UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 27, 2016

Dr. Ayman I. Hawari, Director
Nuclear Reactor Program
North Carolina State University
Department of Nuclear Engineering
Campus Box 7909
Raleigh, NC 27695-7909

SUBJECT: NORTH CAROLINA STATE UNIVERSITY PULSTAR RESEARCH REACTOR – ISSUANCE OF AMENDMENT NO. 18 TO ALLOW MIXED ENRICHMENT CORE CONFIGURATIONS (TAC NO. MF6088)

Dear Dr. Hawari:

The U.S. Nuclear Regulatory Commission has issued the enclosed Amendment No. 18 to Renewed Facility License No. R-120 for the North Carolina State University PULSTAR Research Reactor. This amendment consists of changes to the renewed facility operating license and technical specifications (TS) in response to your application dated March 13, 2015, as supplemented on December 18 and 31, 2015, and May 12 and June 10, 2016.

The amendment revises the allowable nominal fuel enrichment, as stated in TS 5.1.a, to permit reactor fuel with a nominal enrichment of 4 percent (%) or 6% in uranium-235, and to delete a section reference in the same specification.

A copy of our safety evaluation supporting Amendment No. 18 is enclosed. If you have any questions, please contact me at (301) 415-3724 or by electronic mail at Duane.Hardesty@nrc.gov.

Sincerely,

*/RA/*

Duane A. Hardesty, Senior Project Manager
Research and Test Reactors Licensing Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Docket No. 50-297

Enclosures:
1. Amendment No. 18 to Renewed Facility License No. R-120
2. Safety Evaluation

cc: See next page

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University of Florida
202 Nuclear Sciences Center
Gainesville, FL 32611

Dr. Kostadin Ivanov, Head
Department of Nuclear Engineering
North Carolina State University
Campus Box 7909
Raleigh, NC 27695-7909

Dr. Louis Martin-Vega, Dean
College of Engineering
North Carolina State University
113 Page Hall
Campus Box 7901
Raleigh, NC 27695-7901

Andrew T. Cook
Manager of Engineering and Operations
Department of Nuclear Engineering
North Carolina State University
Campus Box 7909
2500 Stinson Drive
Raleigh, NC 27695-7909

Gerald Wicks, CHP
Reactor Health Physicist
Department of Nuclear Engineering
North Carolina State University
Campus Box 7909
2500 Stinson Drive
Raleigh, NC 27695-7909

NORTH CAROLINA STATE UNIVERSITY

DOCKET NO. 50-297

AMENDMENT TO RENEWED FACILITY LICENSE

Amendment No. 18
Renewed License No. R-120

1. The U.S. Nuclear Regulatory Commission (the Commission) has found that:

   A. The application for amendment to Renewed Facility License No R-120 filed by North Carolina State University, (the licensee), dated March 13, 2015, as supplemented on December 18 and 31, 2015, and May 12 and June 10, 2016, complies with the standards and requirements of the Atomic Energy Act of 1954, as amended (the Act), and the Commission's rules and regulations as set forth in Title 10 of the *Code of Federal Regulations* (10 CFR) Chapter I;

   B. The facility will operate in conformity with the application, the provisions of the Act, and the rules and regulations of the Commission;

   C. There is reasonable assurance that (i) the activities authorized by this amendment can be conducted without endangering the health and safety of the public and (ii) such activities will be conducted in compliance with the Commission's regulations set forth in 10 CFR Chapter I;

   D. The issuance of this amendment will not be inimical to the common defense and security or to the health and safety of the public;

   E. This amendment is issued in accordance with the regulations of the Commission as stated in 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions," and all applicable requirements have been satisfied; and

   F. Prior notice of this amendment was not required by 10 CFR 2.105, "Notice of proposed action," and publication of a notice of issuance for this amendment is not required by 10 CFR 2.106, "Notice of issuance."

2. Accordingly, the license is amended by changes to the Technical Specifications as indicated in the attachment to this license amendment, and paragraph 2.C.(2) of Renewed Facility License No. R-120 is hereby amended to read as follows:

   (2) Technical Specifications

   The Technical Specifications contained in Appendix A, as revised through Amendment 18, are hereby incorporated in the license. The licensee shall operate the facility in accordance with the Technical Specifications.

3. This license amendment is effective as of its date of issuance and shall be implemented within 30 days of issuance.

FOR THE NUCLEAR REGULATORY COMMISSION

***/RA/***

Alexander Adams, Jr., Chief
Research and Test Reactors Licensing Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Attachment:
Changes to Renewed Facility License
No. R-120 and Technical Specifications

Date of Issuance: June 27, 2016

ATTACHMENT TO LICENSE AMENDMENT NO. 18

RENEWED FACILITY LICENSE NO. R-120

DOCKET NO. 50-297

Replace the following page of the Renewed Facility License with the revised page. The revised page is identified by amendment number and contains a vertical line indicating the area of change.

| Remove | Insert |
|---|---|
| 3 | 3 |

C. This license shall be deemed to contain and is subject to the conditions specified in Parts 20, 30, 50, 51, 55, 70, and 73 of 10 CFR Chapter I, to all applicable provisions of the Act, and to the rules, regulations, and orders of the Commission now or hereafter in effect and to the additional conditions specified below:

(1) Maximum Power Level

The licensee is authorized to operate the facility at steady-state power levels not to exceed 1000 kilowatts (thermal).

(2) Technical Specifications

The Technical Specifications contained in Appendix A, as revised through Amendment 18, are hereby incorporated in the license. The licensee shall operate the facility in accordance with the Technical Specifications.

(3) Physical Security Plan

The licensee shall fully implement and maintain in effect all provisions of the Commission-approved physical security plan, including all amendments and revisions made pursuant to the authority of 10 CFR 50.90 and 10 CFR 50.54(p), which are part of the license. This plan, which contains information withheld from public disclosure under 10 CFR 2.790, is entitled "NCSU PULSTAR Physical Security Plan," Revision 8, dated January 12, 1996.

D. This license is effective as of the date of issuance and shall expire 20 years from its date of issuance.

FOR THE NUCLEAR REGULATORY COMMISSION

/RA/

Seymour H. Weiss, Director
Non-Power Reactors and Decommissioning
Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Enclosure:
Appendix A Technical
Specifications

*Date of Issuance: April 30, 1997*

ATTACHMENT TO LICENSE AMENDMENT NO. 18

RENEWED FACILITY LICENSE NO. R-120

DOCKET NO. 50-297

Replace the following page of the Appendix A, “Technical Specifications,” with the enclosed page. The revised page is identified by amendment number and contains a vertical line indicating the area of change.

| Remove | Insert |
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| 38 | 38 |

# 5.0. DESIGN FEATURES

## 5.1. Reactor Fuel

a. The reactor fuel shall be $UO_2$ with a nominal enrichment of 4% or 6% in U-235, zircaloy clad, with fabrication details as described in the Safety Analysis Report.

b. Total burn-up on the reactor fuel is limited to 20,000 MWD/MTU.

## 5.2. Reactor Building

a. The reactor shall be housed in the Reactor Building, designed for confinement. The minimum free volume in the Reactor Building shall be $2.25\times10^9$ $cm^3$ (refer to SAR Section 13 analysis).

b. The Reactor Building ventilation and confinement systems shall be separate from the Burlington Engineering Laboratories building systems and shall be designed to exhaust air or other gases from the building through a stack with discharge at a minimum of 100 feet above ground level.

c. The openings into the Reactor Building are the truck entrance door, personnel entrance doors, and air supply and exhaust ducts.

d. The Reactor Building is located within the Burlington Engineering Laboratory complex on the north campus of North Carolina State University at Raleigh, North Carolina. Restricted Areas as defined in 10 CFR Part 20 include the Reactor Bay, Ventilation Room, Mechanical Equipment Room, Primary Piping Vault, and Waste Tank Vault. The PULSTAR Control Room is part of the Reactor Building, however it is also a controlled access area and a Controlled Area as defined in 10 CFR Part 20. The facility license applies to the Reactor Building and Waste Tank Vault. Figure 5.2-1 depicts the licensed area as being within the operations boundary.

## 5.3. Fuel Storage

Fuel, including fueled experiments and fuel devices not in the reactor, shall be stored in a geometrical configuration where $k_{eff}$ is no greater than 0.9 for all conditions of moderation and reflection using light water except in cases where a fuel shipping container is used, then the licensed limit for the $k_{eff}$ limit of the container shall apply.

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

SUPPORTING AMENDMENT NO. 18 TO

RENEWED FACILITY LICENSE NO. R-120

NORTH CAROLINA STATE UNIVERSITY PULSTAR REACTOR

DOCKET NO. 50-297

## 1.0 INTRODUCTION

By letter dated March 13, 2015 (Ref. 1, 2, and 3), as supplemented on December 18 and 31, 2015 (Ref. 8 and 9), and May 12, and June 10, 2016 (Ref. 10 and 11), the North Carolina State University (NCSU, the licensee) submitted a license amendment request (LAR) to the U.S. Nuclear Regulatory Commission (NRC or Commission) under the provisions of Section 50.90, "Application for amendment of license, construction permit, or early site permit," of Title 10 of the *Code of Federal Regulations* (10 CFR) to amend the NCSU PULSTAR Reactor Technical Specifications (TS). The licensee stated the purpose of the amendment is to permit mixed enrichment core configurations by revising TS 5.1.a to allow the use of fuel with a nominal enrichment in uranium-235 of 4 percent (%) or 6% in the NCSU PULSTAR core. The 6% enriched fuel was obtained from the Buffalo Materials Research Center (BMRC) PULSTAR reactor at the State University of New York at Buffalo. The licensee also requested to delete an incorrect section reference in the TS.

This Safety Evaluation Report (SER) evaluates the technical adequacy of the NCSU LAR in accordance with review guidance provided in NUREG-1537, Part 2, "Guidance for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Standard Review Plan and Acceptance Criteria" (Ref. 12).

## 2.0 REGULATORY EVALUATION

The NRC staff reviewed the licensee's amendment application, as supplemented, to ensure that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) activities proposed will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public. The NRC staff considered the following regulatory requirements, guidance, and licensing and design basis information during its review of the proposed changes.

Part 20, “Standards for Protection Against Radiation,” of 10 CFR, establishes standards for protection against ionizing radiation resulting from activities conducted under licenses issued by the NRC.

Part 50, “Domestic Licensing of Production and Utilization Facilities,” of 10 CFR, provides the regulatory requirements for licensing of non-power reactors.

Section 50.92, “Issuance of amendment,” of 10 CFR, paragraph(a), states, in part, that: “[i]n determining whether an amendment to a license […] will be issued to the applicant, the Commission will be guided by the considerations which govern the issuance of initial licenses […] to the extent applicable and appropriate.”

Part 51, “Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions,” of 10 CFR, provides regulatory requirements for the protection of the environment.

Section 182a of the Atomic Energy Act of 1954, as amended, requires applicants for utilization facilities to include TS as a part of the license. The regulatory requirements related to the content of the TS are contained in 10 CFR 50.36, “Technical specifications.” The TS requirements in 10 CFR 50.36 include the following categories: (1) safety limits, limiting safety system settings, and limiting control settings, (2) limiting conditions for operation (LCOs), (3) surveillance requirements (SRs), (4) design features, and (5) administrative controls.

NUREG-1537, Part 2 (Ref. 12), provides guidance to NRC staff on the conduct of licensing action reviews for non-power reactor licensing applications. Chapters referenced in the conduct of this review include: Reactor Description (Chapter 4), Auxiliary Systems (Chapter 9), Instrumentation and Control Systems (Chapter 7), Experimental Facilities and Utilization (Chapter 10), Conduct of Operations (Chapter 12), Accident Analyses (Chapter 13), Technical Specifications (Chapter 14), and Comparison with Similar Facilities (Section 1.5 of Chapter 1).

## 3.0 TECHNICAL EVALUATION

The NRC staff reviewed the LAR (Ref. 1, 2, and 3), as well as the NCSU PULSTAR safety analysis report (SAR) submitted for license renewal on September 4, 1995 (Ref. 4). The reactor performance and accident analysis methodology used in the 1995 SAR formed part of the basis for this LAR. The request was reviewed consistent with the guidance of NUREG-1537 standard review plan (Ref. 12).

The NRC staff review identified additional information required to complete the evaluation. A request for additional information (RAI) was sent to the licensee on November 19, 2015 (Ref. 14). The licensee provided the requested additional information for the amendment request in correspondence dated December 18 (Ref. 8) and 31, 2015 (Ref. 9), and May 12 (Ref. 10) and June 10, 2016 (Ref. 11). This SER evaluates the initial license amendment submittal with consideration of the additional information provided in the RAI responses.

3.1 Reactor and Facility Description

The NCSU PULSTAR reactor is located in the Burlington Engineering Laboratory complex on the NCSU campus in Raleigh, North Carolina. The NCSU PULSTAR reactor is a heterogeneous light-water moderated and cooled, pool-type reactor that uses uranium dioxide ($UO_2$) fuel, built by American Machine and Foundry Company. The licensee is authorized to operate the PULSTAR reactor at a maximum steady-state thermal power level of 1.0 megawatt (MW(t)). The NCSU PULSTAR reactor was originally designed to be pulsed routinely to 2200 MW(t) peak power. However, it is no longer licensed for pulse mode with the issuance of Amendment No. 11 to the NCSU license.

The NCSU PULSTAR reactor core is comprised of 25 fuel assemblies. Each assembly contains 25 fuel pins. Each fuel pin consists of a zircaloy-2 tube, filled with sintered $UO_2$ pellets and sealed at the top and bottom. Twenty-five pins are fastened mechanically into bundles and are placed in a zircaloy-2 box. The fuel pins for the reactor are low-enriched with a nominal enrichment of 4% uranium-235 ($^{235}U$). The NCSU PULSTAR core is immersed under 20 feet of water in an open pool. The reactor pool is lined with aluminum and surrounded on the sides and bottom by concrete shielding.

In their supplemental response (Ref. 8), the licensee updated the 1995 SAR for the NCSU PULSTAR reactor (Ref.4). Table 1-1, "Comparison of PULSTAR Reactors," (NCSU and BMRC) was updated to reflect the past and future core configurations, including mixed 4% and 6% enriched fuel element core configurations to address physics parameters of the proposed new mixed-enrichment core configurations. Section 3, "Design Bases," of the NCSU LAR was updated to provide the NCSU core configuration for the proposed 6% enriched fuel mixed core configuration. Section 3.2.2.4 represents the physical description of the fuel elements, and has been updated to state that fuel may be enriched to either 4% or 6% in $^{235}U$. Section 3.2.3.3 has been updated to include detailed operational history on the operation of the NCSU PULSTAR for all operations prior to the proposed amendment.

The updated information contained in Sections 3.2.3.3.1 and 3.2.3.3.2 was used to validate the models of the reactor core and to predict the behavior of the core when loaded with a mixture of 4% and 6% enriched fuel as detailed in Section 3.2.3.3.3. This section of the NCSU SAR also provides guidance and supporting data for the operators to select core configurations that are compatible with the TS of the reactor, and limits the permitted positions of 6% enriched fuel to specific locations within the reactor.

The NRC staff reviewed the information provided by the licensee and finds that the licensees' comparisons show that the NCSU facility would not exceed the safety envelope of similar facilities (i.e., BMRC, State University of New York Buffalo). Additionally, the NRC staff finds that NCSU used appropriate test data from BMRC in evaluating the use of the 6% enriched fuel in the NCSU reactor consistent with the guidance of NUREG-1537 (Ref. 12, Ch. 1.5). On this basis, the NRC staff concludes that the updates to the reactor and facility description to reflect the mixed enrichment core configurations are acceptable.

3.2 Fuel Design and Comparison

In the NCSU amendment request, the licensee states, in part:

> Availability of licensed 4% fuel for the NCSU PULSTAR Reactor is limited to the quantities currently on-hand. NCSU obtained fresh, un-irradiated 6% fuel from the BMRC PULSTAR after it permanently shut down. In order to continue operations, it is necessary for the NCSU PULSTAR to utilize both the current 4% and the 6% fuel in a mixed enrichment core configuration.

The NCSU PULSTAR reactor core is currently fueled by light-water reactor-type fuel. The reactor core is comprised of 25 fuel assemblies containing 25 fuel pins consisting of a 0.02 inch wall thickness zircaloy-2 tube filled with sintered $UO_2$ pellets. The uranium for the currently licensed and in use pellets is enriched to 4% by weight in the $^{235}U$ isotope. Each pellet measures 0.423 inches in diameter and 0.6 inches in length. The finished fuel pin is 0.474 inches in diameter and 26 inches long. The 4% fuel pins contain a total of about 506.91 grams of uranium with approximately 20.41 grams being $^{235}U$ in each pin. Per the licensee, the 6% enriched fuel is identical construction except that the quantity of uranium in a 6% enriched fuel pin is about 513.64 grams of uranium with approximately 30.78 grams being $^{235}U$ (or approximately 1.32 percent more uranium than in a 4% enriched fuel pin).

3.2.1 Allowable Mixed Enrichment Core Configuration Loading Control

NCSU TS 3.1.e., 3.1.f., and 3.2.b., provide limits on maximum worth of a single fuel assembly, total nuclear peaking factor in any fuel assembly, and excess reactivity, respectively, such that the reactor can be shutdown at all times and to help ensure that the safety limits will not be exceeded. In response to the RAI (Ref. 8), the licensee states that the core configuration loadings will be controlled to prevent the insertion of a 6% enriched fuel assembly into a grid plate location that is not allowed. In addition, the licensee states that the NCSU fuel handling procedure (NRP-OP-301), *Reactor Fuel Handling*, is currently utilized and will continue to be used to ensure that all fuel assemblies are loaded into the correct grid plate location. This procedure requires the fuel assembly number and grid location to be confirmed by the fuel handling team prior to, during, and after the movement of each individual fuel assembly. The NRC staff reviewed the information, as described above, and finds that the licensee uses documented original equipment manufacturer (OEM) procedures that are well-accepted and have been validated for use at both the BMRC and NCSU PULSTAR reactors. On this basis, the NRC staff concludes that the procedure utilized at the NCSU PULSTAR reactor to ensure proper fuel loading is acceptable.

3.2.2 Positive Identification of 4% and 6% Enriched Fuel Assemblies

NUREG-1537, Part 2 (Ref. 12), Chapter 14, “Technical Specifications,” states, in part, that “[a]ll conditions that provide reasonable assurance that the facility will function as analyzed in the SAR should be in the technical specifications.” In the LAR, the licensee states that the NCSU 4% enriched fuel is physically and visually identical to the 6% enriched fuel pins obtained from the BMRC PULSTAR reactor at the State University of New York at Buffalo. However, the licensee did not explain how positive identification will be provided so the correct fuel assembly is handled and positioned within an allowable grid plate location to ensure proper placement of the fuel assemblies.

In response to an RAI (Ref. 8), the licensee states that the 4% and 6% enriched fuel assemblies were numbered sequentially when manufactured and are of different number sequences as specified in OEM specifications for PULSTAR fuel assemblies. The licensee has an approved procedure for placing the 6% enriched fuel pins into fuel boxes to make fuel assemblies, which allows the licensee to confirm that an assembly contains the proper enrichment pins. In addition, each fuel assembly has notches on the top that make it possible to identify the fuel assembly without removing it from the core grid plate. Based on the description of the unique identifiers for the fuel assemblies, the NRC staff concludes that a specific TS is not required and the licensee's methodology for controlling fuel pins and assemblies is acceptable.

#### 3.2.3 Conclusions for Fuel Design and Comparison

The NRC staff reviewed the licensee's amendment application and supplemental responses, which describe the NCSU 4% and BMRC 6% enriched fuel. The NRC staff finds that the licensee verified that the BMRC PULSTAR fuel pins (e.g., dimensions, cladding material) are identical to the NCSU PULSTAR fuel except for the difference in enrichment. The NRC staff also finds that the licensee adequately discussed the design of the NCSU and BMRC PULSTAR fuels. On this basis, the NRC staff concludes that the BMRC fuel design is compatible with the existing NCSU fuel design and is acceptable.

### 3.3 Nuclear Design

The regulations in 10 CFR 50.36(c)(1) require, in part, that technical specifications include safety limits. Safety limits for nuclear reactors are limits upon important process variables that are found to be necessary to reasonably protect the integrity of certain of the physical barriers that guard against the uncontrolled release of radioactivity. The primary physical barrier for the NCSU PULSTAR reactor is the fuel cladding. The reactor is designed and licensed to operate under safety limits defined in the TS and controlled by LCO that help ensure that fuel melt or fuel clad damage is prevented. These safety limits are established and supported by the NCSU PULSTAR SAR (Ref. 4).

In Section 1.1 of their analysis (Ref. 3), the licensee states "[a]ll mixed enrichment core configurations are […] shown to meet the current licensed Technical Specifications (TS) of the PULSTAR…" The licensee states that the existing licensing basis bounds the operation of the NCSU PULSTAR for the proposed insertion of 6% enriched fuel in pre-selected locations of the PULSTAR reactor core. In Appendix A of their analysis (Ref. 3), the licensee calculated key TS parameters including core excess reactivity, rod worth values, shutdown margin, and power peaking factors using various initial conditions and core configurations. In the LAR, the licensee states that demonstrating continued compliance with the identified, potentially impacted, LCO "ensures that the NCSU PULSTAR can continue to operate safely and reliably while staying within the licensing basis of the current Safety Analysis Report."

### 3.3.1 Calculational Methodology

The NCSU licensee performed Monte Carlo N-Particle (MCNP) code analysis of the NCSU PULSTAR reactor core to quantify the impact of operating a mixed enrichment core with regard to the limits set forth in the TS. The licensee used this analysis to determine the acceptable mixed core configurations that would meet the existing set of LCOs of the NCSU PULSTAR TS:

TS 3.1.e - The maximum worth of a single fuel assembly shall not exceed 1590 pcm.

TS 3.1.f - The total nuclear peaking factor in any fuel assembly shall not exceed 2.92.

TS 3.2.a - The shutdown margin, with the highest worth scrammable control rod fully withdrawn, with the shim rod fully withdrawn, and with experiments at their most reactive condition, relative to the cold critical condition, is greater than 400 pcm.

TS 3.2.b - The excess reactivity is not greater than 3970 pcm.

TS 3.2.d - The rate of reactivity insertion of the control rods is not greater than 100 pcm per second (critical region only).

TS 5.1.b - Total burn-up on the reactor fuel is limited to 20,000 MWD/MTU.

The NRC staff reviewed the license amendment application, as supplemented, and the 1995 license renewal SAR to compare the licensee's current calculational methodology to the calculational methodology previously approved by the NRC staff. The NRC staff previously reviewed and accepted the calculational methodology proposed by the licensee (Ref. 4). Because the licensee used documented codes that are well-accepted and have been validated against data for PULSTAR reactors, including the NCSU, the NRC staff concludes that the calculational methodology used by the licensee is acceptable.

### 3.3.2 MCNP6 Model Analysis

The guidance in NUREG-1537, Part 2, Section 4.2, "Reactor Core," and Section 4.5, "Nuclear Design," states, in part, that the applicant should present all design information and analyses necessary to demonstrate that the core can be safely operated. Appendix A, Section 3.1, of the NCSU LAR (Ref. 3) describes the general purpose Monte Carlo N-Particle code (MCNP6) model used by the licensee to evaluate the steady-state neutronic characteristics of the PULSTAR reactor.

During the NRC staff's review of the license amendment application, the NRC staff noted that NCSU did not provide the details or assumptions on how the fuel assembly was modeled or how the fuel assembly cells (material/geometry) were treated and tracked during the depletion calculations.

The licensee's supplemental response (Ref. 9) states that the reactor core was modeled based on the OEM specifications. Each fuel pin was uniquely defined and subdivided into 10 unique axial fuel cells to track the change in material composition as a function of position, core configuration, and depletion. Each fuel cell had its own material and density with a corresponding material identification number based on its assembly, pin, and axial position. Within the MCNP model, each fuel cell was defined with a unique material card to ensure that the corresponding material was moved correctly with the fuel cell during fuel shuffling. Fuel shuffling was performed with a script program that tracked each material card during depletion calculations. The NRC staff reviewed the licensee modelling methodology, as described above, and finds the modelling methodology is an acceptable modeling analysis for the reactor core.

The NRC staff also requested (Ref. 14) that the licensee discuss whether the effects of manufacturing tolerances for the fuel assembly were considered in the analysis. On Page 5 of the RAI response (Ref. 9), the licensee states the effects of manufacturing tolerances were accounted for by varying the dimensions and material properties within their OEM specifications. Because the actual core design dimensions are not known and because the nominal dimensions have a small variation due to manufacturing tolerances, an acceptable modeling and benchmarking methodology is to vary the nominal core design dimensions within their manufacturing tolerances to match the calculated power distribution to the measured power distribution. The licensee's computer model for the PULSTAR reactor core utilized the core design dimensions based on the nominal dimensions and manufacturing tolerances associated with the OEM specifications. To better compare the calculated results to the measurement results, the nominal dimensions and material properties of the core design were varied within their OEM tolerances. This methodology was performed for both reactivity related measurements (e.g. excess reactivity) and physical measurements for the core design.
The staff reviewed the licensee response and finds that varying the OEM specifications within manufacturing tolerances to calibrate the model inputs to more accurately reflect the actual fuel dimensions is a conservative an acceptable methodology.

The NRC staff requested that the licensee discuss how the statistical variations and model statistics (e.g., minimizing the calculation uncertainty) were addressed in the calculations. The licensee response states that all of the calculations were performed with a sufficiently large number of particles and inactive cycles to reduce the uncertainty in the reactivity calculations to less than 10 percent millirho[1] (pcm), to reduce the relative uncertainty in the fission energy deposition to less than one percent, and to pass the Shannon entropy statistical check. Furthermore, the MCNP model was run with an initial 16 neutron sources in each fuel cell. The NRC staff reviewed the licensee response and finds that the calculated small uncertainty results and meeting the Shannon entropy statistical check, the statistical variations are bound by the calculated statistical uncertainties. Therefore, the NRC staff finds these methodologies are reasonable in reducing the statistical variations and calculated uncertainties and are acceptable.

The NRC staff asked how the MCNP6 calculated statistical uncertainty was applied to the core reactivity parameter and power peaking results. The licensee response (Ref. 9), states that the Propagation of Uncertainty (Error) methodology was utilized to calculate the statistical

[1] Percent millirho is an alternative unit for reactivity to $\Delta k/k$. The conversions between the units of reactivity is
1 pcm = 0.00001 $\Delta k/k$.

uncertainty for the core reactivity parameters and power peaking results. The NRC staff reviewed and finds that this methodology is reasonable and appropriate to calculate statistical uncertainty and is therefore, acceptable.

The NRC staff requested that the licensee provide justification for why the 15 percent margin added to the calculated peaking factor for mixed enrichment cores provides sufficient confidence that the observed peaking factor will not exceed the limit in NCSU TS 3.1.f., given that the experimental margin was determined from uniform enrichment experiments only. The licensee's response states that the 15 percent margin was derived from the observed relative deviation between the calculated and experimentally measured peaking factors for the eight benchmark core configurations (i.e., the standard core configuration through the currently operating Core Configuration 8). Based on the licensee's statistical calculations, the calculated peaking factor will not deviate by more than 13 percent at the 99.99 percent confidence level. For conservatism, the licensee added an additional 2 percent margin for a total of 15 percent. The NRC staff reviewed the licensee response and finds that the use of a 15 percent margin is conservative in calculating the peaking factor for the mixed enrichment core configurations and is, therefore, acceptable.

The NRC staff requested the licensee to explain how the MCNP6 code utilizing the [Evaluated Nuclear Data Files] ENDF/B-VII cross-sections libraries was validated and how the associated uncertainty margin for the difference between the experimental measured results and the MCNP6 calculated result was addressed. Additionally, the NRC staff requested that the licensee discuss the verification of the model geometry definition and input data, as well as configuration changes for specific core analyses (i.e., fuel shuffling locations) that were performed.

The licensee response (Ref. 9) states that the MCNP6 code with the program's default ENDF/B-VII cross-section library was verified to be installed correctly and validated by running the test suites provided with the MCNP6 code package, and comparing these results with the results provided with the MCNP6 code package data. Furthermore, the previous eight core configurations were modeled and the calculated results were compared to measured core parameters to show that the associated uncertainty margin is very small based on the Propagation of Uncertainty (Errors) methodology. The licensee also used the NJOY nuclear data processing system, which provides comprehensive capabilities to convert evaluated nuclear data in ENDF format into temperature-dependent libraries useful for calculations using a wide variety of the most up-to-date nuclear data. The cross-section libraries generated with the NJOY99 code for use in the MCNP6 code were validated through comparison to the default MCNP6 cross-section library. The licensee states that the geometry of the model and changes to the model were visually verified by reviewing pictures of the MCNP6 model and reviewing its MCNP6 input files. Additionally, the licensee response confirmed that computer script programs were utilized for all fuel shuffling operations and that following the use of a script program to perform fuel shuffling, the data entries were verified by visual inspection.

The NRC staff reviewed the licensees' verification methodology, which uses widely available nuclear data with independent verification of the fuel shuffling script programs and finds the methodology is reasonable and appropriate. Based on the observed behavior of the processed cross-section libraries and the small differences between the MCNP6 ENDF/B-VII cross-section library and the NJOY99 processed cross-section libraries, the NRC staff finds the method of code validation is acceptable.

The NRC staff requested that the licensee discuss whether other benchmark cores were utilized, other than the initial fresh fuel core, to validate the core model and to calculate the uncertainty margin as part of the verification and validation of the MCNP6 code.

The licensee's response (Ref. 9) states that the benchmark cores utilized were the NCSU PULSTAR standard core configuration through the currently operating Core Configuration 8. These eight core configurations were modeled in detail (including depletion effects) and compared to measured results for the NCSU PULSTAR reactor. The licensee used the Propagation of Uncertainty (Errors) methodology to calculate the statistical uncertainty for the core reactivity parameters and power peaking results. The NRC staff performed a comparison of the calculated results and the measurement results from the eight core configurations and find that the comparison shows good agreement. On this basis, the NRC staff finds the benchmark analysis is acceptable.

3.3.3 Mixed enrichment core reactivity parameters and power peaking behavior

The licensee has requested that Technical Specification 5.1.a be changed to permit the use of 6% enriched $UO_2$ fuel. The current TS 5.1.a states:

> The reactor fuel shall be $UO_2$ with a nominal enrichment of 4 percent in U-235, zircaloy clad, with fabrication details as described in Section 3 of the Safety Analysis Report.

The proposed TS 5.1.a states:

> The reactor fuel shall be $UO_2$ with a nominal enrichment of 4% or 6% in U-235, zircaloy clad, with fabrication details as described in the Safety Analysis Report.

The licensee states in the LAR that amending this TS to permit the use of both 4% and 6% enriched fuel can be accomplished while maintaining compliance with all existing LCOs. Specifically, the licensee evaluates TS 3.1.e, 3.1.f, 3.2.a, 3.2.b, and 3.2.d for impact from the requested change to TS 5.1.a. The LAR includes the core analysis results for various mixed core configurations that determined two specific mixed core configurations (identified as 9-1 and 9-2 in the LAR) satisfy TS 3.1.e, 3.1.f, 3.2.a, 3.2.b, and 3.2.d. The PULSTAR reactor core with mixed core loadings of 4% and 6% enriched fuel was simulated using a MCNP6 Monte Carlo code model. The model was validated against operational data and used to evaluate various mixed core configurations to determine and analyze the core parameters related to the noted TS. The licensee's MCNP6 analyses determined specific mixed core configurations that would satisfy the TS LCOs. The licensee states this analysis provides sufficient bases to justify the selected mixed core configurations remain within the licensing basis of the current NCSU SAR (Ref. 4).

Single Fuel Assembly Worth Limit (TS 3.1.e)

The bases for NCSU TS 3.1.e., indicates that the single fuel assembly worth limit is set such that the safety limit is not exceeded during a postulated fuel loading accident, as presented in Section 13.2.2.1 of the NCSU SAR (Ref. 4). The licensee provided an evaluation showing that the assumptions leading to this limit remain valid for a mixed core using 6% enriched fuel assemblies. The calculation with regard to pulsing and step reactivity insertions are based on the results of the 6% enriched fuel tests performed at the BMRC at the State University of New York at Buffalo. The NRC staff reviewed the information provided by the licensee and finds that the calculations and conclusions are conservative because they were performed with a full 6% enriched core configuration and are bounding for the NCSU mixed enrichment core configurations. On this basis, the NRC staff concludes that the worth limit on a single fuel assembly for a mixed core using 6% fuel assemblies is acceptable.

Nuclear peaking factor (TS 3.1.f)

As discussed in Section 3.3.2, of this SER, the licensee provided calculations acceptable to the NRC staff for the peaking factor for the mixed enrichment core configurations using MCNP6 calculations with an applied factor for statistical uncertainty. The licensee's approach for estimation of power peaking factors using MCNP, as discussed in Section 3.3.2 of the SER, was performed by calculating the fission energy deposition rate within each discrete fuel unit in the core. These calculated factors were compared to measured power peaking factors, as described in Section 3.2 of the NCSU LAR (Ref. 3), by measuring the neutron flux in each PULSTAR assembly with a neutron probe. Table 3.2 of the NCSU application (Ref. 3) summarizes the measured and calculated rod worth values, SDM, and assembly averaged peaking factors for the historical 4% enriched cores. The comparison measurements were stated to be within 10 percent near the core interior and within 30 percent near the core periphery. The MCNP6 model was then used to calculate power peaking factors for possible configurations for reflected core 9 with 6% enriched fuel assemblies.

In Table 4.2 of the LAR (Ref. 3), the licensee provided a summary of MCNP6 core parameters for four representative mixed enrichment core configurations. These are represented as reflected core 9-1 through 9-4 (RC 9-1 through RC 9-4). Based on the licensee's calculations, reflected cores 9-1 and 9-2 do not exceed the TS limit of 2.92 are considered acceptable for loading. The licensee deemed reflected core 9-3 and 9-4 unusable based on the power peaking factor (FQ) being greater than the maximum 15 percent deviation established by the licensee, between the calculated and experimentally estimated values, as discussed in Section 3.3.2 of this SER. According to the licensee, "…if FQ for cores 9-3 and 9-4 is multiplied by 1.15 it would yield a value greater than 2.92." The TS 3.1.f limit in the NCSU TS (Ref. 4) for nuclear peaking factor is 2.92. The FQ for reflected core 9-1 and 9-2 was calculated by the licensee to be 2.51 and 2.54, respectively. The NRC staff reviewed the information provided by the license and finds that the value for nuclear peaking for reflected cores 9-1 and 9-2 is acceptable.

Shutdown margin (TS 3.2.a)

Shutdown margin (SDM) is defined as the minimum amount of reactivity necessary to provide confidence that the reactor can be made subcritical by means of the control and safety systems starting from any permissible operating condition and with the most reactive rod in the most reactive position, the non-scrammable rod (shim rod) in its most reactive position, and that the reactor will remain subcritical without further operator action (Ref. 13). Per NCSU TS 3.2.a, the shutdown margin, with the highest worth scrammable control rod fully withdrawn, with the shim rod fully withdrawn, and the experiments at their most reactive condition, relative to the cold critical condition, must be greater than 400 pcm.

Similar to power peaking, the licensee states that historical data from measurements of SDM was available for each core configuration for confirming neutronic calculations. In all cases for both measured and calculated, as presented in Table 3.2 of the NCSU application (Ref. 3), the SDM was in excess of 2300 pcm for all historic 4% enriched cores, as compared to the TS 3.2.a limit of greater than 400 pcm. Additionally, the NRC staff noted that the measured and calculated values for the historical 4% enriched cores were in general agreement for each of the core configurations, except for reflected core 8. The licensee explained in the response submittal (Ref. 9) this larger discrepancy was due to measurements taken with beam port number 6 empty. The licensee provided an update (Ref. 11) to Table 3.2 of the license amendment application, including the SDM measurements and calculations, taken with the beam port flooded. These measurements and calculations show reflected core 8 in agreement with the other historical 4% enriched core configurations (difference within 10 percent). In all cases, the SDM for a flooded verses empty beam port is greater than TS 3.2.a limit 400 pcm. The NRC staff reviewed the revised information provided by the licensee in the RAI response and noted that measured parameters for Reflected Core 8 are in agreement with the MCNP6 core parameters for representative 6% mixed enrichment core configurations. Based on review of this information provided by the licensee, the NRC staff finds that the value for SDM is acceptable for reflected cores 9-1 and 9-2.

Excess reactivity (TS 3.2.b)

The limit on excess reactivity is 3970 pcm by NCSU TS 3.2.b. The data presented by the licensee (Ref. 3) shows close agreement between predicted verses measured excess reactivity (Figure 3-2). For the licensee's chosen core configurations (9-1 and 9-2), 3160 pcm is the maximum excess reactivity, which is 20 percent below the TS limit. The NRC staff reviewed the excess reactivity data and finds the predicted value for core excess reactivity is representative of the measured NCSU cores and core excess reactivity remains below the TS 3.2.b, maximum limit of 3970 pcm. Therefore, the NRC staff finds the values for core excess reactivity for the proposed mixed enrichment cores 9-1 and 9-2 are acceptable.

Control Rod Reactivity Insertion Limit (TS 3.2.d)

Per NCSU TS 3.2.d, the rate of reactivity insertion of the control rods cannot be greater than 100 pcm per second (critical region only). The bases for TS 3.2.d. indicate that the limit on rate of reactivity insertion of the control rods is set such that the energy pulse from a postulated startup accident (as described in NCSU SAR, Section 13.2.2.2) is significantly less than the nominal original design for pulsing the reactor core. The licensee provided an evaluation showing that the assumptions leading to this limit remain valid for a mixed core using 6% enriched fuel assemblies. Calculations show that the reactivity insertion rate of the control rods for the 6% mixed enrichment core configuration is identical to the 4% core configuration (designated as RC8) and is below the TS limit of 100 pcm per second. The NRC staff reviewed the data provided by the licensee and finds that the calculations support the licensee's conclusion that the assumptions for the control rod reactivity insertion remain valid for the mixed enrichment core configurations and are acceptable.

Fuel Burnup Management (TS 5.1.b)

TS 5.1.b limits total burn-up on the NCSU PULSTAR reactor fuel to 20,000 megawatt days per metric ton of uranium (MWd/MTU) or 20 gigawatt days per metric ton of uranium (GWd/MTU). Appendix A, Section 1.2, of the NCSU LAR (Ref. 3) states, in part, "the reactor has been operated under eight core configurations for 1541 MWd with a core average burn-up of less than 5 GWd/MTU and a corresponding maximum fuel burn-up and assembly average burn-up of no more than 15 GWd/MTU and 10 GWd/MTU, respectively." In the RAI response (Ref. 8), the licensee explains how the maximum burn-up of the 6% enriched fuel will be managed and where and how burn-up will be documented. The licensee states that burn-up of the fuel assemblies is tracked by NCSU PULSTAR surveillance procedure, PS-4-07-2, Reactor Fuel Burnup. This surveillance procedure has been updated by the licensee to incorporate tracking of the 6% enriched fuel assemblies.

The licensee's predicted burn-up for the core configuration using 6% enriched fuel assemblies were performed with the mixed enrichment core configuration to simulate the end-of-core behavior. The operational time used in the calculation was 540 MWd. The calculations indicated that this core did not have sufficient excess reactivity to operate beyond this operational time. The NRC staff reviewed the data provided by the licensee and finds the use of operational time conservative in calculating the end-of-core behavior and concludes the licensee's methodology for fuel burnup management for the allowable mixed core configurations is acceptable.

3.3.4 Conclusion for Nuclear Design

In regards to the safety implications for operation with a mixed enrichment core configuration, the licensee provides the following conclusion in the LAR (Ref. 2):

> It is shown that the addition of 6% fuel to the PULSTAR core produces power distributions and kinetic parameters that are within the current operating limits (see Appendix A). Because of this and the fact that this amendment remains within the bounds of the current Safety Analysis Report and its Technical Specifications, the accident analysis and its associated conclusions (as presented in Chapter 13 of the PULSTAR SAR) are considered to remain valid for the anticipated mixed enrichment (4% and 6%) core configurations of the PULSTAR core.

The NRC staff reviewed the license amendment application, as supplemented by RAI responses, the 1995 license renewal SAR, and the licensee's current TS. The current TS 3.1.e TS 3.1.f, TS 3.2.a, TS 3.2.b, and TS 3.2.d require fuel worth, nuclear peaking, shutdown margin, excess reactivity, and control rod worth, respectively to bound operation of the NCSU PULSTAR reactor with 4% and 6% enriched fuel in a mixed enrichment core configuration. The NRC staff finds TS 3.1.e, TS 3.1.f, TS 3.2.a, TS 3.2.b, and TS 3.2.d will continue to help ensure the ability to safely operate and shutdown the reactor for allowable core configurations. Additionally, the staff finds that the basic flow and heat transfer characteristics for the NCSU PULSTAR reactor are unchanged by the use of 6% enriched core configurations given that the power level and thermal hydraulic design are unchanged and operation continues to be bounded by adherence to existing TS. Based on the information discussed above, the NRC staff concludes that the nuclear design, MCNP6 Model Analysis, and calculational methodology are acceptable.

## 3.4 Accident Analysis

NUREG-1537, Part 2, Chapter 13, "Accident Analyses," states, in part, the applicant should provide information and analyses demonstrating that all potential accidents at the reactor facility have been considered and their consequences adequately evaluated. The accident analysis (cause, effect, and consequence) used in the 1995 SAR formed part of the basis for review of the licensees' accident analysis for the LAR.

### 3.4.1 Excursion and non-excursion accidents

The licensee's supplemental response (Ref. 8) provides justification that the NCSU SAR analyses of transients are not significantly impacted by use of 6% enriched fuel in a mixed core configuration. The licensee states the accident analyses documented in Section 13 of the 1995 NCSU SAR (Ref. 4) were reviewed, and a determination made that no changes to the analysis are necessary to account for the mixing of 4% and 6% enriched fuel. All credible excursion and non-excursion accidents, as referenced in NUREG-1537, have been evaluated and shown to remain bounded by the current NCSU 4% core configurations. The licensee states that no new or different types of accidents are created with the use of the mixed fuel enrichment core configurations, and calculations performed support the conclusion that the existing assumptions remain valid for the mixed fuel enrichment core configurations.

The documented non-excursion accidents (with the exception of fuel pin clad failure) depend exclusively on core operation parameters such as power, peaking factor, and core neutron flux, which remain unchanged in the mixed enrichment core.

The documented excursion accidents in Section 13 of the 1995 NCSU SAR (Ref. 4) were reanalyzed by the licensee based on measured and calculated parameters for both 4% and 6% enriched fuel.

- The fuel loading accident depends upon the maximum fuel assembly worth and the feedback mechanism provided through the negative Doppler coefficient of reactivity, which is the change in reactivity per degree Fahrenheit (pcm/°F) change in fuel temperature. The maximum fuel assembly worth of 1590 pcm remains unchanged with the use of mixed enrichment cores, and the Doppler coefficient calculated for mixed enrichment cores (ranging from -1.58 pcm/°F to -1.68 pcm/°F) does not differ significantly from the coefficient for 4% enriched fuel only (-1.66 pcm/°F). Experimental measurements of the NCSU 4% enriched core agrees closely with the calculated value and experiments at the 6% enriched BMRC reactor core, demonstrating no significant change in the consequences of a fuel loading accident with a mixed enrichment core.

- For start-up accident analysis, only one of the stated assumptions (assumption number 2, rate of reactivity insertion) is affected by the enrichment of the fuel. The licensee has demonstrated that the reactivity insertion rate of the control rods for the acceptable mixed-enrichment core configurations, as evaluated in Section 3.3.3 of this SER, and the calculated values of effective delayed neutron fraction ($\beta_{eff}$) and neutron generation time ($l^*$) for the mixed enrichment cores remain identical to those from the 4% core. Therefore, the analysis of the start-up accident is unaffected.

- The NCSU SAR assumes that the accident analysis for an experiment failure is bounded by the analysis of the fuel loading accident due to the limits imposed on reactivity worth of experiments, and this assumption is unchanged by the inclusion of mixed-enrichment fuel.

- The control rod failure accident analysis is unaffected because the minimum shutdown margin is maintained for all acceptable mixed-enrichment core configurations.

- Analysis of the storage of 6% enriched fuel in the specified storage locations results in an effective neutron multiplication factor ($k_{eff}$) that is far below 0.9, and therefore the analysis of a fuel storage excursion accident is unaffected.

- In the case of both excursion and non-excursion accidents detailed in the NCSU SAR, the licensee did not perform analysis regarding accidents arising from pulsed operations, as the NRC removed authorization to pulse the reactor via Amendment No. 11 to the NCSU license.

The NRC staff reviewed the excursion and non-excursion accidents for fuel loading, control rod reactivity insertion and accidents associated with pulsing. The NRC staff finds that the licensee’s explanation demonstrating no significant change based on use of both 4% and 6% enriched fuel in these analyzed accidents is reasonable and acceptable. Other related accidents for fuel pin failure, experiment failure, cold water reactivity excursion, deemed to be possibly affected by the use of 6% enriched fuel are further analyzed in the sections that follow.

### 3.4.2 Fuel Pin Clad Failure

The previous accident analysis of fuel pin clad failure documented in Section 13.2.1.4 of the 1995 NCSU SAR (Ref. 4) depends upon the quantity of fission products present in the fuel cladding gap, which in turn depends upon the total burnup of the fuel. The NCSU PULSTAR maximum burnup limit of 20,000 MWd/MTU (TS 5.1.b) remains unchanged for 4% or 6% enriched fuel, so the difference in fuel burnup depends only upon the quantity of uranium in the fuel.

In the licensee's amendment application (Ref. 2), the licensee states that the manufacturer's quality assurance documentation (listed on the quality assurance paperwork from the manufacturer) indicates that the quantity of uranium in a 6% enriched fuel pin is 1.32 percent greater than in a 4% enriched fuel pin. Therefore, at maximum burnup, the activity of fission products, and therefore the radiation dose in restricted or unrestricted areas from an accidental release would also increase by 1.32 percent.

A review of the three fuel pin failure accident analysis in the 1995 SAR, previously found acceptable by the NRC staff, shows whole-body accident doses that are a maximum of 0.022 millirem total effective dose equivalent for off-site and 50 millirem for occupational workers in the reactor bay. Use of 6% enriched fuel increases these doses to 0.023 millirem for members of the public and 51 millirem for occupational workers in the reactor bay. An increase of this size is considered a minimal impact on radiation dose. These doses remain significantly below the maximum permissible doses under 10 CFR Part 20. The NRC staff finds the licensee's conclusions for the 1.32 percent increase from use of the BMRC 6% enriched fuel appropriate and conservative. The NRC staff concludes that the resultant increase in dose rates is negligible and therefore acceptable to the NRC staff.

### 3.4.3 Experiment Failure

Chapter 10, "Experimental Facilities and Utilization," and Chapter 13, "Accident Analyses," Section 13.1.6, "Experiment Malfunction," of NUREG-1537, states, in part, that the applicant should provide an analysis to demonstrate that the reactor and experimental facilities can be operated safely during normal and abnormal events.

Section 13.2.2.4 of the NCSU SAR, analyzes the impacts of an experiment failure as a step input of 1,000 pcm occurring if an experiment were to fail. The NRC staff asked NCSU to address whether the experimental facilities imposes any impact on the mixed core configuration or any impact the mixed core configuration imposes on the experimental facilities. Additionally, the NRC staff requested that the licensee describe the impact of a neutron beam tube flooding event on a mixed core utilizing 6% fuel.

In the response (Ref. 8), the licensee states that calculations show that the effects of 6% fuel assemblies on experimental facilities and on the beam ports is bounded by the 4% fuel assembly requirements. The staff reviewed the information provided by the licensee and finds that the experiment failure assumptions are bounded by the previously accepted fuel loading accident analyzed in Section 13.2.2.1 of the 1995 NCSU SAR (Ref. 4). Additionally, the licensee has demonstrated the assumptions and calculations for fuel loading accidents remain valid, as discussed in Section 3.2.1 and Section 3.2.2 of this SER, and are adequately controlled for the mixed enrichment core configuration. On this basis, the NRC staff concludes that the experiment failure analysis is acceptable.

### 3.4.4 Cold Primary Coolant Slug

NCSU SAR, Section 13.2.2.6, "Cold Primary Coolant Slug," provides an analysis for the conceivable event that a slug of cold pool water might pass through the critical PULSTAR core resulting in a positive reactivity input. The cold primary coolant slug accident analysis assumes a moderator temperature coefficient of 3.9 pcm/°F. The licensee has calculated the moderator temperature coefficient for mixed-enrichment cores to be between 2.96 pcm/°F and 3.44 pcm/°F. The licensee further states that smaller values of the moderator temperature coefficient have the effect of mitigating the impact of the cold primary coolant slug accident, so the mixed enrichment core is bounded by the analysis in the 1995 NCSU SAR

The forced convection analysis in the 1995 SAR (Ref. 4) was based on the temperature difference between the cold water slug and the bulk pool water temperature (27°F (15°C)). However, the NRC staff noted that facility modifications were made in 2013 to the primary and secondary system to increase cooling flow rates and capacities and requested additional information regarding the combination of the potential impact of the use of 6% enriched fuel on the cold primary coolant slug event at the higher flow rate to the analysis described in the NCSU SAR.

In the response to the RAI (Ref. 8), the licensee states that the flow rate of the primary coolant system will remain unchanged. Calculations show that the effects of 6% fuel assemblies on a cold primary coolant slug event is minimal compared to the utilization of a 4% core configuration. As previously analyzed, if this were to occur during maximum licensed power (1 MW(t)) operation, the reactor would be shut down by the high neutron flux level protective system set point at 1.2 MW(t).

The NRC staff reviewed the licensee's responses and finds that given that the flow and maximum permissible power assumptions remain valid for the mixed enrichment core configurations, the impact of a cold primary coolant slug event involving 6% fuel assemblies remains valid. On this basis, the NRC staff concludes that the analysis for the cold primary coolant slug is acceptable.

#### 3.4.5 Conclusion for Accident Analyses

The NRC staff reviewed the license amendment application, supplemental information, and the 1995 renewal SAR. Review of the calculations and assumptions demonstrated that the inventory of radioactivity assumed and other boundary conditions for the accidents while using a mixed 4% and 6% enriched core are acceptable. The radiological consequences to the public and occupational workers from accidents with the 6% enriched core are negligibly higher than the radiological consequences calculated previously for the NCSU PULSTAR reactor and the resultant doses remain well below the regulatory limits of 10 CFR Part 20. As a result of this review, the staff concludes that operation of the reactor with 6% enriched core poses no undue risk from a radiological standpoint to the public or the staff of the NCSU PULSTAR reactor. The addition of the 6% enriched fuel does not change the assumptions, analyses or consequences of accidents analyzed for the NCSU PULSTAR reactor. The licensee did not identify any new reactivity addition accidents not previously analyzed for the NCSU PULSTAR reactor. The licensee also found that other accidents previously considered for NCSU PULSTAR reactor either lead to acceptable results, are bounded by the analysis in the 1995 SAR, or are unchanged with the addition of 6% enriched fuel. Therefore, the risk to the health and safety of reactor staff and the public from the list of accidents in Section 3.4 of this SER does not increase above that previously found acceptable by the NRC staff for the NCSU PULSTAR reactor.

## 3.5 NCSU Auxiliary Systems

### 3.5.1 Shielded Storage for Radioactive Fuel

NUREG-1537, Part 1, Section 9.2, “Handling and Storage of Reactor Fuel,” states, in part, “[t]he applicant should discuss briefly the methods that ensure the prudent control of fuel.” Additionally, Section 9.2, states, in part, “[t]he applicant should provide an analysis and discuss how subcriticality is ensured.”

NCSU currently has a license to possess, but not use, the 6% enriched fuel pins. In the LAR, the licensee states the storage of 6% enriched fuel pins has been permitted in the out-of-pool storage racks by previous design changes in accordance with 10 CFR 50.59.

The licensee performed calculations for the handling and storing of unirradiated 4% and 6% enriched fuel assemblies to show that the $k_{eff}$ is not greater than TS 5.3 criteria of 0.9 for all conditions of moderation and reflection. Furthermore, the 4% and 6% fuel assemblies are numbered sequentially but are of different number sequences, as specified in Section 4.3.6 of the specifications for PULSTAR Fuel Assemblies*,* to make it easy to differentiate them apart. All procedures for fuel handling and shipment, and requirements for radiation monitoring equipment and procedures, are maintained with the inclusion of 6% enriched fuel in the reactor inventory.

The NRC staff reviewed the information provided by the licensee and finds that the licensee adequately described the location and conditions under which 6% fuel pins and assemblies will be handled and stored and included discussions of fuel handling and storage, and applicable administrative controls and procedures. The NRC staff also finds that that the licensee’s analysis demonstrates the calculated $k_{eff}$ for the in-pool storage racks located in the PULSTAR pool containing un-irradiated and irradiated 6% enriched fuel assemblies will remain subcritical (i.e., $k_{eff}$ not to exceed 0.90).

Furthermore, the licensee is currently authorized to possess and store the 6% enriched fuel pins and the NRC staff finds that the storage of 6% enriched fuel as assemblies in the authorized in-pool storage does not present a significant change in the type or significant increases in the consequence for handling and storage of reactor fuel. Therefore, as discussed above, the NRC staff concludes that the assumptions and analysis for the handling and storage of fuel assemblies are reasonable and acceptable.

### 3.5.2 Instrumentation and Control

NUREG-1537, Section 7.4, “Reactor Protection System,” states, in part, that the Reactor Protection System should place the reactor in a subcritical, safe shutdown condition when any of the monitored parameters exceeds the limit as defined in the SAR.

The licensee states in the LAR that the elements of the reactor protection system were analyzed to ensure that the use of a mixed-enrichment core did not affect the conclusions of Section 7 of the 1995 NCSU SAR, which states that the reactor will be placed in a subcritical, safe shutdown condition with any of the monitored parameters exceed the established limits specified in the SAR. The licensee's conclusions related to Section 7 of the NCSU SAR are as follows:

- The Nuclear Instrumentation system will respond the same with mixed-enrichment cores as with those considered in the SAR, as the kinetic parameters of the reactor remain essentially unchanged (as previously demonstrated).

- The Non-Nuclear Instrumentation systems are independent of fuel enrichment, and are therefore unaffected by the use of a mixed-enrichment core.

- The SCRAM logic unit depends only upon the channels supplying input signals. Since those channels are unaffected by the use of mixed-enrichment cores, so too is the analysis of the SCRAM logic unit.

The NRC staff reviewed the information provided by the licensee and Chapter 7 of the 1995 NCSU SAR and finds that the licensee adequately describes why changes to the instrumentation and control system that affect the reactor protection system for the PULSTAR reactor are not required by the use of the mixed core using 6% enriched fuel. On this basis, the NRC staff concludes that the existing NCSU instrumentation and control systems are acceptable for utilizing mixed enrichment core configurations.

3.6 Conduct of Operation

NUREG-1537, Section 12.11, "Startup Plan," states, in part, that the applicant should submit a startup plan whenever significant core modifications are being made. The NRC staff requested (Ref. 14) that the licensee describe the NCSU start-up procedure for the reactor core utilizing the mixed enrichment core configuration loadings that will provide confirmation of analysis predictions for the mixed enrichment core.

In the response to the RAI (Ref. 8), the licensee states that current NCSU procedures for evaluating and loading core configurations will be utilized for the mixed enrichment core configurations. The established PULSTAR reactor procedures cover: (1) utilizing an acceptable core configuration that satisfies all TS; (2) loading and measuring the core parameters prior to routine operations (reactor must be critical at low power to measure parameters); and (3) certifying that the core meets all TS.

The licensee's method for determining the acceptable mixed core configurations and their approach for implementing the mixed core fuel loadings is defined as:

1. Use the established MCNP model to predict a core loading pattern that meets the licensed technical specifications limits.

2. Configure the core according to the predicted loading pattern.

3. During startup testing, use existing procedures to confirm the MCNP predictions of maximum worth of a single fuel assembly, total nuclear peaking factor, shutdown margin, excess reactivity, and rate of reactivity insertion of the control rods.

4. If any of the quantities in Step 3 do not meet the licensed technical specifications limits, the reactor will be shutdown.

In their approach, the licensee describes measurement of operational reactor physics parameters, and comparison of the measured and predicted reactor physics parameters and precautions and process for startup of the reactor with a mixed enrichment configuration.

The NRC staff reviewed the licensee's startup plan, as discussed above, and finds that implementation of the proposed method described by the licensee will provide reasonable assurance that the reactor is operating as described and analyzed in the NCSU SAR for the mixed enrichment core configurations. On this basis, the NRC staff concludes that the startup plan is acceptable.

### 3.7 Existing License Conditions and Proposed Changes to Technical Specifications

The licensee has proposed changes to the NCSU PULSTAR TS to allow the use of the BMRC fuel enriched to 6% $^{235}$U in a mixed core configuration with the NCSU fuel enriched to 4% $^{235}$U.

#### 3.7.1. Existing License Conditions

Section 2.B(2) of the PULSTAR Renewed Facility License No. R-120 authorizes the use of reactor fuel that is enriched to less than 20 percent in the isotope $^{235}$U.

The NRC staff reviewed the NCSU PULSTAR license conditions related to the license amendment request. The NRC staff finds the existing license condition 2.B.(2) is consistent with the use of 6% fuel and, therefore, is acceptable.

#### 3.7.2. Proposed Changes to Technical Specifications

In the license amendment application, as supplemented by responses to RAIs (Ref. 1, 8, 9, 10 and 10), the licensee has proposed a change to the NCSU PULSTAR TS 5.1.a. Specifically, the proposed changes would add the 6% fuel to the description for the reactor fuel and delete the SAR section reference.

The current TS 5.1.a states:

> The reactor fuel shall be $UO_2$ with a nominal enrichment of 4 percent in U-235, zircaloy clad, with fabrication details as described in Section 3 of the Safety Analysis Report.

The amendment request proposes changing TS 5.1.a to state:

> The reactor fuel shall be $UO_2$ with a nominal enrichment of 4% or 6% in U-235, zircaloy clad, with fabrication details as described in the Safety Analysis Report.

The NRC staff reviewed the proposed NCSU TS 5.1.a and finds that the proposed TS 5.1.a will permit the use of both 4% and 6% enriched fuel while maintaining all other specifications. NCSU PULSTAR reactor operations remain bounded by the 1995 license renewal SAR (Ref. 4), as analyzed in the license amendment application (Ref. 2). Because the proposed TS does not change the licensing basis of the 1995 license renewal SAR and the NCSU PULSTAR will continue operations within prior acceptable limits as analyzed in the amendment application, as supplemented and evaluated in Sections 3.3, “Nuclear Design,” and 3.4, “Accident Analysis,” of this SER, the NRC staff finds the change to TS 5.1.a for 6% enriched $UO_2$ is acceptable.

In addition to the proposed change for the fuel enrichment above, NCSU also proposed an editorial change to TS 5.1.a that changes the reference for fuel fabrication details from “…Section 3 of the Safety Analysis Report” to “…the Safety Analysis Report.”

The licensee responded (Ref. 10) to the NRC staff RAI and states that the fabrication details are in Section 1 and 3 of the NCSU SAR. The licensee states that removing the specific location in the SAR from the TS avoids requesting a license amendment (pursuant to 10 CFR 50.59(c)(1)(i)) if the SAR is subsequently changed. NUREG-1537, Part 2 (Ref. 12) states that the TS should follows the format of American National Standards Institute/American Nuclear Society (ANS/ANSI) 15.1-1990 (Ref. 13) for development of TS for research reactors. ANS/ANSI 15.1 recommends that references to a particular portion of the SAR be placed in the basis statement for the specification rather than in the specification. The NRC staff finds that, although without a specific section reference, the proposed TS 5.1 continues to require the fuel fabrication details to be in the SAR. Therefore, the NRC staff concludes this change is acceptable.

### 3.8 Conclusions

The NRC staff has reviewed the license amendment application, as supplemented by responses to an RAI. The NRC staff finds the licensee has appropriately justified the technical bases for these changes, as discussed in this SER, and that the proposed changes to TS 5.1.a are acceptable. The NRC staff concludes that the proposed TS 5.1.a provides for use of 4% and 6% enriched fuel in a mixed enrichment core configuration without adversely impacting the functional capability required for safe operation. The licensee provided analyses that show two proposed mixed enrichment core configurations that meet the requirements of the existing TS LCOs. The licensee has demonstrated the ability to design other mixed enrichment cores when needed. On this basis, the NRC staff concludes that the use of 6% enriched fuel in the NCSU PULSTAR reactor and the proposed TS 5.1.a are acceptable.

## 4.0 ENVIRONMENTAL CONSIDERATION

The NRC’s regulations in 10 CFR 51.22(a) state that licensing actions may be found eligible for a categorical exclusion if the Commission has declared that the action does not individually or cumulatively have a significant effect on the human environment. This amendment involves changes in the installation or use of a facility component located within the restricted area, as defined in 10 CFR Part 20. Therefore, as required by 10 CFR 51.22(c)(9), an evaluation of the effect on the human environment is presented below:

(i) The amendment or exemption involves no significant hazards consideration; [10 CFR 51.22(c)(9)(i)]

The NRC's regulations in 10 CFR 50.92(c) state that a license amendment involves no significant hazards consideration if operation of the facility, in accordance with the proposed amendment, would not:

(1) involve a significant increase in the probability or consequences of an accident previously evaluated; or [10 CFR 50.92(c)(1)]

On page 13 of the licensee's analysis (Ref. 2), the licensee states that the PULSTAR reactor "…can be operated with cores containing fuel enriched to 4% and 6% in $^{235}U$ while meeting the current Technical Specifications limits and operational objectives." As discussed in Section 3.4 of this SER, the staff considered accidents previously evaluated for the NCSU PULSTAR. The radiological consequences to the public and occupational workers from an accident using the 6% enriched fuel are only 1.32 percent higher than the radiological consequences calculated for the 4% enriched fuel and the resultant dose remains well within the regulatory limits of 10 CFR Part 20. The staff did not identify any significant increase in the probability of an accident previously evaluated. The analysis remains within the bounds of the previously approved safety analysis and TS (Ref. 3). The accident analysis and its associated conclusions are considered to remain valid for the proposed mixed enrichment (4% and 6%) core configurations of the PULSTAR core. Therefore, the NRC staff finds this change does not significantly increase the consequences of an accident previously evaluated.

(2) create the possibility of a new or different kind of accident from any accident previously evaluated; or [10 CFR 50.92(c)(2)]

In Section 13 of the SAR (Ref. 3), the licensee analyzed the credible excursion and non-excursion accident scenarios identified in NUREG-1537 for the NCSU PULSTAR and the NRC staff previously found the results of these accident analyses to be acceptable (Ref. 4). As discussed in Section 3.4 of this SER, the licensee considered all credible accident scenarios at the PULSTAR reactor facility and their consequences adequately evaluated and remain valid for mixed enrichment core configurations as detailed in Appendix A (Ref. 2) of the amendment request. The existing TS limits and operational objectives are unchanged by this amendment and the NCSU PULSTAR reactor remains bounded by these previous analyses. For these reasons, the proposed mixed enrichment (4% and 6%) core configurations of the PULSTAR core do not create the possibility of a new or different kind of accident from any accident previously evaluated.

(3) involve a significant reduction in a margin of safety [10 CFR 50.92(c)(3)]

The NRC staff finds existing TS will continue to ensure the ability to safely operate the NCSU PULSTAR reactor core under various configurations. As discussed in Section 3.3.3 of this SER, the NRC staff finds the analysis of the addition of 6% enriched fuel to the PULSTAR core for shutdown margin, excess reactivity, rod worth and peaking factors, as well as, the reactivity coefficients (moderator and fuel temperature coefficients) are within the current operating limits and, therefore, are acceptable. For these reasons, the proposed mixed enrichment (4% and 6%) core configurations of the PULSTAR core does not involve a significant reduction in a margin of safety.

Based on the above, the NRC staff concludes that this amendment involves no significant hazards consideration.

(ii) There is no significant change in the types or significant increase in the amounts of any effluents that may be released offsite; and [10 CFR 51.22(c)(9)(ii)]

The fission products generated by operation with the proposed mixed enrichment (4% and 6%) core configurations of the PULSTAR core will not significantly change from the fission products generated by previous operation of the reactor with 4% enriched fuel and already present in the reactor fuel. Also, the amendment does not change potential release paths from the facility. For these reasons, there is no significant change in the types or significant increase in the amounts of any effluents that may be released offsite.

(iii) There is no significant increase in individual or cumulative occupational radiation exposure. [10 CFR 51.22(c)(9)(iii)]

The amendment will permit operation of the NCSU PULSTAR reactor with mixed enrichment (4% and 6%) core configurations. However, the licensed power level and basic configuration of the facility are unchanged. Accordingly, the resultant occupational dose remains unchanged and well within the regulatory limits of 10 CFR Part 20. Furthermore, the amendment will not change existing administrative controls or the radiation protection program at NCSU for limiting individual or cumulative occupational radiation doses. Therefore, the NRC staff finds that there is no significant increase in individual or cumulative occupational radiation exposure.

The amendment also makes editorial, corrective, or other minor revisions to the TS. Accordingly, this amendment meets the eligibility criteria for categorical exclusion as set forth in 10 CFR 51.22(c)(9) and 10 CFR 51.22(c)(10)(v). Pursuant to 10 CFR 51.22(b) no environmental impact statement or environmental assessment need be prepared in connection with the issuance of the amendment.

## 5.0 CONCLUSIONS

The NRC staff has concluded, on the basis of the considerations discussed above, that (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) there is reasonable assurance that such activities will be conducted in compliance with the Commission’s regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

## 6.0 REFERENCES


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3. Hawari, Ayman, I. and Wormald, J. L., North Carolina State University, “Appendix A, Examination of Mixed Enrichment Core Loading for the NCSU PULSTAR Reactor,” ADAMS Accession No. ML15076A020.

4. North Carolina State University, “Updated Safety Analysis Report, PULSTAR Reactor (redacted), License No. R-120, Docket No. 50-297, Amendment 11, September 4, 1995,” ADAMS Accession No. ML16145A256.

5. U.S. Nuclear Regulatory Commission, NUREG-1572, “Safety Evaluation Report Related to the Renewal of the Operating License for the Research Reactor at North Carolina State University,” April 1997, ADAMS Accession No. ML15124A090.

6. U.S. Nuclear Regulatory Commission, “Appendix A, Technical Specifications for the North Carolina State University PULSTAR Reactor, Facility License No. R-120, Docket No. 50-297, Amendment No. 17,” September 8, 2008, ADAMS Accession No. ML082310386.

7. U.S. Nuclear Regulatory Commission, “Safety Evaluation by the Office of Nuclear Reactor Regulation Supporting Amendment No. 17 to Facility License No. R-120, North Carolina State University, Docket No. 50-297,” September 8, 2008, ADAMS Accession No. ML081480431.

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11. Hawari, Ayman, I., North Carolina State University, letter to the U.S. Nuclear Regulatory Commission, “Response Submittal 3 to the Request for Additional Information for Technical Specification Amendment 19 – Use of 6% Enriched Fuel, License No. R-120, Docket No. 50-297,” June 10, 2016, ADAMS Accession No. ML16162A671.

12. U.S. Nuclear Regulatory Commission, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Standard Review Plan and Acceptance Criteria, NUREG-1537, Part 2,” February 1996, ADAMS Accession No. ML042430048.

13. American Nuclear Society, “ANSI/ANS 15.1-2007, The Development of Technical Specifications for Research Reactors,” 2007.

14. Hardesty, Duane A., U.S. Nuclear Regulatory Commission, letter to Hawari, Ayman I., North Carolina State University, “North Carolina State University PULSTAR Research Reactor– Request for Additional Information Regarding the License Amendment Related to the use of Six Percent Enriched Fuel (TAC NO. MF6088),” November 19, 2015, ADAMS Accession No. ML15316A581.

Principal Contributors: E. Wenzinger, Navarro Research and Engineering, Inc.
S. Parra, Navarro Research and Engineering, Inc.
P. Caracappa, Navarro Research and Engineering, Inc.
D. Hardesty, U.S. Nuclear Regulatory Commission

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