.385	n/a	n/a
Clad Outer Diameter, Inches	0.563 ± 0.0025	0.493 ± 0.0025	0.483 ± 0.0025	0.483 ± 0.0025	0.44 ± 0.0025	0.374
Clad Inner Diameter, Inches	0.489 ± 0.0025	0.425 ± 0.0025	0.419 ± 0.0025	0.419 ± 0.0025	0.384 ± 0.0025	0.329
Clad Material	Zr-2	Zr-2	Zr-2	Zr-2	Zr-2	Zr-4
Pellet Diameter, Inches	0.477 ± 0.0005	0.416 ± 0.0005	0.411 ± 0.0005	0.411 ± 0.0005	0.376 ± 0.0005	0.3225
Stack Density g/cc	10.31 ± 0.17	10.32 ± 0.17	10.32 ± 0.17	10.44 ± 0.17	10.45 ± 0.17	10.6312
Full Length Rods Active	144	146	150	150	146	144
Part Length Rods Active	n/a	n/a	n/a	n/a	108	n/a
Number of Full Length Rods	49	63	62	62	66	264
Number of Part Length Rods	n/a	n/a	n/a	n/a	8	n/a
Fuel Rod Array	7x7	8x8	8x8	8x8	9x9	17x17
Blanket Length, Inches	n/a	n/a	6 top, 6 bottom	6 top, 6 bottom	8 top, 6 bottom	n/a
Blanket Enrichment	n/a	n/a	natural	natural	natural	n/a
Fuel Rod Pitch, Inches	0.738 ± 0.0055	0.64 ± 0.0055	0.64 ± 0.0055	0.64 ± 0.0055	0.566 ± 0.0055	0.496
Number of Water Rods	0	1	2	2	2	25
Water Rod Outer Diameter, Inches	n/a	0.493 ± 0.0025	0.591 ± 0.0025	0.591 ± 0.0025	0.98 ± 0.0025	0.474
Water Rod Inner Diameter, Inches	n/a	0.425 ± 0.0025	0.531 ± 0.0025	0.531 ± 0.0025	0.92 ± 0.0025	0.45
Water Rod Pitch, Inches	n/a	n/a	n/a	n/a	1.024	n/a
Channel Inner Diameter, Inches	5.278 ± 0.01	5.278 ± 0.01	5.278 ± 0.01	5.278 ± 0.01	5.278 ± 0.01	n/a
Channel Thickness, Inches	0.08 ± 0.004	0.08 ± 0.004	0.08 ± 0.004	0.08 ± 0.004	0.07 ± 0.004	n/a
Channel Corner Radius, Inches	0.38	0.38	0.38	0.38	0.45	n/a
Channel Height Above Active Fuel, Inches	20.175	18.175	14.175	n/a	n/a	n/a

Table 4.5.1.b

Additional Fuel Assembly Parameters
[4.10]

Fuel Assembly Design	Maximum Fuel Assembly Type IMPAE[4] in SFP (wt% U-235)	Minimum Fuel Assembly Type Average Burnup (MWD/MTU)
GE3	2.301	4902.7
GE4	2.737	11970.8
GE5 and GE6	3.192	20729.2
GE7	3.192	24723.6
GE8	3.688	31280.1
GE9-1	3.768	13506.7
GE9-2	3.778	34211.5
GE10	3.968	27430.7
GE13	4.178	34675.4

Note: there is only one GE9-1 assembly in the Harris SFP.

[4] Note: The IMPAE in this table does not include the enrichment tolerance (except for GE13).

Table 4.5.2
Specification of the Pool A and B Fuel Storage Racks [4.8]

Parameter	Value		
Rack Type	BWR BORAFLEX™	BWR BORAL	PWR BORAFLEX™
Number of Racks	3 Pool A, 5 Pool B	12 Pool B	6 Pool A, 12 Pool B
Storage Rack Material	304 SS	304 SS	304 SS
Rack Height (top of baseplate to top of rack), Inches	169	169	168.56
Distance from Pool Liner to Rack Baseplate, Inches	8.92	8.92	6
Distance Baseplate Extension Protrudes from Rack Envelope, Inches	0.4	0.25	0.25
Distance from Rack Baseplate to Bottom of Neutron Absorber, Inches	5.28	5.28	4.5
Length of Neutron Absorber, Inches	150	150	144.25
Neutron Absorber Thickness, Inches	0.045	0.075	0.075
Neutron Absorber Width, Inches	5.1	5.0	7.46
Storage Cell Inner Diameter, Inches	6.05 ± 0.02	6.06	8.75
Storage Cell Pitch, Inches	6.25 ± 0.03	6.25	10.5
Storage Cell Box Wall Thickness, Inches	0.075 ± 0.004	0.075	0.0747
Storage Cell Neutron Absorber Pocket Thickness, Inches	0.07 ± 0.01	0.08	0.1
Storage Cell Neutron Absorber Sheathing Thickness, Inches	0.035 ± 0.002	0.035	0.035
Storage Cell Neutron Absorber Sheathing Inside Width, Inches	5.15 ± 0.0625	5.0	7.46
Neutron Absorber Type	Degraded BORAFLEX™ (modeled as water)	BORAL	Degraded BORAFLEX™ (modeled as water)
Neutron Absorber areal density (g/sqcm) [5]	n/a	0.015 min	n/a
Neutron Absorber Density, g/cc	n/a	2.665	n/a

[5] Note: For the Boral racks, 90% of the value in the table is used per [4.12].

Table 4.5.3
Rack to Rack Gaps [4.8]

Description	Value
PWR to PWR rack (inches)	1.625
PWR to PWR rack N-S Pool A (inches)	8.5
PWR to BWR rack (inches)	1.5
BWR to BWR rack (inches)	1.875

Table 4.5.4
Metamic Insert Specification

Description	Value
Thickness (inches)	[redacted]
Width[6] (inches)	[redacted]
Length (inches)	[redacted]
Areal density (g/cm^2)	[redacted]

6 [redacted]

Table 4.5.5 (1 of 5)
Material Compositions

Element	MCNP ZAID[7] [4.1],[4.4]	Weight Fraction
Steel (density 7.92 g/cc) [4.10]		
Cr	24050.21c	0.00790496
	24052.21c	0.15852660
	24053.21c	0.01832179
	24054.21c	0.00464667
Mn	25055.21c	0.02001000
Fe	26054.21c	0.03898260
	26056.21c	0.63458000
	26057.21c	0.01491736
	26058.21c	0.00202002
Ni	28058.21c	0.06719768
	28060.21c	0.02677598
	28061.21c	0.00118336
	28062.21c	0.00383482
	28064.21c	0.00100815
Zr (density = 6.55 g/cc) [4.10]		
Zr	40090.21c	0.50706120
	40091.21c	0.11180900
	40092.21c	0.17278100
	40094.21c	0.17891100
	40096.21c	0.02943790

Table 4.5.5 (2 of 5)
Material Compositions

Element	MCNP ZAID[8] [4.1],[4.4]	Weight Fraction
Metamic (density = 2.6 g/cc)		
B	5010.21c	[redacted]
	5011.21c	[redacted]
C	6000.21c	[redacted]
Al	13027.21c	[redacted]
BORAL (density = 2.67 g/cc) [4.10]		
B	5010.21c	0.04322397
	5011.21c	0.19129520
C	6000.21c	0.06513745
Al	13027.21c	0.70034320
Pure water (density = 1.0 g/cc)		
H	1001.21c	0.11188600
	1002.21c	0.00002572
O	8016.21c	0.88579510
	8017.21c	0.00229319
500 ppm Borated Water (density = 1.0 g/cc)		
H	1001.21c	0.11183010
	1002.21c	0.00002570
O	8016.21c	0.88535220
	8017.21c	0.00229204
B	5010.21c	0.00009215
	5011.21c	0.00040784
1000 ppm Borated Water (density = 1.0 g/cc)		
H	1001.21c	0.11177410
	1002.21c	0.00002569
O	8016.21c	0.88490930
	8017.21c	0.00229090
B	5010.21c	0.00018430
	5011.21c	0.00081569

[7] [8] The MCNP ZAID used is customized for ENDF/B-VII NJOY adjusted cross

Table 4.5.5 (3 of 5)
Material Compositions

Element	MCNP ZAID[9] [4.1],[4.4]	Weight Fraction
GE7 Fresh 3.282 wt% U-235 Fuel[10]		
U	92235.21c	0.02893000
	92238.21c	0.85257000
O	8016.21c	0.11850000
BORAL (density = 2.67 g/cc) [4.10]		
B	5010.21c	0.04322397
	5011.21c	0.19129520
C	6000.21c	0.06513745
Al	13027.21c	0.70034320
Pure water (density = 1.0 g/cc)		
H	1001.21c	0.11188600
	1002.21c	0.00002572
O	8016.21c	0.88579510
	8017.21c	0.00229319
500 ppm Borated Water (density = 1.0 g/cc)		
H	1001.21c	0.11183010
	1002.21c	0.00002570
O	8016.21c	0.88535220
	8017.21c	0.00229204
B	5010.21c	0.00009215
	5011.21c	0.00040784
1000 ppm Borated Water (density = 1.0 g/cc)		
H	1001.21c	0.11177410
	1002.21c	0.00002569
O	8016.21c	0.88490930
	8017.21c	0.00229090
B	5010.21c	0.00018430
	5011.21c	0.00081569

[9] The MCNP ZAID used is customized for ENDF/B-VII NJOY adjusted cross sections.
[10] Other fresh fuel compositions are used, the design basis case is provided as an example.

Table 4.5.5 (4 of 5)
Material Compositions

MCNP ZAID[11]	
PWR Spent Fuel Isotopic Composition [4.10] (weight fractions vary depending on axial node and burnup considered)	
92234.21c	45105.21c
92235.21c	47109.21c
92236.21c	53135.21c
92238.21c	54131.21c
92239.21c	55133.21c
93237.21c	55134.21c
94239.21c	55135.21c
94238.21c	55137.21c
94239.21c	60143.21c
94240.21c	60145.21c
94241.21c	61147.21c
94242.21c	61148.21c
95241.21c	61149.21c
95242.21c	62147.21c
95243.21c	62149.21c
96242.21c	62150.21c
96243.21c	62151.21c
96244.21c	62152.21c
96245.21c	63153.21c
96246.21c	63154.21c
36083.21c	63155.21c
45103.21c	64155.21c

[11] The MCNP ZAID used is customized for ENDF/B-VII NJOY adjusted cross sections.

Table 4.5.5 (5 of 5)
Material Compositions

Element	MCNP ZAID[12] [4.1],[4.4]	Weight Fraction [4.15]
Bounding Concrete Composition [4.15]		
O	8016.21c	0.424102100
	8017.21c	0.001097938
C	6000.21c	0.140000000
Na	11023.21c	0.023200000
Mg	12024.21c	0.058696310
	12025.21c	0.007740914
	12026.21c	0.008862759
Al	13027.21c	0.027200000
Si	14028.21c	0.247507000
	14029.21c	0.013016850
	14030.21c	0.008876131
Ca	20040.21c	0.034024950
	20042.21c	0.000238430
	20043.21c	0.000050900
	20044.21c	0.000805311
	20046.21c	0.000001610
	20048.21c	0.000078800
Fe	26054.21c	0.000254050
	26056.21c	0.004135569
	26057.21c	0.000097200
	26058.21c	0.000013200

[12] The MCNP ZAID used is customized for ENDF/B-VII NJOY adjusted cross sections.

Table 4.7.1
Summary of the Analysis Results

Analysis Criticality Results Summary For Normal Conditions	
Normal conditions maximum k_{calc}, 0 ppm (Case 4.2.3.6.1)	0.9455
Normal conditions maximum k_{calc}, 500 ppm (Case 4.2.3.6.6)	0.8714
Analysis Criticality Results Summary For Accident Conditions	
Accident conditions maximum k_{calc}, 0 ppm (Case 4.2.5.5.29) – With Administrative Requirement 3	1.0303
Accident conditions maximum k_{calc}, 1000 ppm (Case 4.2.5.5.22) – With Administrative Requirement 3	0.8880
Analysis Uncertainties Summary	
MCNP5-1.51 bias uncertainty (95/95) (Table 4.2.3)	0.0124
MCNP5-1.51 calculation statistics (2 sigma)	0.0006
Metamic Coupon Measurement uncertainty (Case 4.2.3.3.6)	0.0149
Analysis Bias Summary	
NRC Administrative Margin	0.0100
MCNP5-1.51 bias (Table 4.2.3)	0.0011
Determination of k_{eff} for Normal Conditions	
Normal Conditions maximum k_{eff}, 0 ppm	0.9660
Normal Conditions margin to regulatory limit for 0 ppm	0.0240
Normal Conditions maximum k_{eff}, 500 ppm	0.8919
Normal Conditions margin to regulatory limit for 500 ppm	0.0481
Determination of k_{eff} for Accident Conditions[13]	
Accident Conditions maximum k_{eff}, 0 ppm	1.0495
Accident Conditions maximum k_{eff}, 1000 ppm	0.9085
Accident Conditions margin to regulatory limit for 1000 ppm	0.0315

[13] The maximum reactivity case is selected from the most reactive of the 1000 ppm calculations from among the Administrative Requirement 3 cases. The calculations for NO application of Administrative Requirement 3 cases are presented in Appendix 4.A for information only.

Table 4.7.2

Reactivity Effect of Various Analysis Methods

Parameter	Bounding		Nominal		Delta
	Case	k_{calc}	Case	k_{calc}	
Fuel Assembly Parameters	2.3.6.1	0.9455	2.3.6.2	0.9439	0.0016
			2.3.6.3	0.9445	0.0010
Storage Rack Parameters	2.3.6.1	0.9455	2.3.6.4	0.9457	-0.0002
Planar Average enrichment versus pin specific enrichments	2.3.1.2.1	0.9044	2.3.1.2.10	0.8870	0.0174
Metamic Insert Parameters	2.3.6.1	0.9455	2.3.6.5	0.9259	0.0196
Eccentric Positioning and Fuel Channel	2.3.5.9	0.9395	2.3.5.1	0.9015	0.0380

Figure 4.1.1
Pool A Metamic Rack Insert Orientation

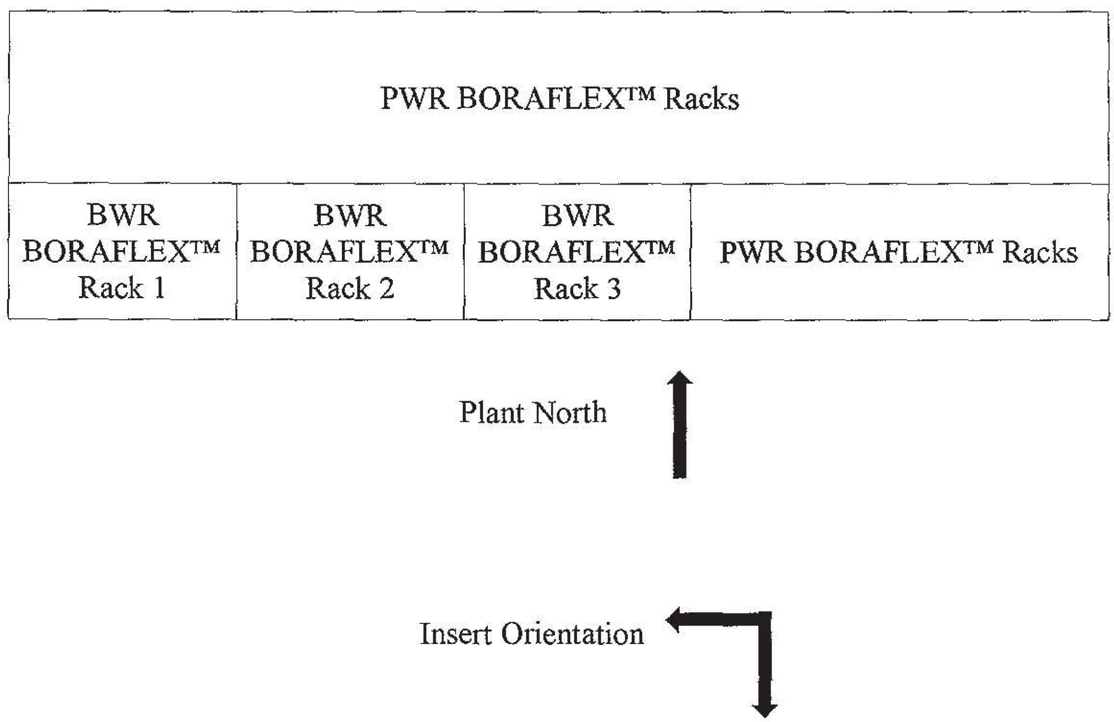


Figure 4.1.2
Pool B Metamic Rack Insert Orientation

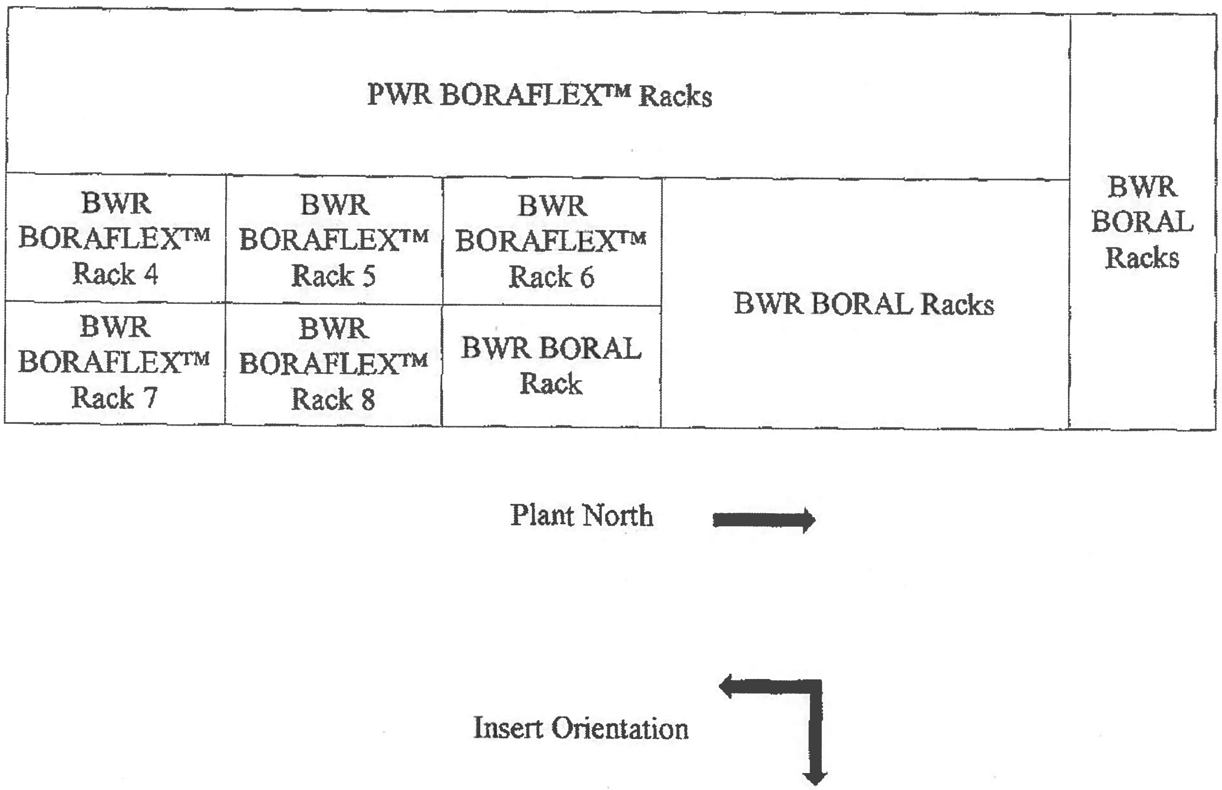
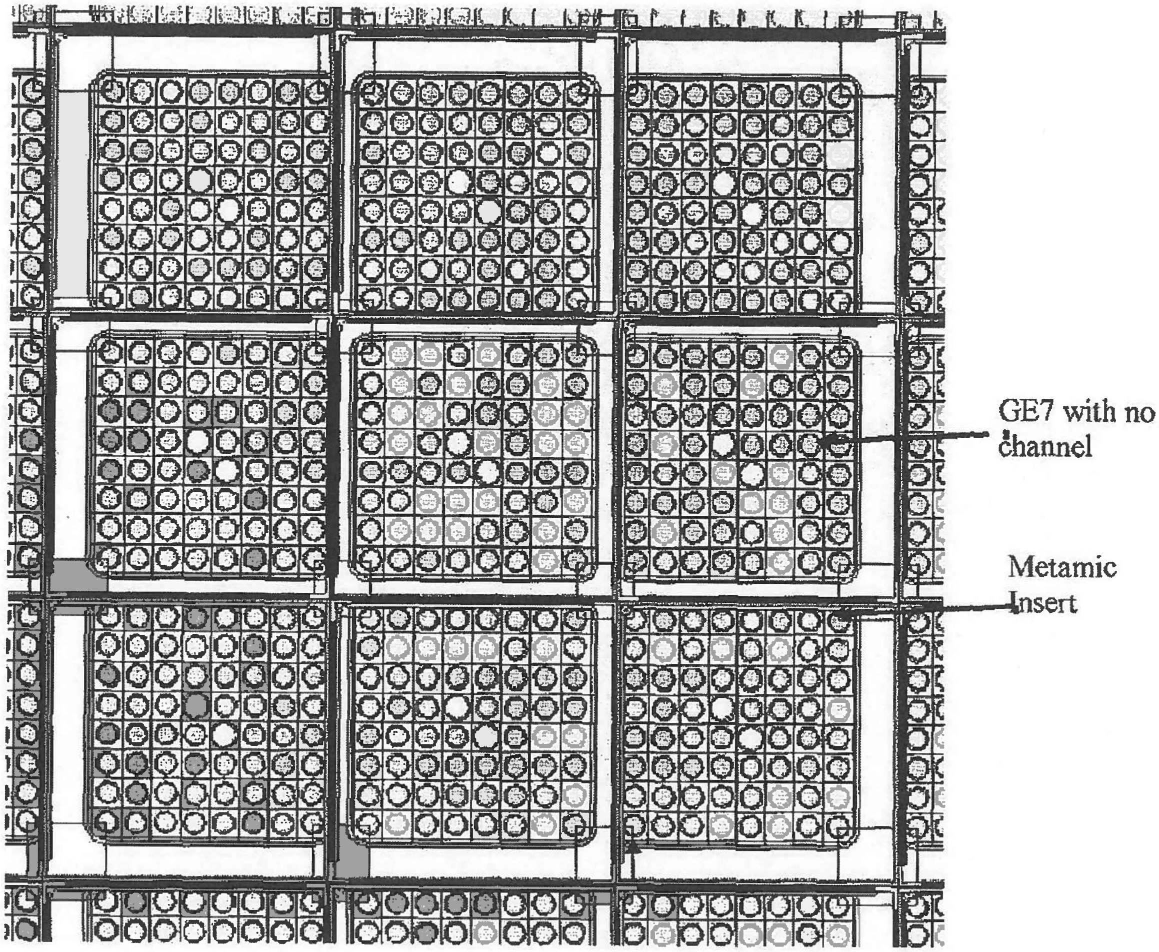
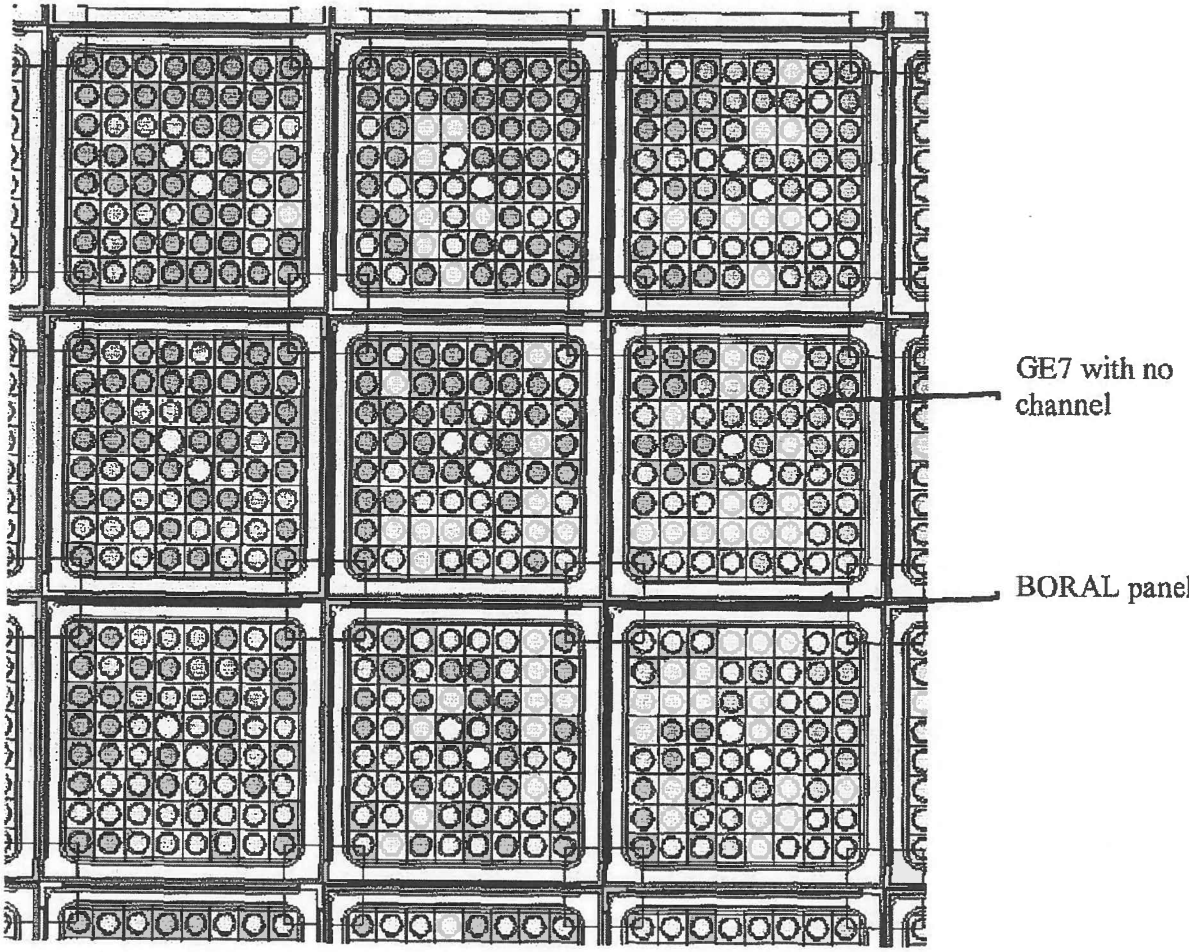


Figure 4.2.1
MCNP5-1.51 BWR BORAFLEX™ Design Basis Model



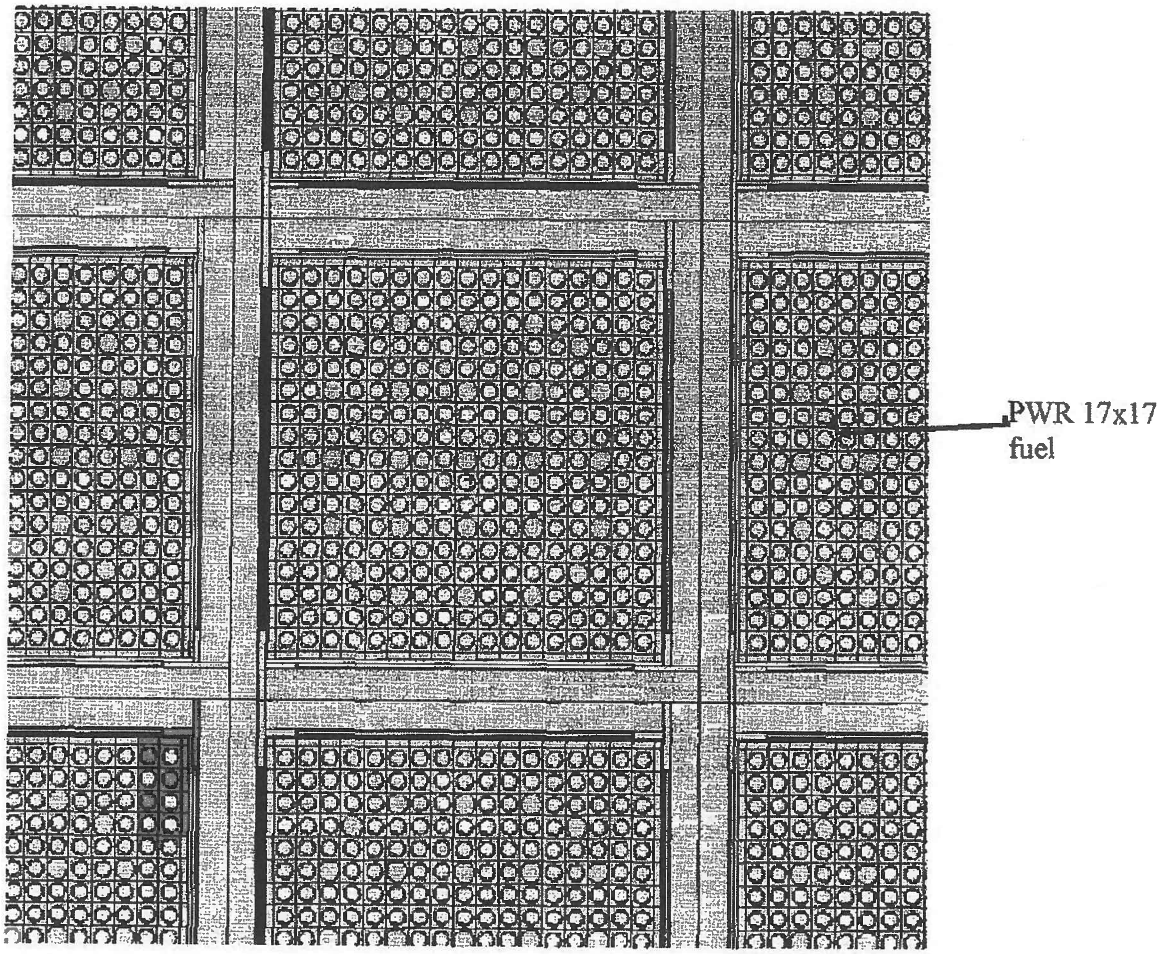
This is a partial 2D representation of the design basis model showing the center location with a missing insert. The GE7 fuel has no channel (the outline of the channel location is visible) and is eccentrically positioned towards the center location. All Metamic inserts are adjacent to the upper left corner of the storage cell.

Figure 4.2.2
MCNP5-1.51 BWR BORAL Interface Assumption Model



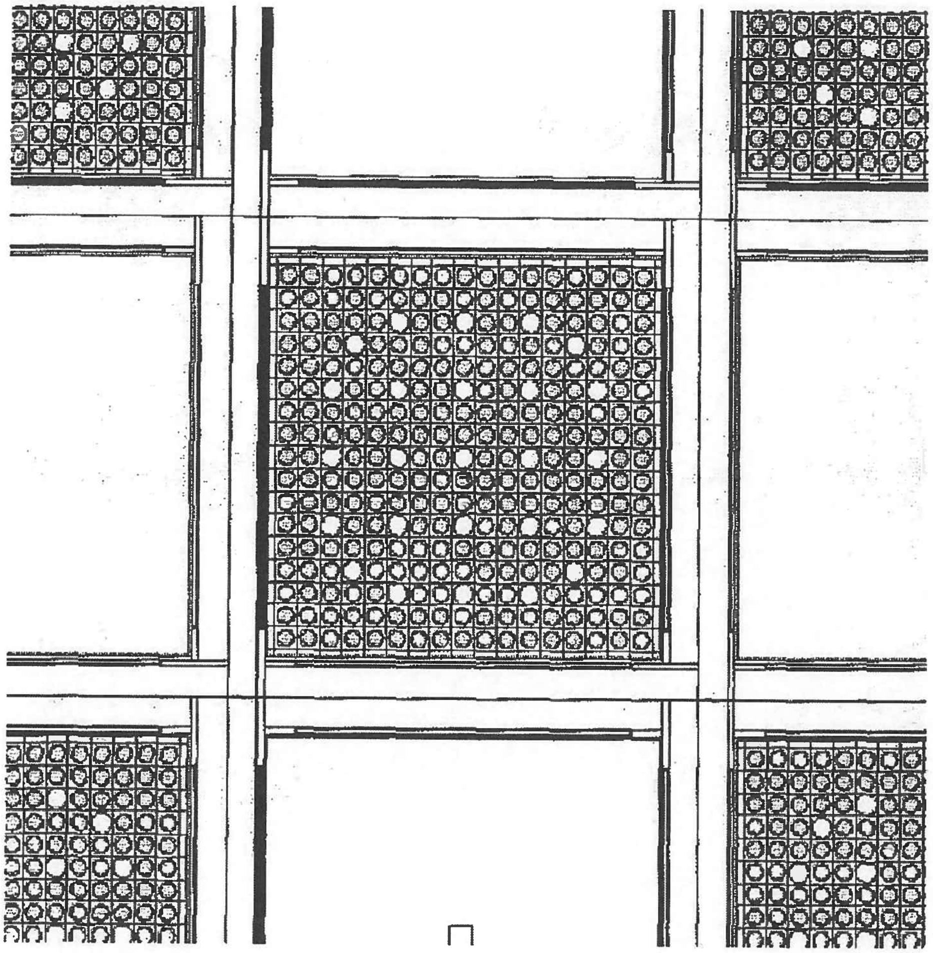
This is a partial 2D representation of the BWR BORAL model. The GE7 fuel is cell centered and has no channel (the outline of the channel location is visible).

Figure 4.2.3
MCNP5-1.51 PWR BORAFLEX™ Interface Assumption Model with Spent PWR 17x17 Fuel



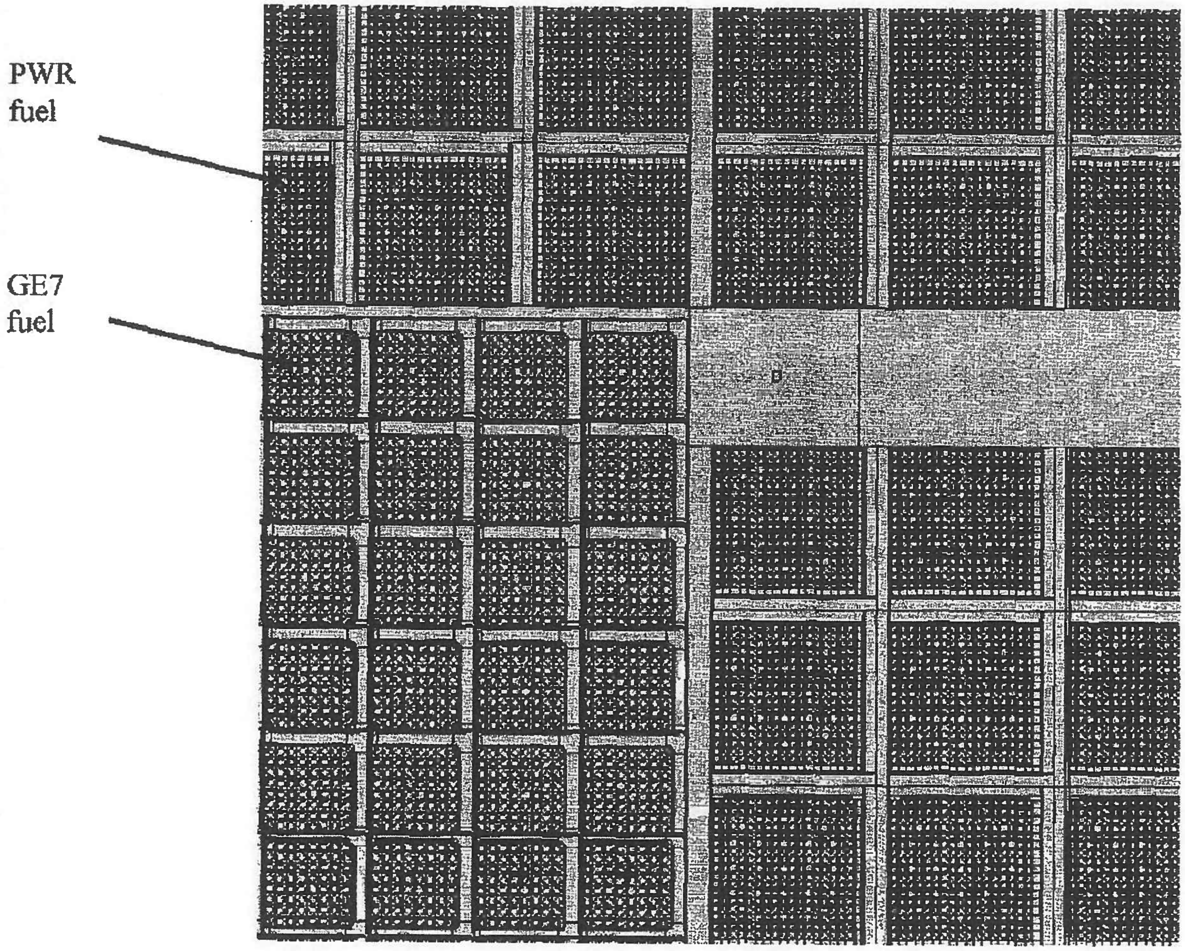
This is a partial 2D representation of the PWR model. The PWR spent fuel is cell centered, and there is no BORAFLEX™ present.

Figure 4.2.4
MCNP5-1.51 PWR BORAFLEX™ Interface Assumption Model with Fresh PWR 17x17 Fuel



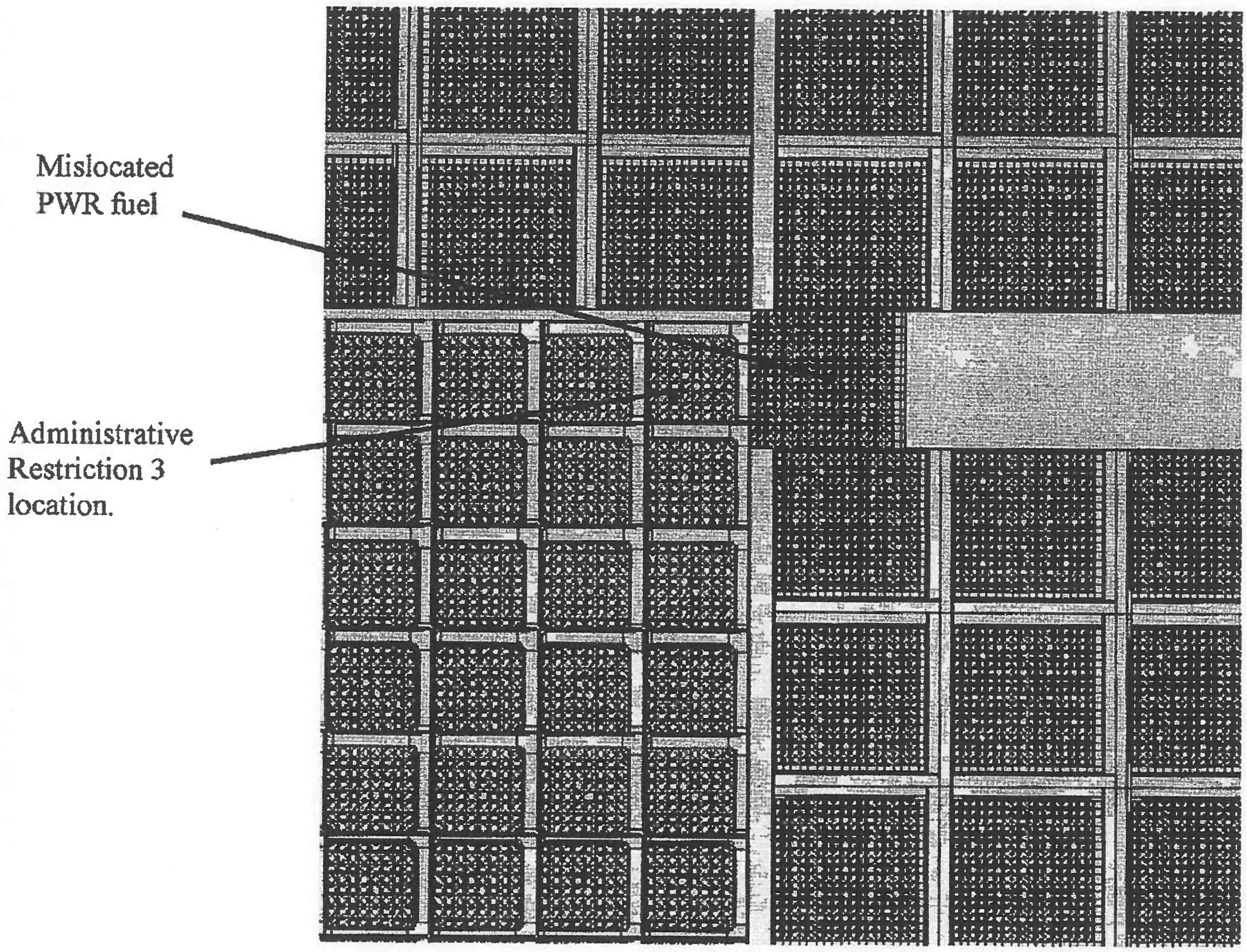
This is a partial 2D representation of the PWR model. The PWR fresh fuel is cell centered, and there is no BORAFLEX™ present.

Figure 4.2.5
MCNP5-1.51 Pool A Interface Calculation Model



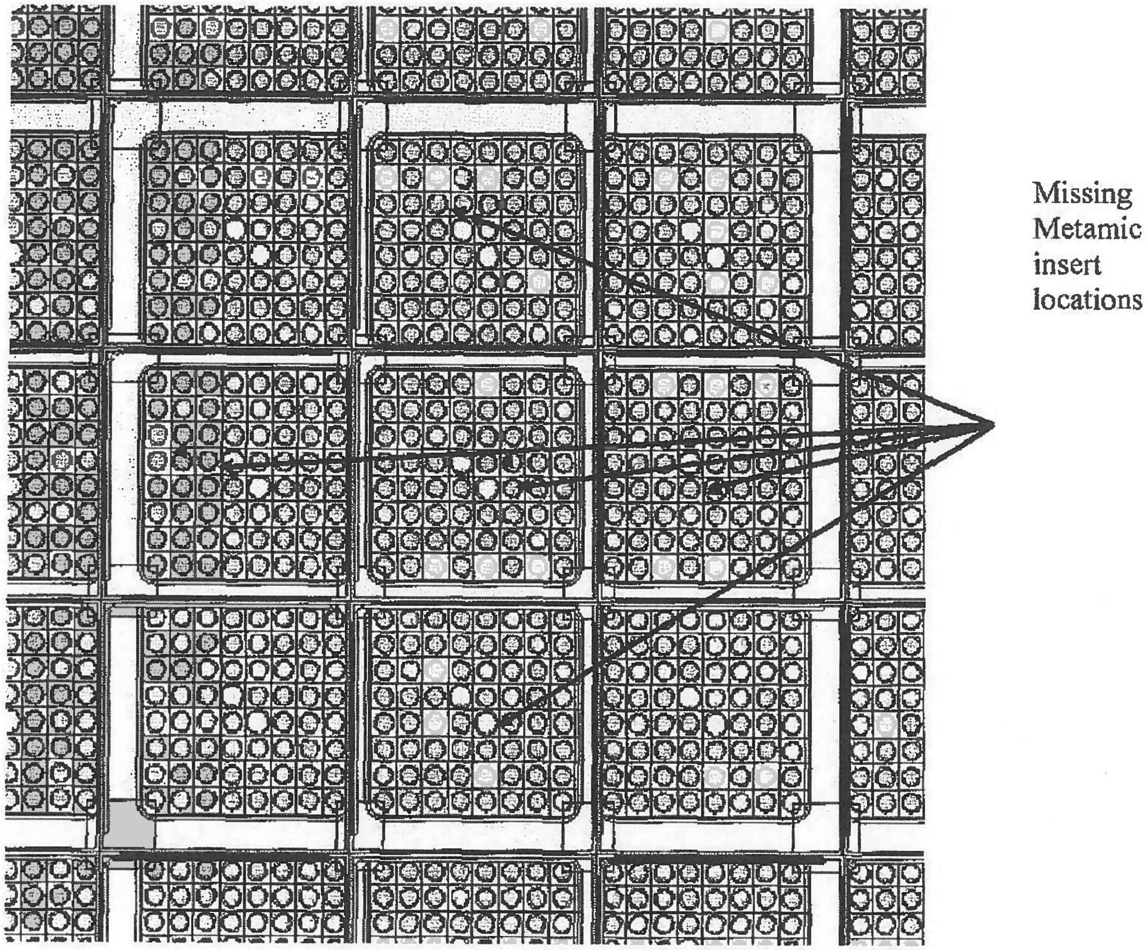
This is a partial 2D representation of the full pool model showing the center of the pool where the two rows of PWR racks meet with the row of BWR racks. The PWR fuel is eccentrically positioned towards the BWR fuel and the BWR fuel is in the same configuration as the design basis model (see Case 4.2.3.6.1).

Figure 4.2.6
Mislocated Accident Location



This is a partial 2D representation of the full pool model showing the center of the pool wherethe two rows of PWR racks meet with the row of BWR racks. The spent PWR fuel in the racks is eccentrically positioned towards the BWR fuel and the BWR fuel is in the same configuration as the design basis model (see Case 4.2.3.6.1). The mislocated fresh PWR fuel assembly is positioned in a location that is slightly smaller than its actual size, and as close to the BWR rack as possible. There is no neutron absorber between the mislocated PWR fuel and any other fuel in the three adjacent racks. This is Case 4.2.5.5.1. Note that for Administrative Restriction 3 the BWR fuel assembly directly adjacent to the mislocated PWR fuel assembly is removed (the storage location is assumed to be blocked).

Figure 4.2.7
Mis-oriented Metamic Insert Accident Configuration



This is a partial 2D representation of the 11x11 BWR BORAFLEX™ rack model for the mis-orientation of Metamic inserts accident case showing the center of the rack. The BWR fuel is in the same configuration as the design basis model (see Case 4.2.3.6.1. The location of the missing four additional missing Metamic inserts is shown, along with the design basis center location missing Metamic insert.

Appendix 4.A

Analysis Results

Table 4.A.1
MCNP5-1.51 Results for Fuel Design Reactivity

Case	k_{calc}	sigma	Description
4.2.3.1.1.1	0.8203	0.0003	GE3 with maximum IMPAE + enrichment tolerance.
4.2.3.1.1.2	0.8595	0.0003	GE4 with maximum IMPAE + enrichment tolerance.
4.2.3.1.1.3	0.8991	0.0003	GE6 with maximum IMPAE + enrichment tolerance.
4.2.3.1.1.4	0.9015	0.0003	GE7 with maximum IMPAE + enrichment tolerance.
4.2.3.1.1.5	0.9546	0.0003	GE13 with maximum IMPAE + enrichment tolerance.

Table 4.A.2
MCNP5-1.51 Results for Bounding Fuel Design Parameters

Case	k_{calc}	sigma	Delta k_{calc} (95/95)	Description
4.2.1.3.1.4	0.9015	0.0003	ref	GE7 with maximum IMPAE + enrichment tolerance, nominal fuel dimensions.
4.2.3.1.2.1	0.9044	0.0003	0.0035	All tolerance parameters nominal (except fuel pellet diameter and density which are maximum).
4.2.3.1.2.2	0.9053	0.0003	0.0015	Minimum cladding thickness.
4.2.3.1.2.3	0.9017	0.0003	-0.0021	Maximum cladding thickness.
4.2.3.1.2.4	0.9030	0.0003	-0.0008	Minimum fuel rod pitch.
4.2.3.1.2.5	0.9057	0.0003	0.0019	Maximum fuel rod pitch.
4.2.3.1.2.6	0.9040	0.0003	0.0003	Minimum fuel channel thickness.
4.2.3.1.2.7	0.9040	0.0003	0.0002	Maximum fuel channel thickness.
4.2.3.1.2.8	0.9035	0.0003	-0.0003	Minimum water rod thickness.
4.2.3.1.2.9	0.9033	0.0003	-0.0004	Maximum water rod thickness.
4.2.3.1.2.10	0.8870	0.0003	-0.0144	Pin specific enrichment for the IMPAE considered in Case 4.2.3.1.1.4.

Table 4.A.3
MCNP5-1.51 Results for Bounding BWR BORAFLEX Storage Rack Parameters

Case	k_{calc}	sigma	Delta k_{calc} (95/95)	Description
4.2.3.2.1	0.9015	0.0003	ref	Reference case. All storage rack parameters nominal.
4.2.3.2.2	0.9005	0.0003	-0.0004	Minimum storage cell inner diameter.
4.2.3.2.3	0.9023	0.0003	0.0015	Maximum storage cell inner diameter.
4.2.3.2.4	0.9017	0.0003	0.0008	Minimum storage cell wall thickness.
4.2.3.2.5	0.9014	0.0003	0.0006	Maximum storage cell wall thickness.
4.2.3.2.6	0.9058	0.0003	0.0049	Minimum storage cell pitch.

Table 4.A.4
MCNP5-1.51 Results for Bounding Metamic Insert Parameters

Case	k_{calc}	sigma	Delta k_{calc} (95/95)	Description
4.2.3.3.1	0.9100	0.0003	ref	Reference case. Minimum B_4C wt%, nominal insert thickness and width (nominal loading at minimum B_4C wt%).
4.2.3.3.2	0.9017	0.0003	-0.0076	Alternative missing insert location along rack edge, in center location. Minimum B_4C wt%, nominal insert thickness and width (nominal loading at minimum B_4C wt%).
4.2.3.3.3	0.8984	0.0003	-0.0110	Alternative missing insert location along rack edge, in corner location. Minimum B_4C wt%, nominal insert thickness and width (nominal loading at minimum B_4C wt%).
4.2.3.3.4	0.9025	0.0003	-0.0069	Minimum B_4C wt%, maximum thickness and width (maximum loading at minimum B_4C wt%).
4.2.3.3.5	0.9206	0.0003	0.0113	Minimum B_4C wt%, minimum thickness and width (minimum loading at minimum B_4C wt%).
4.2.3.3.6	0.9243	0.0003	0.0149	Coupon testing measurement uncertainty. Minimum B_4C wt% – 5%, minimum thickness and width (minimum loading at minimum B_4C wt% – 5%).

Table 4.A.5
MCNP5-1.51 Results for Bounding SFP Water Temperature

Case	k_{calc}	sigma	Delta k_{calc} (95/95)	Description
4.2.3.4.1	0.9015	0.0003	ref	Reference case. Same model as discussed in Section 4.2.3.1.1.
4.2.3.4.2	0.9007	0.0003	-0.0002	Minimum nominal temperature 85 °F.
4.2.3.4.3	0.8919	0.0003	-0.0089	Maximum nominal temperature 105 °F.
4.2.3.4.4	0.8856	0.0003	-0.0152	Maximum possible temperature 212 °F.

Table 4.A.6
MCNP5-1.51 Results for Fuel Assembly Channel and Radial Positioning of Fuel Assembly and Metamic Insert

Case	k_{calc}	sigma	Delta k_{calc} (95/95)	Description
Fuel Assembly Cell Centered, Fuel Channel Present				
4.2.3.5.1	0.9015	0.0003	ref	Reference case. Metamic inserts are between fuel assembly and cell corner.
4.2.3.5.2	0.9219	0.0003	0.0210	Metamic inserts are adjacent to the cell corner.
4.2.3.5.3	0.8934	0.0003	-0.0074	Metamic inserts are adjacent to the fuel assembly.
Fuel Assembly Cell Centered, Fuel Channel Missing				
4.2.3.5.4	0.8980	0.0003	-0.0029	Metamic inserts are centered between fuel assembly and cell corner.
4.2.3.5.5	0.9195	0.0003	0.0222	Metamic inserts are adjacent to the cell corner.
4.2.3.5.6	0.8589	0.0003	-0.0420	Metamic inserts are adjacent to the fuel assembly.
Fuel Assembly Positioned Towards Rack Center, Fuel Channel Present				
4.2.3.5.7	0.9368	0.0003	0.0359	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is centered in rack cell.
4.2.3.5.8	0.9348	0.0003	0.0340	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is eccentric in rack cell.
Fuel Assembly Positioned Towards Rack Center, Fuel Channel Missing				
4.2.3.5.9	0.9395	0.0003	0.0386	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is centered in rack cell.
4.2.3.5.10	0.9329	0.0003	0.0321	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned towards the rack center while center location is centered in rack cell.
Fuel Assembly Positioned Away From Rack Center, Fuel Channel Present				
4.2.3.5.11	0.9001	0.0003	-0.0008	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is centered in rack cell.
4.2.3.5.12	0.8996	0.0003	-0.0013	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is eccentric in rack cell.
Fuel Assembly Positioned Away From Rack Center, Fuel Channel Missing				
4.2.3.5.13	0.8740	0.0003	-0.0268	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is centered in rack cell.
4.2.3.5.14	0.8735	0.0003	-0.0274	Metamic inserts are adjacent to the cell corner. All fuel assemblies are positioned away from the rack center while center location is eccentric in rack cell.

Table 4.A.7
MCNP5-1.51 Results for the Design Basis Model

Case	k_{calc}	sigma	Delta k_{calc} (95/95)	Description
4.2.3.6.1	0.9455	0.0003	ref	Design basis model maximum k_{calc} with GE7 fuel with design IMPAE 3.282 wt% U-235.
4.2.3.6.2	0.9439	0.0003	-0.0010	Design basis model except with nominal fuel rod cladding thickness.
4.2.3.6.3	0.9445	0.0003	-0.0004	Design basis model except with nominal fuel rod pitch.
4.2.3.6.4	0.9457	0.0003	0.0008	Design basis model except with nominal storage rack cell pitch.
4.2.3.6.5	0.9259	0.0003	-0.0190	Design basis model except with maximum Metamic thickness and width.
4.2.3.6.6	0.8714	0.0003	-0.0736	Design basis model with 500 ppm soluble boron.

Table 4.A.8
MCNP5-1.51 Results for the Interface Calculations

Case	k_{calc}	sigma	Description
4.2.3.7.1	0.9455	0.0003	BWR BORAFLEX™ storage rack infinite array. Same as design basis model (Case
4.2.3.7.2	0.9128	0.0003	BWR BORAL storage rack infinite array.
4.2.3.7.3	0.9455	0.0003	PWR BORAFLEX™ storage rack infinite array with a uniform loading of spent PWR fuel at about 45 GWD/MTU.
4.2.3.7.4	0.9289	0.0003	PWR BORAFLEX™ storage rack infinite array with a checkerboard of empty and fresh PWR with an enrichment of 5.0 wt% U-235.
4.2.3.7.5	0.9455	0.0003	Pool A, bounding BWR BORAFLEX configuration, spent PWR fuel eccentric towards the BWR racks.
4.2.3.7.6	0.9456	0.0003	Pool A, bounding BWR BORAFLEX configuration, spent PWR fuel cell centered.
4.2.3.7.7	0.9459	0.0003	Pool A, bounding BWR BORAFLEX configuration, fresh PWR fuel eccentric towards the BWR racks.
4.2.3.7.8	0.9463	0.0003	Pool A, bounding BWR BORAFLEX configuration, fresh PWR fuel cell centered.
4.2.3.7.9	0.9464	0.0003	Pool A, BWR fuel eccentric toward PWR fuel, spent PWR fuel eccentric towards the BWR racks.
4.2.3.7.10	0.9366	0.0003	Pool A, BWR fuel eccentric toward PWR fuel, spent PWR fuel cell centered.
4.2.3.7.11	0.8972	0.0003	Pool A, BWR fuel eccentric toward PWR fuel, fresh PWR fuel eccentric towards the BWR racks.
4.2.3.7.12	0.8965	0.0003	Pool A, BWR fuel eccentric toward PWR fuel, fresh PWR fuel cell centered.
4.2.3.7.13	0.9460	0.0003	Pool A, bounding BWR BORAFLEX configuration, no PWR fuel.
4.2.3.7.14	0.8974	0.0003	Pool A, BWR fuel eccentric toward PWR racks, no PWR fuel.

Table 4.A.9
MCNP5-1.51 Results for the Accident Calculations

Case	k_{calc}	sigma	Description
4.2.5.4.1	1.0335	0.0003	Misloaded fresh 5.0 wt% U-235 GE13 fuel assembly, 0 ppm soluble boron.
4.2.5.4.2	0.9011	0.0003	Misloaded fresh 5.0 wt% U-235 GE13 fuel assembly, 1000 ppm soluble boron
4.2.5.5.1	1.0499	0.0003	Mislocated fresh 5.0 wt% U-235 17x17 PWR fuel assembly, PWR racks with spent fuel, 0 ppm soluble boron.
4.2.5.5.2	0.9062	0.0003	Same as Case 4.2.5.5.1 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.3	0.9925	0.0003	Same as Case 4.2.5.5.1 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.4	0.8552	0.0003	Same as Case 4.2.5.5.3 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.5	1.0652	0.0003	Same as Case 4.2.5.5.1 except the BWR fuel is eccentrically positioned toward the mislocated PWR fuel.
4.2.5.5.6	0.9266	0.0003	Same as Case 4.2.5.5.5 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.7	1.0017	0.0003	Same as Case 4.2.5.5.5 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.8	0.8692	0.0003	Same as Case 4.2.5.5.7 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.9	1.0363	0.0003	Same as Case 4.2.5.5.1 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.10	0.8889	0.0003	Same as Case 4.2.5.5.9 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.11	0.9797	0.0003	Same as Case 4.2.5.5.3 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.12	0.8390	0.0003	Same as Case 4.2.5.5.11 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.13	1.0636	0.0003	Same as Case 4.2.5.5.5 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.14	0.9075	0.0003	Same as Case 4.2.5.5.13 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.15	1.0016	0.0003	Same as Case 4.2.5.5.7 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.16	0.8542	0.0003	Same as Case 4.2.5.5.15 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.6.1	0.9798	0.0003	Rack movement accident, PWR racks with spent fuel, 0 ppm soluble boron.
4.2.5.6.2	0.8378	0.0003	Same as Case 4.2.5.6.1 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.6.3	0.9460	0.0003	Same as Case 4.2.5.6.1 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.6.4	0.8102	0.0003	Same as Case 4.2.5.6.3 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.6.5	0.9802	0.0003	Same as Case 4.2.5.6.1 except the BWR fuel is eccentrically positioned toward the central BWR rack location where two PWR racks are adjacent to the BWR
4.2.5.6.6	0.8376	0.0003	Same as Case 4.2.5.6.5 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.6.7	0.8944	0.0003	Same as Case 4.2.5.6.5 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.6.7	0.8944	0.0003	Same as Case 4.2.5.6.7 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.8.1	1.0590	0.0003	Mis-orientation of Metamic inserts.
4.2.5.8.2	0.8888	0.0003	Same as Case 4.2.5.8.1 except the SFP moderator has 1000 ppm soluble boron.

Table 4.A.10
MCNP5-1.51 Results for the Mislocated Fuel Assembly Accident Calculations with Administrative Requirement 3

Case	k_{calc}	sigma	Description
4.2.5.5.17	1.0185	0.0003	Same as Case 4.2.5.5.1 except administrative requirement 3 is applied.
4.2.5.5.18	0.8783	0.0003	Same as Case 4.2.5.5.17 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.19	0.9597	0.0003	Same as Case 4.2.5.5.17 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.20	0.8292	0.0003	Same as Case 4.2.5.5.19 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.21	1.0290	0.0003	Same as Case 4.2.5.5.17 except the BWR fuel is eccentrically positioned toward the mislocated PWR fuel.
4.2.5.5.22	0.8880	0.0003	Same as Case 4.2.5.5.21 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.23	0.9670	0.0005	Same as Case 4.2.5.5.21 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.24	0.8330	0.0003	Same as Case 4.2.5.5.23 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.25	1.0231	0.0003	Same as Case 4.2.5.5.17 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.26	0.8812	0.0003	Same as Case 4.2.5.5.25 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.27	0.9670	0.0003	Same as Case 4.2.5.5.19 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.28	0.8332	0.0003	Same as Case 4.2.5.5.27 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.29	1.0303	0.0003	Same as Case 4.2.5.5.21 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.30	0.8853	0.0003	Same as Case 4.2.5.5.29 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.31	0.9704	0.0003	Same as Case 4.2.5.5.23 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.32	0.8348	0.0003	Same as Case 4.2.5.5.31 except the SFP moderator has 1000 ppm soluble boron.

Appendix 4.B

Additional Mislocated Accident Results

(Total of 9 pages)

Table 4.B.1
Additional MCNP5-1.51 Results for the Mislocated Fuel Assembly Accident Calculations with Administrative Requirement 3

Case	k_{calc}	sigma	Description
4.2.5.5.33	1.0194	0.0003	Same as Case 4.2.5.5.17 except the SFP concrete wall is present.
4.2.5.5.34	0.8793	0.0003	Same as Case 4.2.5.5.33 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.35	0.9608	0.0003	Same as Case 4.2.5.5.33 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.36	0.8296	0.0003	Same as Case 4.2.5.5.35 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.37	1.0284	0.0003	Same as Case 4.2.5.5.33 except the BWR fuel is eccentrically positioned toward the mislocated PWR fuel.
4.2.5.5.38	0.8869	0.0003	Same as Case 4.2.5.5.37 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.39	0.9653	0.0003	Same as Case 4.2.5.5.37 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.40	0.8329	0.0003	Same as Case 4.2.5.5.39 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.41	1.0224	0.0003	Same as Case 4.2.5.5.33 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.42	0.8803	0.0003	Same as Case 4.2.5.5.41 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.43	0.9675	0.0003	Same as Case 4.2.5.5.35 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.44	0.8329	0.0003	Same as Case 4.2.5.5.43 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.45	1.0309	0.0003	Same as Case 4.2.5.5.37 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.46	0.8869	0.0003	Same as Case 4.2.5.5.45 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.47	0.9701	0.0003	Same as Case 4.2.5.5.39 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.48	0.8348	0.0003	Same as Case 4.2.5.5.47 except the SFP moderator has 1000 ppm soluble boron.

Table 4.B.2
Additional MCNP5-1.51 Results for the Mislocated Fuel Assembly Accident Calculations with NO Administrative Requirement 3

Case	k_{calc}	sigma	Description
4.2.5.5.49	1.0505	0.0003	Same as Case 4.2.5.5.1 except with concrete wall present.
4.2.5.5.50	0.9063	0.0003	Same as Case 4.2.5.5.49 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.51	0.9921	0.0003	Same as Case 4.2.5.5.49 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.52	0.8547	0.0003	Same as Case 4.2.5.5.51 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.53	1.0651	0.0003	Same as Case 4.2.5.5.49 except the BWR fuel is eccentrically positioned toward the mislocated PWR fuel.
4.2.5.5.54	0.9261	0.0003	Same as Case 4.2.5.5.53 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.55	1.0018	0.0003	Same as Case 4.2.5.5.53 except the PWR fuel is a checkerboard of fresh fuel and empty cells.
4.2.5.5.56	0.8703	0.0003	Same as Case 4.2.5.5.55 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.57	1.0369	0.0003	Same as Case 4.2.5.5.49 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.58	0.8887	0.0003	Same as Case 4.2.5.5.57 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.59	0.9799	0.0003	Same as Case 4.2.5.5.51 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.60	0.8392	0.0003	Same as Case 4.2.5.5.59 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.61	1.0627	0.0003	Same as Case 4.2.5.5.53 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.62	0.9065	0.0003	Same as Case 4.2.5.5.61 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.63	1.0018	0.0003	Same as Case 4.2.5.5.55 except the mislocated PWR fuel face adjacent to the PWR fuel in the PWR BORAFLEX ™ racks.
4.2.5.5.64	0.8542	0.0003	Same as Case 4.2.5.5.63 except the SFP moderator has 1000 ppm soluble boron.

Table 4.B.3
MCNP5-1.51 Results for the Mislocated Fuel Assembly Accident Outside the BWR BORAFLEX™ Rack

Case	k_{calc}	sigma	Description
4.2.5.5.65	0.9973	0.0003	Same as Case 4.2.5.5.1 except the mislocated PWR fuel is between the BWR rack and the concrete wall and adjacent the BWR rack. See Figure 4.B.1.
4.2.5.5.66	0.8384	0.0003	Same as Case 4.2.5.5.65 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.67	0.9978	0.0003	Same as Case 4.2.5.5.3 except the mislocated PWR fuel is between the BWR rack and the concrete wall and adjacent to the BWR rack.
4.2.5.5.68	0.8385	0.0003	Same as Case 4.2.5.5.67 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.69	1.0155	0.0003	Same as Case 4.2.5.5.65 except the BWR fuel is eccentric towards the mislocated PWR fuel. See Figure 4.B.2.
4.2.5.5.70	0.8643	0.0003	Same as Case 4.2.5.5.69 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.71	1.0162	0.0003	Same as Case 4.2.5.5.67 except the BWR fuel is eccentric towards the mislocated PWR fuel.
4.2.5.5.72	0.8643	0.0003	Same as Case 4.2.5.5.71 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.73	1.0005	0.0003	Same as Case 4.2.5.5.65 except the mislocated PWR fuel face adjacent to the concrete wall. See Figure 4.B.3.
4.2.5.5.74	0.8390	0.0003	Same as Case 4.2.5.5.73 except the SFP moderator has 1000 ppm soluble boron.
4.2.5.5.75	1.0000	0.0003	Same as Case 4.2.5.5.67 except the mislocated PWR fuel is adjacent to the concrete wall.
4.2.5.5.76	0.8397	0.0004	Same as Case 4.2.5.5.75 except the SFP moderator has 1000 ppm soluble boron.

Table 4.B.4

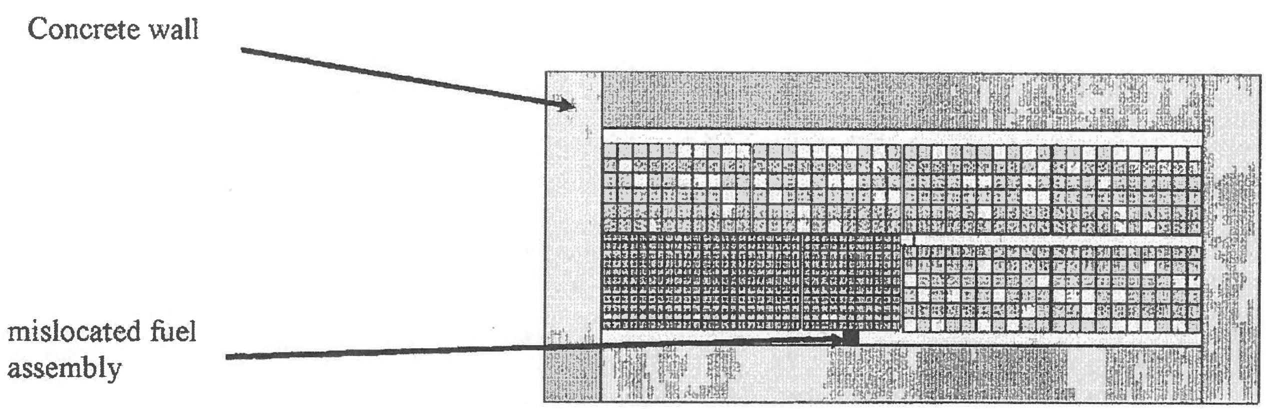
Summary of the Mislocated Accident Results

Result Table	Bounding Case	k_{calc} 0 ppm	k_{calc} 1000 ppm	Description
4.A.9	4.2.5.5.5	1.0652	0.9266	Mislocated in center of pool, NO Administrative Requirement 3, water reflector around SFP.
4.A.10	4.2.5.5.22[1]	1.0290	0.8880	Mislocated in center of pool, Administrative Requirement 3, water reflector around SFP.
4.B.1	4.2.5.5.45	1.0309	0.8869	Mislocated in center of pool, Administrative Requirement 3, concrete reflector around SFP.
4.B.2	4.2.5.5.53	1.0651	0.9261	Mislocated in center of pool, NO Administrative Requirement 3, concrete reflector around SFP.
4.B.3	4.2.5.5.71	1.0162	0.8643	Mislocated outside rack, NO Administrative Requirement 3, concrete reflector around SFP.

[1] The maximum reactivity case is selected from the most reactive of the 1000 ppm calculations.

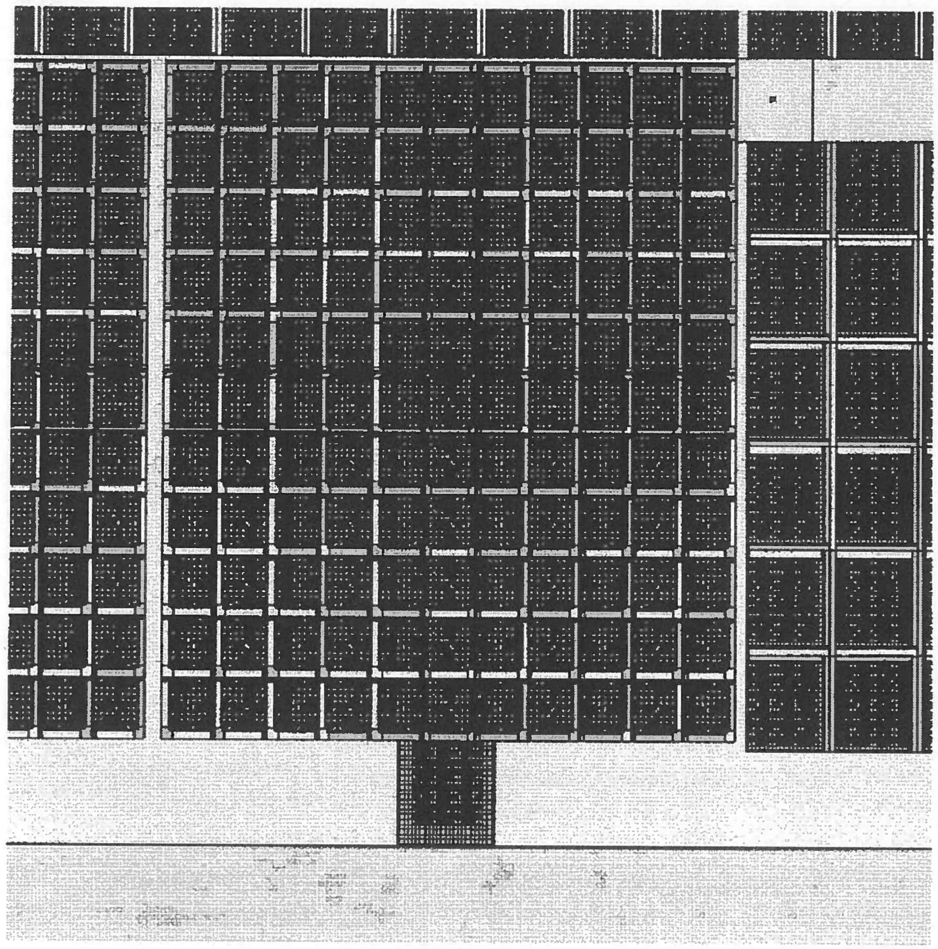
Figure 4.B.1 (1 of 2)

Additional Mislocated Fuel Assembly Accident Location



A low resolution 2D image of the mislocated fuel assembly accident outside the BWR BORAFLEX™ rack.

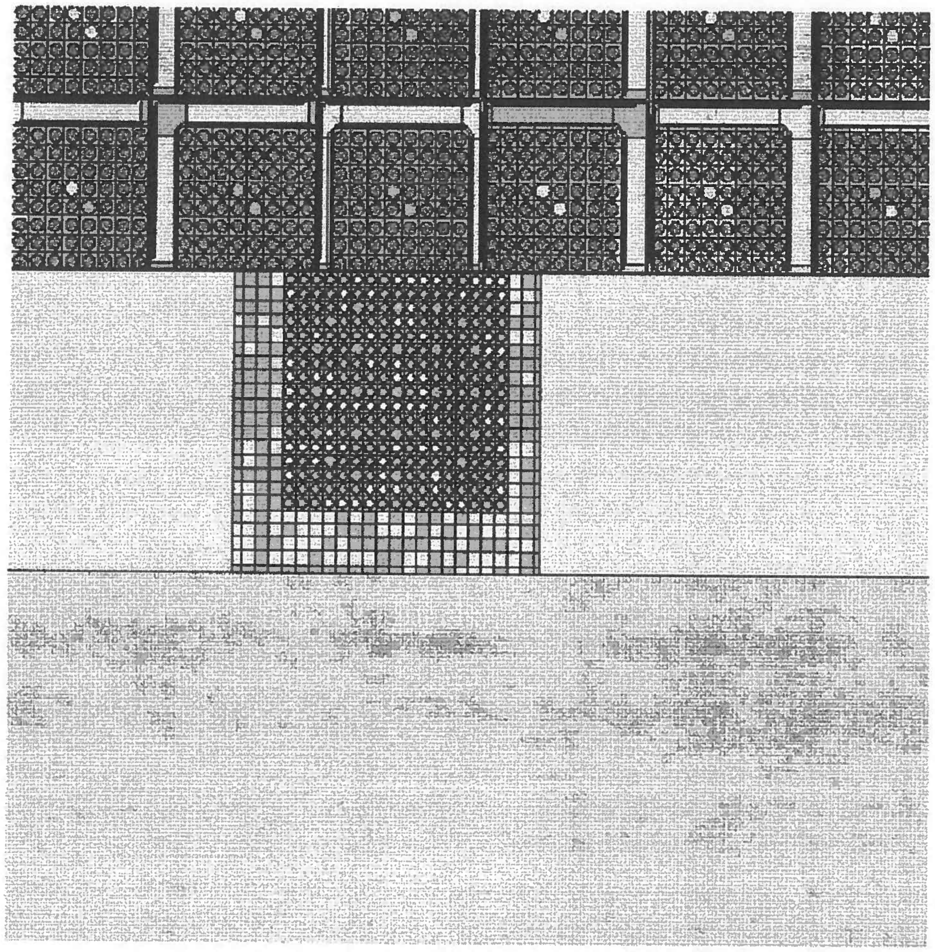
Figure 4.B. 1 (2 of 2)



A partial 2D representation of the MCNP model for Case 4.2.5.5.65 with BWR fuel in bounding eccentric position.

Figure 4.B.2

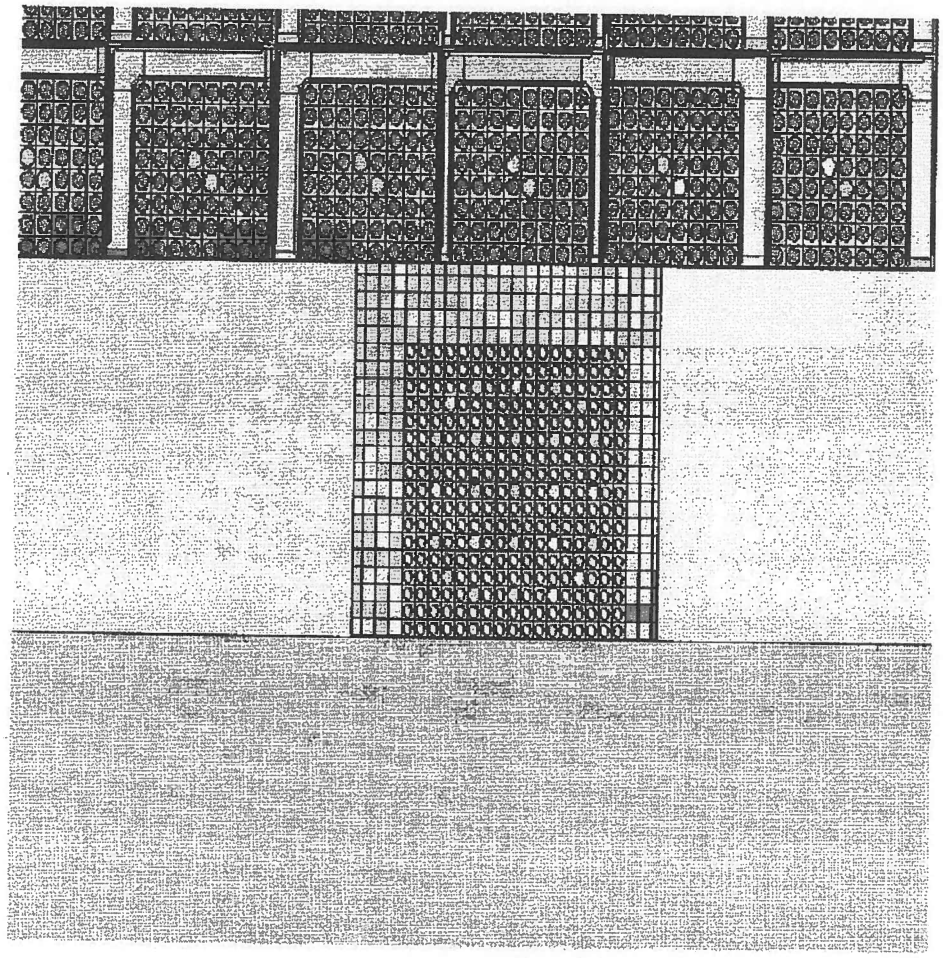
Additional Mislocated Fuel Assembly Accident Configuration



A partial 2D representation of the MCNP model for Case 4.2.5.5.69 with BWR fuel eccentric towards the mislocated PWR fuel assembly.

Figure 4.B.3

Additional Mislocated Fuel Assembly Accident Configuration Adjacent to the SFP Concrete Wall



A partial 2D representation of the MCNP model for Case 4.2.5.5.73 with BWR fuel eccentric towards the mislocated PWR fuel assembly.

CHAPTER 5: THERMAL-HYDRAULIC EVALUATION

5.1 Introduction

This chapter provides a summary of the methods, models, analyses and numerical results to demonstrate that the Westinghouse-supplied BWR spent fuel storage racks (SFSRs) in Shearon Harris spent fuel pools (SFPs) A & B will continue to meet the thermal-hydraulic requirements for safe storage of spent fuel following installation of Holtec-supplied DREAM inserts. Similar thermal-hydraulic analyses have been used for spent fuel storage licensing applications at Harris in the past.

The following specific thermal-hydraulic analyses are performed:

1. Assessment of the plant's current SFP bulk thermal evaluation to determine if it will continue to apply following installation of the DREAM inserts.

2. Assessment of the plant's current SFP time-to-boil evaluation to determine if it will continue to apply following installation of the DREAM inserts.

3. A rigorous Computational Fluid Dynamics (CFD) based study to conservatively quantify the peak local water temperatures in the Westinghouse-supplied BWR SFSRs following installation of the DREAM inserts.

4. Determination of a bounding maximum fuel cladding temperature in the Westinghouse-supplied BWR SFSRs following installation of the DREAM inserts.

These analyses are described in detail in Sections 5.3 through 5.5. A single scenario is postulated and analyzed, with all Westinghouse BWR SFSRs loaded with fuel assemblies having the maximum decay heat per assembly permitted in the Vectra IF-300 shipping cask used to transport them to Shearon Harris and the SFP bulk temperature set to the bulk temperature limit of 150°F.

In the sections that follow, analysis methods are described, a single scenario is evaluated and results are presented.

5.2 Acceptance Criteria

Applicable codes, standards and regulations include the following:

a. NUREG-0800, Standard Review Plan, Section 9.1.3 [5.2.1].
b. USNRC OT Position Paper for Review and Acceptance of Spent Fuel Storage and Handling Application, 4/78 [5.2.2].

The design of the DREAM inserts must ensure that all fuel assemblies in the Westinghouse BWR SFSRs will continue to be adequately cooled by circulation of water for the design-basis scenario. The Westinghouse BWR SFSRs with DREAM inserts are evaluated to the following criteria:

1. Following the planned offload fuel assemblies from the Harris reactor and with forced cooling available, the bulk SFP temperatures shall be limited to 150°F. This criterion can be met by demonstrating that the existing licensing basis remains applicable.

2. Under a complete failure of active cooling during the limiting fuel offload scenario, the water surface is allowed to reach saturation. Sufficient time must be available before the onset of bulk boiling to implement corrective measures. This criterion can be met by demonstrating that the existing licensing basis remains applicable.

3. Local water and fuel cladding temperatures for the fuel assemblies within the Westinghouse BWR SFSRs shall not exceed the local saturation temperature of water.

5.3 Assumptions and Design Data

5.3.1 Assumptions

The following assumptions are applied to render a conservative portrayal of thermal-hydraulic conditions in Shearon Harris SFPs A and B.

1. Heat loss by natural convection, mass diffusion and thermal radiation from the surface of the SFP water is neglected, as is conduction heat transfer through the SFP structure. Thus, all decay heat loads are considered to be removed by the SFP cooling system alone, maximizing computed temperatures.

2. No downcomer flow is assumed to exist between the Westinghouse BWR SFSR modules in the SFPs, minimizing the ability of cooled water to enter the bottom of the rack cells.

3. All SFSR cells are assumed to have the inlet flow holes geometry of the pedestal cells. This conservatively reduces the water flow area into the storage cells, thereby increasing the hydraulic resistance.

4. An additional heat transfer resistance of 0.01 $hr \times ft^2 \times °F/Btu$ is conservatively imposed on the outside of the fuel rods, to account for any crud layer, thereby increasing the calculated fuel cladding superheat.

5. The maximum local water temperature (at the SFSR cell exits) and the peak heat flux (typically near the mid-height of the active fuel region) are considered to occur co-incidentally. The superposition of these two maximum values ensures that the calculated peak fuel cladding temperature bounds the fuel cladding temperature anywhere along the length of the fuel assembly.

5.3.2 Design Data

The principal design data employed to determine if the current licensing-basis time-to-boil remains applicable are summarized in Table 5.3.1. The principal design data employed for the local thermal-hydraulic analyses are presented in Table 5.3.2.

Table 5.3.1
SUMMARY OF INPUTS FOR TIME-TO-BOIL EVALUATION

INPUT DATA	VALUE
Westinghouse BWR SFSR Weight	10890 lb.
Holtec BWR SFSR Weight	18200 lb.
Number of Westinghouse BWR SFSRs	8
DREAM Insert Weight	20 lb.
Maximum Number of DREAM Inserts	967
Stainless Steel Density	501 lb./ft.^{3}
Metamic Density	2.65 gm./cm.^{3}

Table 5.3.2

SUMMARY OF INPUTS FOR LOCAL TEMPERATURE ANALYSES

INPUT DATA	VALUE
SFP Water Elevations Floor Water Surface	 246 ft. 284 ft.
SFP Rack-to-Wall Gaps SFP A – South Wall SFP B – West Wall SFP B – South Wall SFP B – East Wall	 10 3/4 in. 12 3/4 in. 7 3/4 in. 2 3/4 in.
SFSR Plan Width	5 ft. 9 1/2 in.
Racks-to-Floor Plenum Height	6 1/2 in.
Rack Cell Length	169 in.
Active Fuel Length	144 in.
Fuel Assembly Array Size	9×9
Rack Cell Pitch	6 1/4 in.
Fuel Assembly Channel ID	5.278 in.
Number of Flow Holes per Pedestal	4
Rack Pedestal Flow Holes Diameter	2 in.
Maximum Nominal Fuel Assembly Heat	2353 Btu/hr.
Assembly Axial Peaking Factor	1.25
Assembly Radial Peaking Factor	1.6

5.4 Bulk SFP Temperatures

5.4.1 Equilibrium SFP Temperature Evaluation

The effect of the addition of the inserts on the equilibrium SFP temperatures is evaluated by reviewing the current licensing basis evaluation to identify whether the SFP water volume or thermal inertia is credited in performing the calculation. This review indicates that steady-state heat balances are used to determine the equilibrium bulk temperatures. No credit is taken for heat energy storage by the SFP water, so neither SFP water volume nor thermal inertia is credited. Because no water volume is credited the displacement of water by the DREAM inserts has no impact and the existing licensing basis evaluation remains applicable following addition of the inserts. This satisfies Acceptance Criterion 1.

5.4.2 Time-To-Boil Evaluation

The addition of the DREAM inserts displaces a quantity of SFP water, which slightly reduces the thermal inertia of the SFP. The current licensing basis time-to-boil calculation is a transient evaluation, so the SFP thermal inertia is credited. The effect of the addition of the inserts on the time-to-boil is evaluated by reviewing the current licensing basis evaluation to determine if the credited water volume contains sufficient margin to bound the addition of the DREAM inserts. The results of this comparison are presented in Table 5.4.1. The credited water volume in the current licensing basis evaluation is low enough to bound the addition of the inserts. This satisfies Acceptance Criterion 2.

Table 5.4.1 SUMMARY OF TIME-TO-BOIL EVALUATION RESULTS	
Conservatism in Credited Water Volume	117.9 $ft.^3$
Total Dream Insert Displaced Volume	116.9 $ft.^3$

5.5 Local Water and Fuel Cladding Temperatures

The objective of the local temperature analyses is to demonstrate that the principal thermal-hydraulic criterion of ensuring local subcooled conditions in the Westinghouse BWR SFSRs is met. Adequate cooling is demonstrated by performing a rigorous evaluation of the coupled velocity and temperature fields in the Westinghouse BWR SFSRs in each SFP.

For determining the maximum local water temperature, three-dimensional Computational Fluid Dynamics (CFD) analyses are implemented. There are several significant geometric and thermal-hydraulic features of the Westinghouse BWR SFSRs in each SFP that need to be considered for a rigorous CFD analysis. From a fluid flow-modeling standpoint, there are two regions to be considered. One region is the bulk region outside the Westinghouse BWR SFSRs, where the classical Navier-Stokes equations are solved with turbulence effects included. The other region is the heat-generating zone of Westinghouse BWR SFSRs loaded with fuel assemblies, where water flow is directed vertically upwards by the buoyancy forces through relatively small flow channels formed by the fuel assembly rod arrays in each rack cell. The Westinghouse BWR SFSRs are modeled as porous medium regions in which Darcy's Law [5.5.1] governs fluid flow.

The CFD analyses are performed using version 6.3.26 of the Fluent [5.5.2] fluid flow and heat transfer modeling program. The Fluent code enables buoyancy flow and turbulence effects to be included in the CFD analysis. Turbulence effects are modeled by relating time-varying "Reynolds' Stresses" to the mean bulk flow quantities by the standard k-ε turbulence model.

The peak fuel rod cladding temperature is computed by following a series of calculation steps as outlined below:

Step 1: Compute the maximum local water temperatures as just described above.

Step 2: Compute the maximum cladding to local water temperature difference (ΔT_c).

Step 3: Compute a bounding maximum fuel rod cladding temperatures by adding ΔT_c to the maximum local water temperatures.

The procedure to perform Step 2 is presented next.

The maximum specific decay power of a single fuel assembly is denoted by Q_A. The most emissive fuel rod can produce f_r times the average heat emission rate, where f_r is the radial peaking factor. A fuel rod can also produce f_z times the average heat emission rate over a small length, where f_z is the axial peaking factor. The axial heat distribution in a fuel rod is highest in the central region, and tapers off at its two extremities. Thus, peak cladding heat flux per unit heat transfer area of fuel rod is given by the equation:

$$q_{peak} = \frac{Q_A \times f_r \times f_z}{A_{rods}}$$

where A_{rods} is the total external heat transfer area of the cladding in the active fuel region of a single fuel assembly.

Within each fuel assembly rod sub-channel, water is continuously heated by the cladding as it moves axially upwards from bottom to top under laminar flow conditions. Rohsenow and Hartnett [5.5.3] report a Nusselt number, Nu, for heat transfer in a laminar flow situation through a heated channel as:

$$Nu = \frac{h_c}{k_{water}} \times D_h = 4.364$$

$$h_c = 4.364 \times \frac{k_{water}}{D_h}$$

where:

k_{water}	is the water thermal conductivity, Btu/(hr.-ft.-ºF)
h_c	is the laminar flow convective heat transfer coefficient, Btu/(hr.-ft.^{2}-ºF)
D_h	is the sub-channel hydraulic diameter, ft.

In order to introduce some additional conservatism in the analysis, it is assumed that the fuel cladding has a crud deposit thermal resistance, R_{crud}, which covers the entire surface. Therefore,

the overall heat transfer coefficient U, considering a crud deposit resistance R_{crud}, can be defined by the following:

$$U = \frac{1}{\left(\frac{1}{h_c} + R_{crud}\right)}$$

The temperature drop, ΔT_c, between the outer surface of the fuel cladding and the water flowing up through the assembly at the peak cladding flux location is computed by the following:

$$\Delta T_c = \frac{q_{peak}}{U}$$

Finally, the maximum fuel rod temperature (Step 3 above) is defined by the following:

$$T_{rod} = T_{local} + \Delta T_c$$

where:

T_{rod} is the maximum fuel clad temperature
T_{local} is the maximum local water temperature

A solution of each CFD model is performed to obtain the coupled flow and temperature fields, the maximum local water temperature is extracted from each temperature field, and then the maximum fuel cladding temperatures are computed as described. The maximum local water temperatures, fuel cladding superheat and bounding fuel cladding temperatures are summarized in Table 5.5.1. Temperature contours in a vertical plane through the center of the Westinghouse BWR SFSRs in each SFP are shown in Figures 5.5.1 and 5.5.2. At the top of the active fuel length, the local saturation temperature is approximately 240ºF. From the local water and fuel cladding temperature results, it is concluded that local water and fuel cladding temperatures remain below saturation, satisfying Acceptance Criterion 3.

Table 5.5.1
SUMMARY OF LOCAL TEMPERATURE RESULTS

PARAMETER	CALCULATED VALUE
Maximum Water Temperature SFP A SFP B	 152.6°F 152.7°F
Fuel Cladding Superheat	1.4°F
Bounding Fuel Cladding Temperature SFP A SFP B	 154.0°F 154.1°F

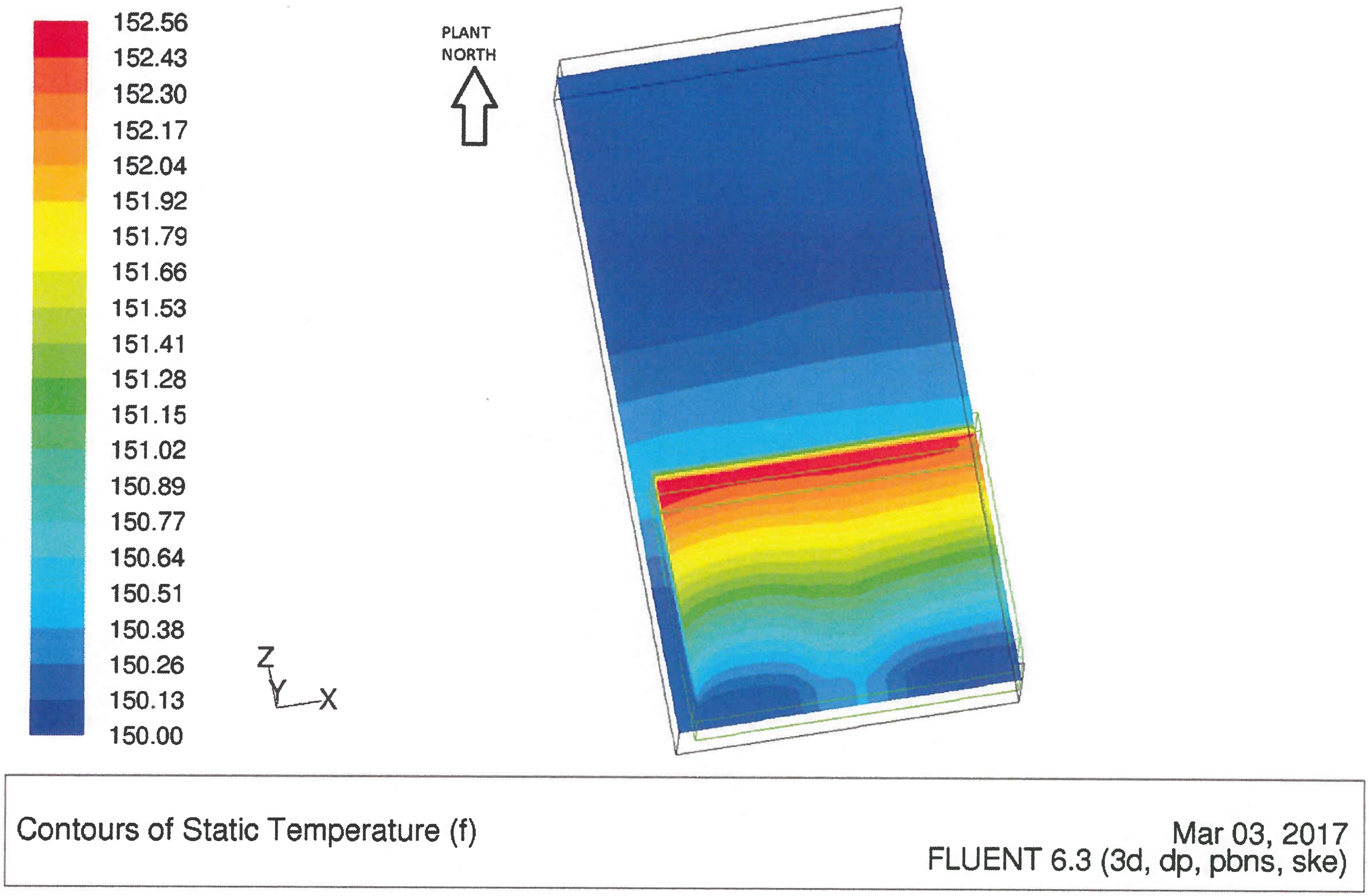


FIGURE 5.5.1: CONTOURS OF STATIC TEMPERATURE IN A PLANE THROUGH THE CENTER OF THE WESTINGHOUSE BWR SFSRs IN SFP A

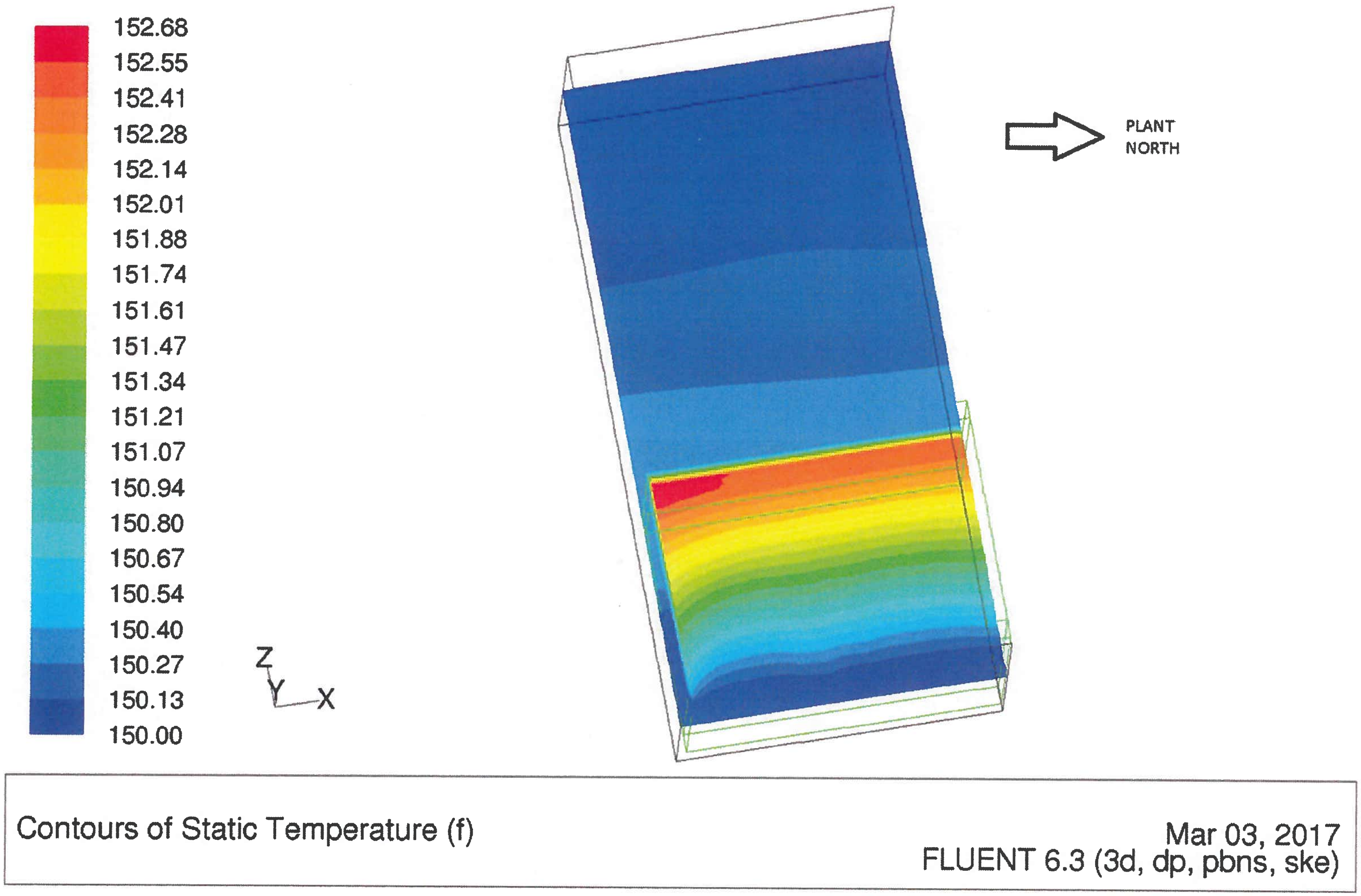


FIGURE 5.5.2: CONTOURS OF STATIC TEMPERATURE IN A PLANE THROUGH THE CENTER OF THE WESTINGHOUSE BWR SFSRs IN SFP B

5.6 References

[5.2.1] "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants – LWR Edition," NUREG-0800, Revision 2, June 1987.

[5.2.2] "OT Position Paper for Review and Acceptance of Spent Fuel Storage and Handling Applications," April 14, 1978.

[5.5.1] "Flow of Fluids Through Valves, Fittings, and Pipe," Crane Technical Paper No. 410, Crane Valve Company, Twenty-Second Printing, 1985.

[5.5.2] Fluent Computational Fluid Dynamics Software, Ansys Inc.

[5.5.3] Rohsenow, W.M. and J.P. Hartnett, "Handbook of Heat Transfer," McGraw Hill Book Company, NY, 1973.

6.0 STRUCTURAL/SEISMIC CONSIDERATIONS

6.1 Introduction

This section examines the structural adequacy of the Shearon Harris Spent Fuel Pool (SFP) racks, after Dream™ inserts have been added to the existing BWR Boraflex racks located in Pools A and B. Loadings postulated to occur during normal, seismic, and accident conditions have been considered. The effects of the Dream™ inserts on the structural design bases are evaluated by reviewing the existing analysis reports listed as References [6.7.1] through [6.7.3].

The evaluation of the structural design bases for Harris Pools A and B considered the following specific areas:

- Seismic Qualification of Existing BWR Boraflex Racks
- Fuel Pool Structural Qualification
- Pool Liner Qualification
- Mechanical Accident Evaluation

The findings and conclusions with respect to each of these structural areas are presented below.

6.2 Seismic Qualification of Existing BWR Boraflex Racks

There are three (3) existing 11x11 BWR Boraflex racks in Pool A and five (5) existing 11x11 BWR Boraflex racks in Pool B that will receive Dream™ inserts. Per Table 2.2 of Chapter 2, a single Dream™ insert weighs only [redacted] which is a small fraction of the total weight of a loaded rack as shown below.

Item	Quantity	Dry Weight (lb)	Quantity x Weight (lb)	Source
11x11 BWR Boraflex Rack	1	10,890	10,890	Reference [6.7.1]
BWR Fuel Assembly	121	681 (max.)	82,401	Table C-5 of Ref. [6.7.2]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total Weight	-	-	95,711	-

In percentage terms, the Dream™ inserts account for only [redacted] of the total rack weight. Furthermore, the existing seismic qualification for the spent fuel racks in Pool B (Ref. [6.7.3]) conservatively uses an input value of 13,100 lb for the dry weight of an empty 11x11 BWR Boraflex Rack (as opposed to actual weight of 10,890 lb). This additional weight (13,100 lb – 10,890 lb = 2,210 lb) is almost equal to the total weight of the Dream™ inserts installed in the rack [redacted] Thus, the conservatism in the existing analysis for Pool B offsets the added weight of the Dream™ such that the net difference in the loaded weight of a 11x11 BWR Boraflex Rack is very small (< 1%). Given that the Dream™ inserts have a negligible effect on the loaded rack weight, it can also be concluded that their planned use in Pools A and B will likewise have a negligible impact on the existing seismic qualification of the 11x11 BWR Boraflex Racks.

6.3 Fuel Pool Structural Qualification

The Dream™ inserts have even a smaller impact on the fuel pool structural qualifications for Pool A and Pool B. This is because the total weight of the installed Dream™ inserts is extremely small in comparison to the other load contributors (e.g., pool water, rack weight, fuel weight). For example, the table below lists the static loads on the pool floor for Pool B, which has the largest number of Dream™ inserts.

Item	Quantity	Weight (lb)	Quantity x Weight (lb)	Source
11x11 BWR Boraflex Rack	5	10,890	54,450	Reference [6.7.1]
11x11 BWR Holtec Rack	13	13,100	170,300	Reference [6.7.3]
6x10 PWR Boraflex Rack	5	18,000	90,000	Reference [6.7.3]
7x10 PWR Boraflex Rack	6	21,000	126,000	Reference [6.7.3]
6x8 PWR Boraflex Rack	1	14,400	14,400	Reference [6.7.3]
BWR Fuel Assembly	2,178	681 (max.)	1,483,218	Table C-5 of Ref. [6.7.2]
PWR Fuel Assembly	768	1,440 (max.)	1,105,920	Table B-2 of Ref. [6.7.2]
Neutron Absorber Insert (5 BWR racks)	605	[redacted]	[redacted]	[redacted]
SFP Water (50' L x 27' W x 35' min. height)	1	2,948,400	2,943,675	Assumed height; water density = 62.3 pcf
Total Weight	-	-	> 6,000,000	-

From the above table, it is obvious that the Dream™ inserts have an infinitesimal impact on the fuel pool structural qualification for Pool B, as they represent only [redacted] of the total load on the pool floor. Although it is smaller in size and capacity, the conclusion is the same for Pool A.

6.4 Pool Liner Qualification

During a seismic event, the Spent Fuel Racks transmit vertical and horizontal forces to the pool liner through the support pedestals at the base of the racks. The loads acting on the liner are proportional to the loaded weight of the Spent Fuel Racks. As discussed above, the Dream™ inserts represent a very small portion of the total loaded weight of a 11x11 BWR Boraflex rack, and therefore the inserts will have minimal effect on the pool liner qualification.

6.5 Mechanical Accident Evaluation

The addition of the Dream™ inserts can only improve the result of the mechanical accident analysis as the insert would provide some reinforcement to the cell wall and absorb some of the impact energy during an accidental fuel assembly drop. The accidental drop of a neutron absorber insert plus its handling tool onto the top of a Spent Fuel Rack is also bounded by the existing drop analysis as the weight of the insert plus handling tool (< 200 lb) is much less than a BWR fuel assembly.

6.6 Conclusion

In conclusion, the structural design bases for the existing 11x11 BWR Boraflex racks in Harris Pools A and B, as well as the structural qualification of the pool structures, are not adversely affected by the planned installation of neutron absorber inserts in three (3) 11x11 BWR Boraflex racks in Pool A (363 locations) and in five (5) 11x11 BWR Boraflex racks in Pool B (605 locations). The weight of the neutron absorber inserts are negligibly small in comparison to the overall dead weight of these structures and their contents.

Furthermore, the structural integrity of the Dream™ inserts under normal (i.e. installation and handling) and accident condition (i.e seismic events) loads has been evaluated in [6.7.4]. Per the analysis in [6.7.4], Dream™ inserts are found to be structurally adequate to perform their intended design function under both normal and seismic conditions.

6.7 References

[6.7.1] CP&L Calc ID SF-0038, "Spent Fuel Pool Heat Up Rate / Time to Boil Calculation", Revision 2.

[6.7.2] CP&L Calculation No. HNP-F/NFSA-0076, "Spent Fuel Shipping and Storage Parameters", Revision 2.

[6.7.3] Holtec Report No. HI-90526, "Sourcebook for New BWR Racks and Whole Pool Module Layout for the Shearon Harris Nuclear Power Plant", Revision 0.

[6.7.4] Holtec Report No. HI-2167295, "Structural Evaluation of Harris Dream Insert", Revision 2.