ENCLOSURE 8

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NEDO-33377, Revision 2,
"LANCR02 Lattice Physics Model Qualification"

Non-Proprietary Information - Class I (Public)

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NEDO-33377
Revision 2
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Non-Proprietary Information – Class I (Public)

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LANCR02 LATTICE PHYSICS MODEL QUALIFICATION REPORT

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Revision Status

Revision	Description of Change
0	GNF Internal Document
1	Initial Submittal to NRC
2	Updates following NRC request for additional information

Table of Contents

1. Introduction

LANCR02 is an Engineering Computer Program (ECP) that supports design, evaluation, and verification of the nuclear characteristics of BWR fuel lattices. LANCR02 generates the detailed nuclear characteristics of a BWR fuel lattice by 1) evaluating the temperature-dependent microscopic cross sections for each material in the lattice, 2) calculating the detailed neutron and gamma angular flux in the lattice using a Method of Characteristics (MoC) transport solution, and 3) calculating the isotopic concentrations in each region of the lattice as a function of exposure. The details of the LANCR02 solution are contained in the LANCR02 Lattice Physics Model Description [Ref. 1].

This report describes the methods and results used to validate LANCR02. The LANCR02 results are validated in three ways. The first set of validation cases are critical experiments run with MCNP using the ENDF/B-VII.0 data library. The purpose of these cases is to validate the basic cross section library used in LANCR02. The second set of validation cases models over 1000 single BWR lattices with LANCR02 and compare the results to MCNP. This set of cases validates the cross section library and transport solution used in LANCR02. The third set of validation cases are BWR lattice depletions run with LANCR02 and the results are compared to the independent code MONTEBURNS. The purpose of this test is to validate the depletion models in LANCR02.

2. Definitions

This section defines several terms used throughout this document. Note that these definitions are only applicable to this document and should not necessarily be applied to other applications.

k	critical eigenvalue
pcm	10^{-5} Δk (percent mille)
ppm	parts per million (of boron)
NAT	natural zone
PSZ	power shaping zone
DOM	dominate zone
VAN	vanishing zone
N-V	natural vanishing zone
N-T	natural top zone
MID	middle zone
UNC	uncontrolled
CON	controlled
HOTUNC	hot uncontrolled
HOTCON	hot controlled
COLDUNC	cold uncontrolled
COLDCON	cold controlled

In the following definitions, the subscript 0 is the reference case (usually the MCNP result) and the subscript 1 is the alternate case (usually the LANCR02 result).

Eigenvalue Difference

$$\Delta k = k_1 - k_0$$

Rod Worth

$$RW = \frac{k_{\mathrm{UNC}} - k_{\mathrm{CON}}}{k_{\mathrm{UNC}}}$$

Rod Worth Difference

$$\Delta RW = \frac{RW_1 - RW_0}{RW_0}$$

Doppler Constant of Proportionality which is used to calculate the Doppler coefficient in core simulators (Temperatures are in degrees K) [Ref. 2]

$$CDOP = \frac{k(T_{HI}) - k(T_{LOW})}{\left(\sqrt{T_{HI}} - \sqrt{T_{LOW}}\right) \cdot k(T_{LOW})}$$

Doppler Constant of Proportionality Difference

$$\Delta CDOP = \frac{CDOP_1 - CDOP_0}{CDOP_0}$$

Pin Fission Rate (for pin *n*)

$$P^n \text{, where } AVE(P^n) \equiv 1.0$$

Fission Rate RMS

$$\text{Pin RMS} = \sqrt{\frac{1}{N}\sum_{n}(P_1^n - P_0^n)^2}$$

Relative Pin Peaking Factor

$$\text{PPF} = MAX(P^n)$$

Relative Pin Peaking Factor Difference (note that according to this definition, the pin peaking factor does not have to occur in the same location in both of the cases).

$$\Delta PPF = \frac{PPF_1 - PPF_0}{PPF_0}$$

Verification - the process of confirming that an installed computer code correctly performs the intended numerical calculations.

Validation - the process of determining the applicability of a computational method and establishing the bias of the method by using benchmarks appropriate for intended evaluation of operations.

3. Codes and Libraries

As part of the LANCR02 validation, the LANCR02 results are compared to the independent codes MCNP and MONTEBURNS. This section describes the codes and data libraries used.

3.1. LANCR02

LANCR02 is a lattice physics code that uses a deterministic transport solution based on the Method of Characteristics. The details of the LANCR02 solution method are included in the LANCR02 Lattice Physics Model Description [Ref. 1]. The latest LANCR02 production neutron library used is based on data from ENDF/B-VII.0.

Many of the physics models in LANCR02 are described in the open literature in [Ref. 3], however NEDC-33376 [Ref. 1] should be considered as the official reference for the version of LANCR02 used to generate this report.

3.2. MCNP

MCNP is a Monte-Carlo transport code developed by Los Alamos National Laboratory that uses continuous energy cross section data [Ref. 4]. Since the transport solution and library format are completely different and independent of LANCR02, the results provide independent validation of the LANCR02 solution.

In this document, the term MCNP is a generic term that can represent several different specific versions of the code. The specific versions of the code are described below.

In the critical experiment evaluations (Section 4) and the qualification test cases (Section 5), the MCNP cases were run with the GNF qualified version of MCNP5, which is referred to as MCNP-05P. The details of MCNP-05P are described in Section 3.3.

For the depletion test cases (Section 6), MCNP version MCNPX [Ref. 6] was used. This is an alternate version of MCNP that is also released by Los Alamos National Laboratory. Version MCNP-05P was not available at the time the depletion cases were run.

The MCNP data libraries were generated from NJOY in a manner consistent with the LANCR02 libraries. [[

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3.3. MCNP-05P

MCNP-05P is a modified version of MCNP5 [Ref. 4] that has been developed and qualified for use at GNF. The modifications made to MCNP-05P are described in this section.

MCNP5 produces prompt gamma rays at fission sites from an associated fission event, provided a problem is run in the coupled neutron/photon mode. MCNP-05P has been enhanced with the addition of a delayed fission gamma ray model that creates the delayed gammas stemming from fission products. For non-fission collision events, only prompt gamma production is accounted for, and only for those materials for which photon production data exist in the respective ENDF/B isotopic evaluations.

The capability to produce and track delayed fission gammas in MCNP-05P is facilitated by the inclusion of a new subroutine that produces delayed fission gammas at fission sites and stores them in the particle bank for subsequent tracking. Gamma rays produced by the subroutine contribute to the photon source in the same way that prompt gammas do and thus there is no distinction made within the resultant photon source as to the nature of the contributing particles.

MCNP-05P has also been modified to account for the energy associated with the decay beta particles from fission products. The MCNP-05P modification accounts only for the beta energy at fission sites for tallying purposes, when the delayed fission gamma production option is enabled. Disabling the delayed gamma model neglects the inclusion of decay beta energy in fission and neutron heating tallies. The decay beta model does not create and track the electron resulting from the decay beta process.

3.4. MONTEBURNS

MONTEBURNS [Ref. 5] is an independent code that links stationary MCNP calculations with an ORIGEN depletion calculation. The MONTEBURNS results are used to validate the depletion methodology used in LANCR02.

GNF has made some structural changes to the original MONTEBURNS code to allow up to 200 depletion regions. The original MONTEBURNS was limited to 49 depletion regions.

4. Validation using Critical Experiments

The first step of the validation process is to confirm that the ENDF/B-VII.0 nuclear data library is appropriate for BWR analysis. This is done by analyzing actual experimental critical configurations using MCNP-05P. (LANCR02 cannot analyze the critical configurations directly because the experiments are three-dimensional.)

The ENDF/B-VII.0 nuclear data library is qualified by analyzing the following critical experiments using MCNP:

- 2 Jersey Central critical configurations,
- 9 KRITZ-75 critical configurations, and
- 52 critical configurations from the NCA critical facility, and
- 127 critical configurations from the International Criticality Safety Benchmark Evaluation Project (ICSBEP) handbook.

These experimental configurations and results are described in the following sections.

4.1. Jersey Central Experiments

4.1.1. Description

The Jersey Central Experiments consist of two experiments of 7x7 fuel lattices arranged in a 4x4 bundle at the GE Vallecitos Nuclear Center [Ref. 7]. Figure 4.1-1 shows a 1/8-core symmetry model of the experiment while Figure 4.1-2 shows the bundle dimensions and spacing.

The first experiment was clean (no control blades, no poison curtains) while the second had borated stainless steel curtains surrounding the 4 central bundles. The fuel and poison curtains extended to a height of [[ ]] above the bottom of the active fuel region. A [[ ]] water reflector region extended below the bottom of the active fuel while the top of the active fuel region extended [[ ]] above the top of the water level (since the water level height could be varied to achieve a critical system). Dimensions and materials are included in [Ref. 8].

All calculations were performed with material and cross section data representative of the system at 20^{o}C.

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Figure 4.1-1 1/8 Core Symmetry Model of Jersey Central Experiments

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Figure 4.1-2 Jersey Central Bundles and Spacing

4.1.2. Results

The eigenvalue results for the Jersey Central criticals are included in Table 4.1-1. The MCNP results show excellent agreement between the two configurations with no significant bias between the two. The MCNP cases reported eigenvalue uncertainties less than 24 pcm.

Table 4.1-1 Benchmark Results for Jersey Central Criticals

Case	Identification	K-effective
1	No poison curtains	[[
2	With poison curtains	]]

4.2. KRITZ-75 Experiments

4.2.1. Description

The KRITZ-75 experiments consisted of nine experiments of a 4x4 array of fuel bundles, each based on an 8x8 fuel lattice design. The bundles contained either three Gd_2O_3 rods in each of the four center bundles, five Gd_2O_3 rods in each of the four center bundles or three Gd_2O_3 rods in all sixteen bundles. The moderator contained dissolved boron at various concentrations and the water level height inside the tank could be adjusted to obtain a critical system. [Ref. 8] provides a detailed summary of these experiments. Figure 4.2-1 shows the ½-core symmetry model set-up while Figure 4.2-2 shows the details of the fuel bundle and relative pin orientations.

Three calculations were performed with material and cross section data representative of the system at 293 K, three at 362 K and three at 516 K. The KRITZ experimental results are noteworthy because they are calculated at temperatures other than room temperature.

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Figure 4.2-1 KRITZ-75 Half-Core Symmetry Model

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Figure 4.2-2 KRITZ-75 Bundle Configuration

4.2.2. Results

The eigenvalue results for the KRITZ-75 criticals as calculated with MCNP are included in Table 4.2-1. The maximum MCNP eigenvalue uncertainty for all cases is 53 pcm. The MCNP results show excellent agreement to measured results, with an average eigenvalue for all 9 criticals of [[ ]] and a standard deviation of [[ ]]. The results also show no significant bias with moderator temperature.

Table 4.2-1 Benchmark Results for KRITZ-75 Criticals

Case	Temp. (K)	Gd (wt.%)	# Bundles with Gad Rods	K-effective
1	293	5	4	[[
2	362	5	4	
3	516	5	4	
4	293	3	16	
5	362	3	16	
6	516	3	16	
7	293	3	4	
8	362	3	4	
9	516	3	4	
Average				]]

4.3. NCA Critical Experiments

4.3.1. Description

The NCA critical experiments consist of fifty-two critical benchmark experiments performed at the Toshiba Nuclear Critical Assembly (NCA) facility. These experiments were designed to test 8x8 (Step II), 9x9 (Step III) and 9x9 (GNF1) lattices. Earlier results for the NCA critical experiments were presented in [Ref. 9] using the ENDF/B-VII.beta library. The results shown here are based upon the latest ENDF/B-VII.0 library.

4.3.2. NCA Step II & Step III Criticals

The first series of fifteen critical benchmark experiments was performed at the Toshiba Nuclear Critical Assembly (NCA) facility in 1994-1995. These experiments were designed to test 8x8 (Step II) and 9x9 (Step III) lattice configurations for cold 0% void, simulated hot 0% void and simulated hot 40% void conditions. The NCA facility is an open-vessel tank critical system whereby low-enriched UO_2 pin lattices can be assembled.

Unirradiated UO_2 and UO_2/Gad fuel pins are held at a fixed lattice pitch by upper and lower grid spacer plates attached to the lower fuel support plate and tank respectively. The small-core arrangement essentially consists of a 2x2 array of interior fuel bundle/lattices (test zone) surrounded by an array of UO_2 pins that simulate up to twelve (driver zone) bundle/lattices (Figure 4.3-1). The test zone bundle/lattices contain different combinations of 2% and 3% enriched UO_2 pins with up to ten U(2%) O_2-Gad(5%) burnable absorber pins in two of the four lattices. In addition, the test zone can also contain hollow (voided) aluminum tubes that are inserted between the fuel pins to simulate the effects of voiding within the

lattice. The driver zone fuel pins are 2% enriched UO_2 rods (no Gad) and can be arranged around the test zone bundle/lattices in rows as needed to increase the system reactivity to obtain a critical configuration in combination with adjusting the water level height within the tank. In the MCNP models, the aluminum tubes were explicitly modeled and average void fractions were not used.

A series of fifteen experiments was performed (nine with 9x9 lattices in the test zone and six with 8x8 lattices). Of the nine 9x9 lattice cases, three were performed at the cold 0% void condition, three at the simulated hot 0% void condition and three at the simulated hot 40% void condition. For the six 8x8 lattice experiments, three were at the cold 0% void condition and three were at the simulated hot 40% void condition. The number of driver pins and tank water level height needed to achieve criticality varied depending on the number and arrangement of Gadolinium bearing fuel rods in the test zone as well as the simulated void condition used in the test zone lattice.

4.3.3. NCA GNF1 Criticals

Another series of thirty-seven critical benchmark experiments was performed at the Toshiba Nuclear Critical Assembly (NCA) facility in 2000-2001. These experiments were designed to test 9x9 lattice configurations for the GNF1 fuel design. Like the Step II & III experiments, the GNF1 criticals consisted of a 2x2 test zone region surrounded by an array of driver pins. In the GNF1 experiments, the test zone region contained UO_2 pins at 3%, 4% and 5% enrichment with up to sixteen $U(2\%)O_2$-Gad pins located in two of the four test zone lattices. The UO_2-Gad test zone pins were either 1.0%, 1.5% or 5.0 wt.% Gad depending on the experiment and the number of UO_2-Gad rods in each of the two test zone bundles varied from 4 to 16. The driver zone region contained $U(2\%)O_2$ pins only.

A series of thirty-seven experiments was performed (seventeen at the cold 0% void condition and twenty at the simulated hot 40% condition). Like the Step II & III experiments, the number of driver pins and tank water level height needed to achieve criticality varied depending on the number and arrangement of Gadolinium bearing fuel rods in the test zone as well as the size of the void tubes used in the test zone lattice.

Figure 4.3-2 shows a schematic of the 9x9 GNF1 test lattice with both driver zone and test zone fuel pins.

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Figure 4.3-1 Schematic of the Step II & III Test Zone Lattices

[[

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Figure 4.3-2 Schematic of GNF1 Fuel with Void Tubes in Test Zone

4.3.4. Results

The eigenvalue results of the NCA critical experiments are shown in Table 4.3-1. The averaged k-effective of the 52 experiments is [[ ]] with a standard deviation of [[ ]] when using the MCNP library based on ENDF/B-VII.0 data. The results show good agreement between the calculated values and measured data. The results are consistent with measurement accuracy and there is no significant bias with respect to core configurations.

Table 4.3-1 NCA Critical Results

Expt. #	Experiment	Input Name	K-eff	Expt. #	Experiment	Input Name	K-eff
1	[[						
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
							]]

In addition to the integral criticality results, axial and radial gamma scans were performed on individual pins for a subset of the configurations. These measurements were taken to obtain relative pin-power fission density estimates for direct benchmark comparison to transport method calculations.

Figure 4.3-3to Figure 4.3-5 show the axial gamma scan results for 3 pins (labeled A, B, C) in configuration "GNF1 1upper8_40V". The MCNP results show excellent agreement with the measured gross gamma scan results from the post-experiment exams. Axial RMS errors are in the range from [[ ]]. Even the minor effects of the thin (5mm) aluminum spacer that was inserted into the test zone region for these measurements (to ensure no pin movement) can be seen in the axial fission density plots for rods A and B. Almost no perturbation of the shape is seen in the rod that was outside the test zone (rod C).

Figure 4.3-6 to Figure 4.3-8 show the axial gamma scan results for 3 pins (labeled D, E, F) in configuration "GNF1 2upper7_40V". Again, the MCNP results show excellent agreement with the measured gross gamma scan results from the post-experiment exams. Axial RMS errors are in the range from [[ ]].

2-D radial measurements across the axial mid-plane of fuel pins were also made for a subset of the configurations. For these tests, selected individual fuel rods were removed and scanned over small section of the fuel rod near the core mid-plane. The gross gamma scan measurements were then tabulated and normalized to provide a 2-D pin power fission density distribution across the bundle/lattice. These results were then compared to direct MCNP calculations. The results of the radial fission rate RMS are shown in Table 4.3-2. The locations of the pin that were measured are shown in Figure 4.3-9 to Figure 4.3-11.

Table 4.3-2 Radial Pin Measurement Results

Configuration	Number of Pins	Radial Fission Rate RMS (%)
GNF1 1upper8_40V	[[	
GNF1 2upper7_40V		
GNF1 4upper6_40V		]]

The radial fission rate comparisons show excellent agreement between calculation and measurement.

[[

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Figure 4.3-3 Measured vs. Calculated Fission Density Rod A

[[

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Figure 4.3-4 Measured vs. Calculated Fission Density Rod B

[[

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Figure 4.3-5 Measured vs. Calculated Fission Density Rod C

[[

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Figure 4.3-6 Measured vs. Calculated Fission Density Rod D

[[

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Figure 4.3-7 Measured vs. Calculated Fission Density Rod E

[[

]]

Figure 4.3-8 Measured vs. Calculated Fission Density Rod F

[[

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Figure 4.3-9 Radial Pin locations for Configuration GNF1 1upper8_40V

[[

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Figure 4.3-10 Radial Pin Locations for Configuration GNF1 2upper7_40V

[[

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Figure 4.3-11 Radial Pin Locations for Configuration GNF1 4upper6_40V

4.4. ICSBEP Critical Experiments

4.4.1. Description

This section gives results for 127 critical benchmarks described in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) handbook [Ref. 10]. Not all the experiments described in the handbook are used in this report since some lacked direct applicability to LWR fuel lattices. These benchmark experiments were chosen to represent the best available, internationally accepted, benchmark evaluations currently available for low-enriched pin-lattice in water experiments. The W/F ratios for these experiments range from 1.50 to 4.22.

The geometric descriptions of these experiments can be found in [Ref. 10].

4.4.2. Results

The eigenvalue results for the ICSBEP criticals are shown in Table 4.4-1. The reported uncertainty in the MCNP cases ranged from 27 to 43 pcm. The averaged k-effective of the 127 experiments is [[ ]] with a standard deviation of [[ ]] when using the MCNP library based on ENDF/B-VII.0 data. The results show excellent agreement between the calculated values and measured data.

Table 4.4-1 Critical Eigenvalues for ICSBEP Critical Experiments

Experiment	#	U-235 (%)	W/F	Model K-eff	Model Uncertainty (pcm)	MCNP K-eff
LEU-COMP-THERM-001	1	2.35	3.21	0.9998	310	[[
LEU-COMP-THERM-001	2	2.35	3.21	0.9998	310	
LEU-COMP-THERM-001	3	2.35	3.21	0.9998	310	
LEU-COMP-THERM-001	4	2.35	3.21	0.9998	310	
LEU-COMP-THERM-001	5	2.35	3.21	0.9998	310	
LEU-COMP-THERM-001	6	2.35	3.21	0.9998	310	
LEU-COMP-THERM-001	7	2.35	3.21	0.9998	310	
LEU-COMP-THERM-001	8	2.35	3.21	0.9998	310	
LEU-COMP-THERM-002	1	4.31	1.85	0.9997	200	
LEU-COMP-THERM-002	2	4.31	1.85	0.9997	200	
LEU-COMP-THERM-002	3	4.31	1.85	0.9997	200	
LEU-COMP-THERM-002	4	4.31	1.85	0.9997	200	
LEU-COMP-THERM-002	5	4.31	1.85	0.9997	200	
LEU-COMP-THERM-006	1	2.6	1.50	1	200	
LEU-COMP-THERM-006	2	2.6	1.50	1	200	
LEU-COMP-THERM-006	3	2.6	1.50	1	200	
LEU-COMP-THERM-006	4	2.6	1.83	1	200	
LEU-COMP-THERM-006	5	2.6	1.83	1	200	
LEU-COMP-THERM-006	6	2.6	1.83	1	200	
LEU-COMP-THERM-006	7	2.6	1.83	1	200	
LEU-COMP-THERM-006	8	2.6	1.83	1	200	
LEU-COMP-THERM-006	9	2.6	2.48	1	200	

Experiment	#	U-235 (%)	W/F	Model K-eff	Model Uncertainty (pcm)	MCNP K-eff
LEU-COMP-THERM-006	10	2.6	2.48	1	200	
LEU-COMP-THERM-006	11	2.6	2.48	1	200	
LEU-COMP-THERM-006	12	2.6	2.48	1	200	
LEU-COMP-THERM-006	13	2.6	2.48	1	200	
LEU-COMP-THERM-006	14	2.6	3.00	1	200	
LEU-COMP-THERM-006	15	2.6	3.00	1	200	
LEU-COMP-THERM-006	16	2.6	3.00	1	200	
LEU-COMP-THERM-006	17	2.6	3.00	1	200	
LEU-COMP-THERM-006	18	2.6	3.00	1	200	
LEU-COMP-THERM-009	1	4.31	4.13	1	210	
LEU-COMP-THERM-009	2	4.31	4.13	1	210	
LEU-COMP-THERM-009	3	4.31	4.13	1	210	
LEU-COMP-THERM-009	4	4.31	4.13	1	210	
LEU-COMP-THERM-009	5	4.31	4.13	1	210	
LEU-COMP-THERM-009	6	4.31	4.13	1	210	
LEU-COMP-THERM-009	7	4.31	4.13	1	210	
LEU-COMP-THERM-009	8	4.31	4.13	1	210	
LEU-COMP-THERM-009	9	4.31	4.13	1	210	
LEU-COMP-THERM-009	24	4.31	4.13	1	210	
LEU-COMP-THERM-009	25	4.31	4.13	1	210	
LEU-COMP-THERM-009	26	4.31	4.13	1	210	
LEU-COMP-THERM-009	27	4.31	4.13	1	210	
LEU-COMP-THERM-016	1	2.35	3.21	1	310	
LEU-COMP-THERM-016	2	2.35	3.21	1	310	
LEU-COMP-THERM-016	3	2.35	3.21	1	310	
LEU-COMP-THERM-016	4	2.35	3.21	1	310	
LEU-COMP-THERM-016	5	2.35	3.21	1	310	
LEU-COMP-THERM-016	6	2.35	3.21	1	310	
LEU-COMP-THERM-016	7	2.35	3.21	1	310	
LEU-COMP-THERM-016	8	2.35	3.21	1	310	
LEU-COMP-THERM-016	9	2.35	3.21	1	310	
LEU-COMP-THERM-016	10	2.35	3.21	1	310	
LEU-COMP-THERM-016	11	2.35	3.21	1	310	
LEU-COMP-THERM-016	12	2.35	3.21	1	310	
LEU-COMP-THERM-016	13	2.35	3.21	1	310	
LEU-COMP-THERM-016	14	2.35	3.21	1	310	
LEU-COMP-THERM-016	18	2.35	3.21	1	310	
LEU-COMP-THERM-016	28	2.35	3.21	1	310	
LEU-COMP-THERM-016	29	2.35	3.21	1	310	
LEU-COMP-THERM-016	30	2.35	3.21	1	310	
LEU-COMP-THERM-016	31	2.35	3.21	1	310	
LEU-COMP-THERM-016	32	2.35	3.21	1	310	
LEU-COMP-THERM-034	1	4.738	4.22	1	470	
LEU-COMP-THERM-034	2	4.738	4.22	1	470	
LEU-COMP-THERM-034	3	4.738	4.22	1	390	
LEU-COMP-THERM-034	4	4.738	4.22	1	390	
LEU-COMP-THERM-034	5	4.738	4.22	1	390	
LEU-COMP-THERM-034	6	4.738	4.22	1	390	
LEU-COMP-THERM-034	7	4.738	4.22	1	390	

Experiment	#	U-235 (%)	W/F	Model K-eff	Model Uncertainty (pcm)	MCNP K-eff
LEU-COMP-THERM-034	8	4.738	4.22	1	390	
LEU-COMP-THERM-034	10	4.738	4.22	1	480	
LEU-COMP-THERM-034	11	4.738	4.22	1	480	
LEU-COMP-THERM-034	12	4.738	4.22	1	480	
LEU-COMP-THERM-034	13	4.738	4.22	1	480	
LEU-COMP-THERM-034	14	4.738	4.22	1	430	
LEU-COMP-THERM-034	15	4.738	4.22	1	430	
LEU-COMP-THERM-039	1	4.738	2.42	1	140	
LEU-COMP-THERM-039	2	4.738	2.50	1	140	
LEU-COMP-THERM-039	3	4.738	2.73	1	140	
LEU-COMP-THERM-039	4	4.738	2.64	1	140	
LEU-COMP-THERM-039	5	4.738	3.46	1	140	
LEU-COMP-THERM-039	6	4.738	3.32	1	140	
LEU-COMP-THERM-039	7	4.738	2.42	1	140	
LEU-COMP-THERM-039	8	4.738	2.50	1	140	
LEU-COMP-THERM-039	9	4.738	2.50	1	140	
LEU-COMP-THERM-039	10	4.738	2.73	1	140	
LEU-COMP-THERM-039	11	4.738	2.42	1	140	
LEU-COMP-THERM-039	12	4.738	2.42	1	140	
LEU-COMP-THERM-039	13	4.738	2.42	1	140	
LEU-COMP-THERM-039	14	4.738	2.42	1	140	
LEU-COMP-THERM-039	15	4.738	2.42	1	140	
LEU-COMP-THERM-039	16	4.738	2.42	1	140	
LEU-COMP-THERM-039	17	4.738	2.42	1	140	
LEU-COMP-THERM-062	1	2.6	2.12	1	160	
LEU-COMP-THERM-062	2	2.6	2.12	1	160	
LEU-COMP-THERM-062	3	2.6	2.12	1	160	
LEU-COMP-THERM-062	4	2.6	2.12	1	160	
LEU-COMP-THERM-062	5	2.6	2.12	1	160	
LEU-COMP-THERM-062	6	2.6	2.12	1	160	
LEU-COMP-THERM-062	7	2.6	2.12	1	160	
LEU-COMP-THERM-062	8	2.6	2.12	1	160	
LEU-COMP-THERM-062	9	2.6	2.12	1	160	
LEU-COMP-THERM-062	10	2.6	2.12	1	160	
LEU-COMP-THERM-062	11	2.6	2.12	1	160	
LEU-COMP-THERM-062	12	2.6	2.12	1	160	
LEU-COMP-THERM-062	13	2.6	2.12	1	160	
LEU-COMP-THERM-062	14	2.6	2.12	1	160	
LEU-COMP-THERM-062	15	2.6	2.12	1	160	
LEU-COMP-THERM-065	1	2.6	2.12	1	140	
LEU-COMP-THERM-065	2	2.6	2.12	0.9999	140	
LEU-COMP-THERM-065	3	2.6	2.12	0.9996	150	
LEU-COMP-THERM-065	4	2.6	2.12	0.9997	150	
LEU-COMP-THERM-065	5	2.6	2.12	1	140	
LEU-COMP-THERM-065	6	2.6	2.12	0.9998	140	
LEU-COMP-THERM-065	7	2.6	2.12	0.9991	140	
LEU-COMP-THERM-065	8	2.6	2.12	1	160	
LEU-COMP-THERM-065	9	2.6	2.12	1.0001	150	
LEU-COMP-THERM-065	10	2.6	2.12	1.0002	160	

Experiment	#	U-235 (%)	W/F	Model K-eff	Model Uncertainty (pcm)	MCNP K-eff
LEU-COMP-THERM-065	11	2.6	2.12	1.0005	160	
LEU-COMP-THERM-065	12	2.6	2.12	1	170	
LEU-COMP-THERM-065	13	2.6	2.12	1.0001	160	
LEU-COMP-THERM-065	14	2.6	2.12	1.0003	160	
LEU-COMP-THERM-065	15	2.6	2.12	0.9994	160	
LEU-COMP-THERM-065	16	2.6	2.12	0.9998	170	
LEU-COMP-THERM-065	17	2.6	2.12	1.0003	160	
Average						]]

For the benchmark experiments taken from LE-U-COMP-THERM-006, the Water-to-Fuel (W/F) ratios reported in the LANCR02 Qualification LTR are identical to those reported in the International Handbook September 2008 edition. For all other benchmark experiments, the W/F ratios were calculated using the following equation(s):

$$W/F = \frac{A_w}{A_F} = \frac{A_{unitcell} - A_{fuel}}{A_{fuel}} = \frac{A_{unitcell}}{A_{fuel}} - 1$$

$$A_{unitcell} = (LatticePitch)^2$$

$$A_{fuel} = \pi R_{fuel}^2$$

4.5. Discussion

This section presented results of several critical experiments modeled with MCNP. The eigenvalue results obtained with the ENDF/B-VII.0 library are close to unity and show a small standard deviation between experiments, indicating that the library is robust for a range of heavy metal to moderator ratios.

Compared to previous criticality analysis performed with the ENDF/B-V and ENDF/B-VII.Beta libraries, the ENDF/B-VII.0 library gives slightly higher eigenvalues (approximately 100 to 300 pcm), but has a smaller standard deviation among experiments.

The results in this section show that the ENDF/B-VII.0 cross section library is appropriate for BWR analysis.

5. LANCR02 Qualification Test Cases

This section contains direct comparisons between LANCR02 and MCNP for over 1000 single-assembly BWR lattice configurations. The results are arranged into 16 test suites. The first test suite is the most comprehensive and contains results that would typically be encountered in BWR analysis. Test Suite 1 is referred to as the baseline results. The remaining test suites test specific perturbations to look for trends in different parameters (enrichment, gadolinium concentration, borated lattices, etc.).

The LANCR02 and MCNP cases both used a uniform in-channel void distribution. LANCR02 has the ability to calculate an in-channel void distribution, but this option was turned off in these comparisons.

When comparing eigenvalues between LANCR02 and MCNP, the agreement is excellent. In over 1000 cases, [[ ]]. For the baseline results, the average eigenvalue difference is [[ ]], which shows that LANCR02 does not have a meaningful eigenvalue bias when compared to MCNP.

The eigenvalue differences are examined by subgroup (e.g., void, exposure, lattice type, etc.) to look for any meaningful trends in subgroups. Because the results are statistical in nature, the average eigenvalue difference between any two subgroups will almost always be different. [[

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In addition to eigenvalues, the LANCR02 pin-by-pin fission rates were compared to MCNP for applicable test suites. These comparisons included both RMS fission rate comparisons and peak fission rate comparisons.

5.1. Test Suite 1 – Baseline

5.1.1. Purpose

Test the performance of LANCR02 versus MCNP for the current primary product lines.

5.1.2. Description

A single bundle design from each product line in Table 5.1-1 is analyzed, including all unique lattices in each bundle (e.g., NAT, PSZ, DOM, PLE, VAN, etc.). All bundles are analyzed for a C-lattice plant containing a D100 control blade. Fourteen (14) cases at beginning of life (BOL) are analyzed per lattice. The fourteen cases are: hot (560^{o}C) uncontrolled at 0, 40, 80, and 100% voids; hot (560^{o}C) controlled at 0, 40, 80, and 100% voids; hot uncontrolled for a fuel temperature of 1500^{o}C at 0, 40, 80, and 100% void; cold xenon-free uncontrolled at 20^{o}C; and cold xenon-free controlled at 20^{o}C. Comparisons of k-infinity and pin-by-pin fission density are made.

Table 5.1-1 Baseline Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE9	8x8	NAT; PSZ; DOM; MID; SDZ; N-T
GE11	9x9	NAT; PSZ; DOM; VAN; VAN; N-T
GE14	10x10	NAT; PSZ; DOM; PLE; VAN; N-V; N-T

5.1.3. Number of Cases

Number of lattices (19) x Number of cases (14) = 266.

5.1.4. Results

Table 5.1-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.1-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE9	8x8	3547	3475	NAT
			3480	PSZ
			3481	DOM
			3482	MID
			3483	SDZ
			3484	N-E
GE11	9x9	3619	3746	NAT
			3752	PSZ
			3753	DOM
			3754	VAN
			3755	VAN

			3756	N-T
GE14	10x10	2882	7097	NAT
			7098	PSZ
			7099	DOM
			7100	PLE
			7101	VAN
			7102	N-V
			7103	N-T

The GE9 product line contains a large central water rod and a channel box of uniform thickness. The active fuel region spans 150 inches, but pins containing gadolinium pellets span only 144 inches with an additional 6-inch plenum region at the top of the bundle. Any fuel rod may contain axially zoned enrichments and/or axially zoned gadolinium loadings.

The GE11 product line contains 8 part length rods in the interior of the bundle (no edge part length rods). Each part length rod contains a 6-inch plenum in the bottom node and a 6-inch plenum at the top of the rod in the middle of the bundle. As is GNF-A common practice, the plenum at the bottom of the bundle is modeled explicitly, but the plenum zone in the middle of the bundle has been ignored. Fuel rods are uniformly enriched, but may contain axially zoned gadolinium loadings.

The GE14 product line contains 14 part length rods in the interior of the bundle. The top of each part length rod contains a 12-inch plenum region in the middle of the bundle, which is explicitly modeled. Fuel rods are uniformly enriched, but may contain axially zoned gadolinium loadings. The top 12 inches of the bundle contains only natural fuel pellets. The active fuel height of the bundle is 150 inches, but fuel rods containing gadolinium are 144 inches in height with an additional 6 inches of plenum at the top of the rod. The additional plenum is modeled explicitly in the N-T zone.

Figure 5.1-1 through Figure 5.1-6 contain results from all the analyses. There is a separate graph for each of the following parameters:

- eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (RMS difference between LANCR02 and MCNP pin-wise fission rates);
- relative pin peaking factor (% difference between LANCR02 and MCNP);
- eigenvalue differences grouped by void (pcm difference between LANCR02 and MCNP);
- CDOP (% difference between LANCR02 and MCNP);
- rod worth (% difference between LANCR02 and MCNP); and
- cold eigenvalue (pcm difference between LANCR02 and MCNP).

The different product lines are grouped together and separated by lines in each of the graphs. Results to the left of the first vertical line are from the 8x8 product line; results in between the two vertical lines are from the 9x9 product line; and results to the right of the second vertical line are from the 10x10 product line.

Figure 5.1-2 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.1-3 contains a list of conditions for every point in Figure 5.1-1 through Figure 5.1-3. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. There are no controlled results for the 1500ºC fuel temperature cases.

Table 5.1-3 Case Conditions for Figure 5.1-1 through Figure 5.1-3.

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GE9	3475	NAT	[[
2	560	0					
3	1500	40					
4	560	40					
5	1500	80					
6	560	80					
7	1500	100					
8	560	100					
9	1500	0	UNC	GE9	3480	PSZ	
10	560	0					
11	1500	40					
12	560	40					
13	1500	80					
14	560	80					
15	1500	100					
16	560	100					
17	1500	0	UNC	GE9	3481	DOM	
18	560	0					
19	1500	40					
20	560	40					
21	1500	80					
22	560	80					
23	1500	100					
24	560	100					
25	1500	0	UNC	GE9	3482	MID	
26	560	0					
27	1500	40					
28	560	40					
29	1500	80					
30	560	80					
31	1500	100					
32	560	100					
33	1500	0	UNC	GE9	3483	SDZ	
34	560	0					
35	1500	40					
36	560	40					
37	1500	80					
38	560	80					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
39	1500	100					
40	560	100					
41	1500	0	UNC	GE9	3484	N-E	
42	560	0					
43	1500	40					
44	560	40					
45	1500	80					
46	560	80					
47	1500	100					
48	560	100					
49	1500	0	UNC	GE11	3746	NAT	
50	560	0					
51	1500	40					
52	560	40					
53	1500	80					
54	560	80					
55	1500	100					
56	560	100					
57	1500	0	UNC	GE11	3752	PSZ	
58	560	0					
59	1500	40					
60	560	40					
61	1500	80					
62	560	80					
63	1500	100					
64	560	100					
65	1500	0	UNC	GE11	3753	DOM	
66	560	0					
67	1500	40					
68	560	40					
69	1500	80					
70	560	80					
71	1500	100					
72	560	100					
73	1500	0	UNC	GE11	3754	VAN	
74	560	0					
75	1500	40					
76	560	40					
77	1500	80					
78	560	80					
79	1500	100					
80	560	100					
81	1500	0	UNC	GE11	3755	VAN	
82	560	0					
83	1500	40					
84	560	40					
85	1500	80					
86	560	80					
87	1500	100					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
88	560	100					
89	1500	0	UNC	GE11	3756	N-T	
90	560	0					
91	1500	40					
92	560	40					
93	1500	80					
94	560	80					
95	1500	100					
96	560	100					
97	1500	0	UNC	GE14	7097	NAT	
98	560	0					
99	1500	40					
100	560	40					
101	1500	80					
102	560	80					
103	1500	100					
104	560	100					
105	1500	0	UNC	GE14	7098	PSZ	
106	560	0					
107	1500	40					
108	560	40					
109	1500	80					
110	560	80					
111	1500	100					
112	560	100					
113	1500	0	UNC	GE14	7099	DOM	
114	560	0					
115	1500	40					
116	560	40					
117	1500	80					
118	560	80					
119	1500	100					
120	560	100					
121	1500	0	UNC	GE14	7100	PLE	
122	560	0					
123	1500	40					
124	560	40					
125	1500	80					
126	560	80					
127	1500	100					
128	560	100					
129	1500	0	UNC	GE14	7101	VAN	
130	560	0					
131	1500	40					
132	560	40					
133	1500	80					
134	560	80					
135	1500	100					
136	560	100					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
137	1500	0	UNC	GE14	7102	N-V	
138	560	0					
139	1500	40					
140	560	40					
141	1500	80					
142	560	80					
143	1500	100					
144	560	100					
145	1500	0	UNC	GE14	7103	N-T	
146	560	0					
147	1500	40					
148	560	40					
149	1500	80					
150	560	80					
151	1500	100					
152	560	100					
2	560	0	CON	GE9	3475	NAT	
4	560	40					
6	560	80					
8	560	100					
10	560	0	CON	GE9	3480	PSZ	
12	560	40					
14	560	80					
16	560	100					
18	560	0	CON	GE9	3481	DOM	
20	560	40					
22	560	80					
24	560	100					
26	560	0	CON	GE9	3482	MID	
28	560	40					
30	560	80					
32	560	100					
34	560	0	CON	GE9	3483	SDZ	
36	560	40					
38	560	80					
40	560	100					
42	560	0	CON	GE9	3484	N-E	
44	560	40					
46	560	80					
48	560	100					
50	560	0	CON	GE11	3746	NAT	
52	560	40					
54	560	80					
56	560	100					
58	560	0	CON	GE11	3752	PSZ	
60	560	40					
62	560	80					
64	560	100					
66	560	0	CON	GE11	3753	DOM	

Case No.	**Fuel Temp (ºC)**	**Void (%)**	**UNC or CON**	**Bundle Type**	**Lattice No.**	**Lattice Type**	**Difference in Eigenvalues (pcm)**
68	560	40					
70	560	80					
72	560	100					
74	560	0	CON	GE11	3754	VAN	
76	560	40					
78	560	80					
80	560	100					
82	560	0	CON	GE11	3755	VAN	
84	560	40					
86	560	80					
88	560	100					
90	560	0	CON	GE11	3756	N-T	
92	560	40					
94	560	80					
96	560	100					
98	560	0	CON	GE14	7097	NAT	
100	560	40					
102	560	80					
104	560	100					
106	560	0	CON	GE14	7098	PSZ	
108	560	40					
110	560	80					
112	560	100					
114	560	0	CON	GE14	7099	DOM	
116	560	40					
118	560	80					
120	560	100					
122	560	0	CON	GE14	7100	PLE	
124	560	40					
126	560	80					
128	560	100					
130	560	0	CON	GE14	7101	VAN	
132	560	40					
134	560	80					
136	560	100					
138	560	0	CON	GE14	7102	N-V	
140	560	40					
142	560	80					
144	560	100					
146	560	0	CON	GE14	7103	N-T	
148	560	40					
150	560	80					
152	560	100					]]

[[

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Figure 5.1-1 Differences in Hot Eigenvalues

[[

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Figure 5.1-2 Fission Rate RMS

[[

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Figure 5.1-3 Difference in Pin Peaking Factor

Figure 5.1-4 is a plot of the same data as in Figure 5.1-1, except that the data is arranged by void. The purpose of this figure is to be able to visually determine if there is a trend by void. Table 5.1-4 contains a list of conditions for every point in Figure 5.1-4.

Table 5.1-4 Void Case Conditions for Figure 5.1-4.

Case No.	Fuel Temp (°C)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GE9	3475	NAT	[[
		40					
		80					
		100					
2	560	0	UNC	GE9	3475	NAT	
		40					
		80					
		100					
3	1500	0	UNC	GE9	3480	PSZ	
		40					
		80					
		100					
4	560	0	UNC	GE9	3480	PSZ	
		40					
		80					
		100					
5	1500	0	UNC	GE9	3481	DOM	
		40					
		80					
		100					
6	560	0	UNC	GE9	3481	DOM	
		40					
		80					
		100					
7	1500	0	UNC	GE9	3482	MID	
		40					
		80					
		100					
8	560	0	UNC	GE9	3482	MID	
		40					
		80					
		100					
9	1500	0	UNC	GE9	3483	SDZ	
		40					
		80					
		100					
10	560	0	UNC	GE9	3483	SDZ	
		40					
		80					
		100					
11	1500	0	UNC	GE9	3484	N-E	
		40					
		80					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
		100					
12	560	0	UNC	GE9	3484	N-E	
		40					
		80					
		100					
13	1500	0	UNC	GE11	3746	NAT	
		40					
		80					
		100					
14	560	0	UNC	GE11	3746	NAT	
		40					
		80					
		100					
15	1500	0	UNC	GE11	3752	PSZ	
		40					
		80					
		100					
16	560	0	UNC	GE11	3752	PSZ	
		40					
		80					
		100					
17	1500	0	UNC	GE11	3753	DOM	
		40					
		80					
		100					
18	560	0	UNC	GE11	3753	DOM	
		40					
		80					
		100					
19	1500	0	UNC	GE11	3754	VAN	
		40					
		80					
		100					
20	560	0	UNC	GE11	3754	VAN	
		40					
		80					
		100					
21	1500	0	UNC	GE11	3755	VAN	
		40					
		80					
		100					
22	560	0	UNC	GE11	3755	VAN	
		40					
		80					
		100					
23	1500	0	UNC	GE11	3756	N-T	
		40					
		80					
		100					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
24	560	0	UNC	GE11	3756	N-T	
		40					
		80					
		100					
25	1500	0	UNC	GE14	7097	NAT	
		40					
		80					
		100					
26	560	0	UNC	GE14	7097	NAT	
		40					
		80					
		100					
27	1500	0	UNC	GE14	7098	PSZ	
		40					
		80					
		100					
28	560	0	UNC	GE14	7098	PSZ	
		40					
		80					
		100					
29	1500	0	UNC	GE14	7099	DOM	
		40					
		80					
		100					
30	560	0	UNC	GE14	7099	DOM	
		40					
		80					
		100					
31	1500	0	UNC	GE14	7100	PLE	
		40					
		80					
		100					
32	560	0	UNC	GE14	7100	PLE	
		40					
		80					
		100					
33	1500	0	UNC	GE14	7101	VAN	
		40					
		80					
		100					
34	560	0	UNC	GE14	7101	VAN	
		40					
		80					
		100					
35	1500	0	UNC	GE14	7102	N-V	
		40					
		80					
		100					
36	560	0	UNC	GE14	7102	N-V	

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
		40					
		80					
		100					
37	1500	0	UNC	GE14	7103	N-T	
		40					
		80					
		100					
38	560	0	UNC	GE14	7103	N-T	
		40					
		80					
		100					
39	560	0	CON	GE9	3475	NAT	
		40					
		80					
		100					
40	560	0	CON	GE9	3480	PSZ	
		40					
		80					
		100					
41	560	0	CON	GE9	3481	DOM	
		40					
		80					
		100					
42	560	0	CON	GE9	3482	MID	
		40					
		80					
		100					
43	560	0	CON	GE9	3483	SDZ	
		40					
		80					
		100					
44	560	0	CON	GE9	3484	N-E	
		40					
		80					
		100					
45	560	0	CON	GE11	3746	NAT	
		40					
		80					
		100					
46	560	0	CON	GE11	3752	PSZ	
		40					
		80					
		100					
47	560	0	CON	GE11	3753	DOM	
		40					
		80					
		100					
48	560	0	CON	GE11	3754	VAN	
		40					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
		80					
		100					
49	560	0	CON	GE11	3755	VAN	
		40					
		80					
		100					
50	560	0	CON	GE11	3756	N-T	
		40					
		80					
		100					
51	560	0	CON	GE14	7097	NAT	
		40					
		80					
		100					
52	560	0	CON	GE14	7098	PSZ	
		40					
		80					
		100					
53	560	0	CON	GE14	7099	DOM	
		40					
		80					
		100					
54	560	0	CON	GE14	7100	PLE	
		40					
		80					
		100					
55	560	0	CON	GE14	7101	VAN	
		40					
		80					
		100					
56	560	0	CON	GE14	7102	N-V	
		40					
		80					
		100					
57	560	0	CON	GE14	7103	N-T	
		40					
		80					
		100					]]

[[

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Figure 5.1-4 Eigenvalue Differences Grouped by Void

Figure 5.1-5 is a plot of CDOP. Table 5.1-5 contains a list of conditions for every point in this figure. All cases are uncontrolled and represent a change in fuel temperature from 560ºC to 1500ºC.

Table 5.1-5 Doppler Case Conditions for Figure 5.1-5

Case No.	Void (%)	Bundle Type	Lattice No.	Lattice Type	LANCR02 Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs (%)
1	0	GE9	3475	NAT	[[	
2	40					
3	80					
4	100					
5	0	GE9	3480	PSZ		
6	40					
7	80					
8	100					
9	0	GE9	3481	DOM		
10	40					
11	80					
12	100					
13	0	GE9	3482	MID		
14	40					
15	80					
16	100					
17	0	GE9	3483	SDZ		
18	40					
19	80					
20	100					
21	0	GE9	3484	N-E		
22	40					
23	80					
24	100					
25	0	GE11	3746	NAT		
26	40					
27	80					
28	100					
29	0	GE11	3752	PSZ		
30	40					
31	80					
32	100					
33	0	GE11	3753	DOM		
34	40					
35	80					
36	100					
37	0	GE11	3754	VAN		
38	40					
39	80					
40	100					
41	0	GE11	3755	VAN		
42	40					
43	80					

Case No.	**Void (%)**	**Bundle Type**	**Lattice No.**	**Lattice Type**	**LANCR02 Doppler Coeffs (pcm/√K)**	**Difference in Doppler Coeffs (%)**
44	100					
45	0	GE11	3756	N-T		
46	40					
47	80					
48	100					
49	0	GE14	7097	NAT		
50	40					
51	80					
52	100					
53	0	GE14	7098	PSZ		
54	40					
55	80					
56	100					
57	0	GE14	7099	DOM		
58	40					
59	80					
60	100					
61	0	GE14	7100	PLE		
62	40					
63	80					
64	100					
65	0	GE14	7101	VAN		
66	40					
67	80					
68	100					
69	0	GE14	7102	N-V		
70	40					
71	80					
72	100					
73	0	GE14	7103	N-T		
74	40					
75	80					
76	100					]]

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Figure 5.1-5 Difference in CDOP

Figure 5.1-6 is a plot of the difference in rod worth calculated by LANCR02 and MCNP.

Table 5.1-6 contains a list of conditions for every point in this figure. All cold cases are represented at a fuel and coolant temperature of 20ºC, and all hot cases are represented at a fuel temperature of 560ºC.

Table 5.1-6 Rod Worth Case Conditions for Figure 5.1-6

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Bundle Type	Lattice No.	Lattice Type	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
1	560	0	Hot	GE9	3475	NAT	[[	
2	560	40						
3	560	80						
4	560	100						
5	560	0	Hot	GE9	3480	PSZ		
6	560	40						
7	560	80						
8	560	100						
9	560	0	Hot	GE9	3481	DOM		

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Bundle Type	Lattice No.	Lattice Type	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
10	560	40						
11	560	80						
12	560	100						
13	560	0	Hot	GE9	3482	MID		
14	560	40						
15	560	80						
16	560	100						
17	560	0	Hot	GE9	3483	SDZ		
18	560	40						
19	560	80						
20	560	100						
21	560	0	Hot	GE9	3484	N-E		
22	560	40						
23	560	80						
24	560	100						
25	560	0	Hot	GE11	3746	NAT		
26	560	40						
27	560	80						
28	560	100						
29	560	0	Hot	GE11	3752	PSZ		
30	560	40						
31	560	80						
32	560	100						
33	560	0	Hot	GE11	3753	DOM		
34	560	40						
35	560	80						
36	560	100						
37	560	0	Hot	GE11	3754	VAN		
38	560	40						
39	560	80						
40	560	100						
41	560	0	Hot	GE11	3755	VAN		
42	560	40						
43	560	80						
44	560	100						
45	560	0	Hot	GE11	3756	N-T		
46	560	40						
47	560	80						
48	560	100						
49	560	0	Hot	GE14	7097	NAT		
50	560	40						
51	560	80						
52	560	100						
53	560	0	Hot	GE14	7098	PSZ		
54	560	40						
55	560	80						
56	560	100						
57	560	0	Hot	GE14	7099	DOM		

Case No.	**Fuel Temp (ºC)**	**Void (%)**	**Hot or Cold**	**Bundle Type**	**Lattice No.**	**Lattice Type**	**LANCR02 Rod Worths (pcm)**	**Difference in Rod Worths (%)**
58	560	40						
59	560	80						
60	560	100						
61	560	0	Hot	GE14	7100	PLE		
62	560	40						
63	560	80						
64	560	100						
65	560	0	Hot	GE14	7101	VAN		
66	560	40						
67	560	80						
68	560	100						
69	560	0	Hot	GE14	7102	N-V		
70	560	40						
71	560	80						
72	560	100						
73	560	0	Hot	GE14	7103	N-T		
74	560	40						
75	560	80						
76	560	100						
1	20	0	Cold	GE9	3475	NAT		
5	20	0			3480	PSZ		
9	20	0			3481	DOM		
13	20	0			3482	MID		
17	20	0			3483	SDZ		
21	20	0			3484	N-E		
25	20	0	Cold	GE11	3746	NAT		
29	20	0			3752	PSZ		
33	20	0			3753	DOM		
37	20	0			3754	VAN		
41	20	0			3755	VAN		
45	20	0			3756	N-T		
49	20	0	Cold	GE14	7097	NAT		
53	20	0			7098	PSZ		
57	20	0			7099	DOM		
61	20	0			7100	PLE		
65	20	0			7101	VAN		
69	20	0			7102	N-V		
73	20	0			7103	N-T		]]

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Figure 5.1-6 Difference in Rod Worth

Figure 5.1-7 shows the difference in eigenvalues calculated by LANCR02 and MCNP for all of the cold cases.

Figure 5.1-8 shows the RMS differences in pin powers between LANCR02 and MCNP for all of the cold cases. Figure 5.1-9 shows the difference in the pin peaking factor between LANCR02 and MCNP for all of the cold cases. Table 5.1-7 contains a list of conditions for every point in these figures. All cases are represented at a fuel and coolant temperature of 20ºC and there is a single controlled (CON) and uncontrolled (UNC) pair of points for each lattice.

Table 5.1-7 Cold Case Conditions for Figure 5.1-7 through Figure 5.1-9

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	20	0	UNC	GE9	3475	NAT	[[
2					3480	PSZ	
3					3481	DOM	
4					3482	MID	
5					3483	SDZ	
6					3484	N-E	
7	20	0	UNC	GE11	3746	NAT	
8					3752	PSZ	
9					3753	DOM	
10					3754	VAN	
11					3755	VAN	
12					3756	N-T	
13	20	0	UNC	GE14	7097	NAT	
14					7098	PSZ	
15					7099	DOM	
16					7100	PLE	
17					7101	VAN	
18					7102	N-V	
19					7103	N-T	
1	20	0	CON	GE9	3475	NAT	
2					3480	PSZ	
3					3481	DOM	
4					3482	MID	
5					3483	SDZ	
6					3484	N-E	
7	20	0	CON	GE11	3746	NAT	
8					3752	PSZ	
9					3753	DOM	
10					3754	VAN	
11					3755	VAN	
12					3756	N-T	
13	20	0	CON	GE14	7097	NAT	
14					7098	PSZ	
15					7099	DOM	
16					7100	PLE	
17					7101	VAN	
18					7102	N-V	
19					7103	N-T	]]

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Figure 5.1-7 Difference in Cold Eigenvalues

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Figure 5.1-8 Cold Fission Rate RMS

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Figure 5.1-9 Difference in Cold Pin Peaking Factor

5.1.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.1-8. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC), cold uncontrolled (CU), and cold controlled (CC)) and also by product line (i.e., 8x8, 9x9, and 10x10).

The overall average difference in the LANCR02 and MCNP eigenvalues, [[

]]

Table 5.1-8 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.1-9. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent, with the largest discrepancy between pin-wise fission rates being less than [[ ]]. The lattices with the best agreement in pin-wise fission rates are always the natural segments.

Table 5.1-9 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.1-10. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.1-10 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.2. Test Suite 2 – Variation in Lattice Type

5.2.1. Purpose

Test the performance of LANCR02 versus MCNP for variations from C-lattice plants to D-lattice and N-lattice plants.

5.2.2. Description

A single bundle design from each product line in Table 5.2-1 is analyzed. The analysis includes only DOM and VAN zones (where applicable). All bundles are analyzed for a C-lattice, D-lattice, and N-lattice plant containing a D100 control blade. The 9x9 and 10x10 bundles are part of Test Suite 1 and the C-lattice results for these bundles are taken directly from Test Suite 1. Fourteen (14) cases at beginning of life (BOL) are analyzed per lattice. The fourteen cases are: hot (560^{o}C) uncontrolled at 0, 40, 80, and 100% voids; hot (560^{o}C) controlled at 0, 40, 80, and 100% voids; hot uncontrolled for a fuel temperature of 1500^{o}C at 0, 40, 80, and 100% void; cold xenon-free uncontrolled at 20^{o}C; and cold xenon-free controlled at 20^{o}C. Comparisons of k-infinity and the RMS of the pin-by-pin fission density are made.

An S-lattice was not run as part of this test suite because it does not have any unique characteristics that are not already tested with the C and N-lattice cases. An S-lattice has symmetric gaps like a C and N-lattice, and has the same channel thickness as an N-lattice.

Table 5.2-1 Lattice Type Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE9	8x8	DOM
GE11	9x9	DOM; VAN
GE14	10x10	DOM; VAN

5.2.3. Number of Cases

Number of lattices (5) x Number of plant types (3) x Number of cases (14) = 210.

5.2.4. Results

Table 5.2-2 contains a list of all lattices analyzed for this test suite. Note that the 8x8 lattice analyzed is different from the 8x8 lattices analyzed in Test Suite 1. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.2-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE9	8x8	3745	4148	DOM
GE11	9x9	3619	3753	DOM
			3755	VAN
GE14	10x10	2882	7099	DOM
			7101	VAN

Figure 5.2-1 through Figure 5.2-7 contain results from all analyses. There is a separate graph for each of the following parameters:

- eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (% RMS between LANCR02 and MCNP pin-wise fission rates);
- relative pin peaking factor (% difference between LANCR02 and MCNP);
- eigenvalue difference grouped by void (pcm difference between LANCR02 and MCNP);
- CDOP (% difference between LANCR02 and MCNP); and
- rod worth (% difference between LANCR02 and MCNP).

In each graph, data is separated into lattice type – results to the left of the first vertical line are from a C-lattice; results in between the two vertical lines are from the D-lattice; and results to the right of the second vertical line are from the N-lattice.

Table 5.2-3 contains a list of conditions for every point in Figure 5.2-1 through Figure 5.2-3. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. There are no controlled results for the 1500ºC fuel temperature cases.

Figure 5.2-2 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.2-3 Case Conditions Figure 5.2-1 through Figure 5.2-3

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GE9	4148C	DOM	[[
2	560	0					
3	1500	40					
4	560	40					
5	1500	80					
6	560	80					
7	1500	100					
8	560	100					
9	1500	0	UNC	GE11	3753C	DOM	
10	560	0					
11	1500	40					
12	560	40					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
13	1500	80					
14	560	80					
15	1500	100					
16	560	100					
17	1500	0	UNC	GE11	3755C	VAN	
18	560	0					
19	1500	40					
20	560	40					
21	1500	80					
22	560	80					
23	1500	100					
24	560	100					
25	1500	0	UNC	GE14	7099C	DOM	
26	560	0					
27	1500	40					
28	560	40					
29	1500	80					
30	560	80					
31	1500	100					
32	560	100					
33	1500	0	UNC	GE14	7101C	VAN	
34	560	0					
35	1500	40					
36	560	40					
37	1500	80					
38	560	80					
39	1500	100					
40	560	100					
41	1500	0	UNC	GE9	4148D	DOM	
42	560	0					
43	1500	40					
44	560	40					
45	1500	80					
46	560	80					
47	1500	100					
48	560	100					
49	1500	0	UNC	GE11	3753D	DOM	
50	560	0					
51	1500	40					
52	560	40					
53	1500	80					
54	560	80					
55	1500	100					
56	560	100					
57	1500	0	UNC	GE11	3755D	VAN	
58	560	0					
59	1500	40					
60	560	40					
61	1500	80					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
62	560	80					
63	1500	100					
64	560	100					
65	1500	0	UNC	GE14	7099D	DOM	
66	560	0					
67	1500	40					
68	560	40					
69	1500	80					
70	560	80					
71	1500	100					
72	560	100					
73	1500	0	UNC	GE14	7101D	VAN	
74	560	0					
75	1500	40					
76	560	40					
77	1500	80					
78	560	80					
79	1500	100					
80	560	100					
81	1500	0	UNC	GE9	4148N	DOM	
82	560	0					
83	1500	40					
84	560	40					
85	1500	80					
86	560	80					
87	1500	100					
88	560	100					
89	1500	0	UNC	GE11	3753N	DOM	
90	560	0					
91	1500	40					
92	560	40					
93	1500	80					
94	560	80					
95	1500	100					
96	560	100					
97	1500	0	UNC	GE11	3755N	VAN	
98	560	0					
99	1500	40					
100	560	40					
101	1500	80					
102	560	80					
103	1500	100					
104	560	100					
105	1500	0	UNC	GE14	7099N	DOM	
106	560	0					
107	1500	40					
108	560	40					
109	1500	80					
110	560	80					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
111	1500	100					
112	560	100					
113	1500	0	UNC	GE14	7101N	VAN	
114	560	0					
115	1500	40					
116	560	40					
117	1500	80					
118	560	80					
119	1500	100					
120	560	100					
2	560	0	CON	GE9	4148C	DOM	
4	560	40					
6	560	80					
8	560	100					
10	560	0	CON	GE11	3753C	DOM	
12	560	40					
14	560	80					
16	560	100					
18	560	0	CON	GE11	3755C	VAN	
20	560	40					
22	560	80					
24	560	100					
26	560	0	CON	GE14	7099C	DOM	
28	560	40					
30	560	80					
32	560	100					
34	560	0	CON	GE14	7101C	VAN	
36	560	40					
38	560	80					
40	560	100					
42	560	0	CON	GE9	4148D	DOM	
44	560	40					
46	560	80					
48	560	100					
50	560	0	CON	GE11	3753D	DOM	
52	560	40					
54	560	80					
56	560	100					
58	560	0	CON	GE11	3755D	VAN	
60	560	40					
62	560	80					
64	560	100					
66	560	0	CON	GE14	7099D	DOM	
68	560	40					
70	560	80					
72	560	100					
74	560	0	CON	GE14	7101D	VAN	
76	560	40					
78	560	80					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
80	560	100					
82	560	0	CON	GE9	4148N	DOM	
84	560	40					
86	560	80					
88	560	100					
90	560	0	CON	GE11	3753N	DOM	
92	560	40					
94	560	80					
96	560	100					
98	560	0	CON	GE11	3755N	VAN	
100	560	40					
102	560	80					
104	560	100					
106	560	0	CON	GE14	7099N	DOM	
108	560	40					
110	560	80					
112	560	100					
114	560	0	CON	GE14	7101N	VAN	
116	560	40					
118	560	80					
120	560	100					]]

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Figure 5.2-1 Difference in Hot Eigenvalues

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Figure 5.2-2 Fission Rate RMS

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Figure 5.2-3 Difference in Pin Peaking Factor

Figure 5.2-4 is a figure of the same conditions as Figure 5.2-1, except that the data is arranged by void. Table 5.2-4 contains a list of conditions for every point in this figure.

Table 5.2-4 Void Case Conditions Figure 5.2-4

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GE9	4148C	DOM	[[
		40					
		80					
		100					
2	560	0					
		40					
		80					
		100					
3	1500	0	UNC	GE11	3753C	DOM	
		40					
		80					
		100					
4	560	0					
		40					

Case No.	**Fuel Temp (ºC)**	**Void (%)**	**UNC or CON**	**Bundle Type**	**Lattice No.**	**Lattice Type**	**Difference in Eigenvalues (pcm)**
		80					
		100					
5	1500	0	UNC	GE11	3755C	VAN	
		40					
		80					
		100					
6	560	0					
		40					
		80					
		100					
7	1500	0	UNC	GE14	7099C	DOM	
		40					
		80					
		100					
8	560	0					
		40					
		80					
		100					
9	1500	0	UNC	GE14	7101C	VAN	
		40					
		80					
		100					
10	560	0					
		40					
		80					
		100					
11	1500	0	UNC	GE9	4148D	DOM	
		40					
		80					
		100					
12	560	0					
		40					
		80					
		100					
13	1500	0	UNC	GE11	3753D	DOM	
		40					
		80					
		100					
14	560	0					
		40					
		80					
		100					
15	1500	0	UNC	GE11	3755D	VAN	
		40					
		80					
		100					
16	560	0					
		40					
		80					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
		100					
17	1500	0	UNC	GE14	7099D	DOM	
		40					
		80					
		100					
18	560	0					
		40					
		80					
		100					
19	1500	0	UNC	GE14	7101D	VAN	
		40					
		80					
		100					
20	560	0					
		40					
		80					
		100					
21	1500	0	UNC	GE9	4148N	DOM	
		40					
		80					
		100					
22	560	0					
		40					
		80					
		100					
23	1500	0	UNC	GE11	3753N	DOM	
		40					
		80					
		100					
24	560	0					
		40					
		80					
		100					
25	1500	0	UNC	GE11	3755N	VAN	
		40					
		80					
		100					
26	560	0					
		40					
		80					
		100					
27	1500	0	UNC	GE14	7099N	DOM	
		40					
		80					
		100					
28	560	0					
		40					
		80					
		100					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
29	1500	0	UNC	GE14	7101N	VAN	
		40					
		80					
		100					
30	560	0					
		40					
		80					
		100					
31	560	0	CON	GE9	4148C	DOM	
		40					
		80					
		100					
32	560	0	CON	GE11	3753C	DOM	
		40					
		80					
		100					
33	560	0	CON	GE11	3755C	VAN	
		40					
		80					
		100					
34	560	0	CON	GE14	7099C	DOM	
		40					
		80					
		100					
35	560	0	CON	GE14	7101C	VAN	
		40					
		80					
		100					
36	560	0	CON	GE9	4148D	DOM	
		40					
		80					
		100					
37	560	0	CON	GE11	3753D	DOM	
		40					
		80					
		100					
38	560	0	CON	GE11	3755D	VAN	
		40					
		80					
		100					
39	560	0	CON	GE14	7099D	DOM	
		40					
		80					
		100					
40	560	0	CON	GE14	7101D	VAN	
		40					
		80					
		100					
41	560	0	CON	GE9	4148N	DOM	

Case No.	**Fuel Temp (ºC)**	**Void (%)**	**UNC or CON**	**Bundle Type**	**Lattice No.**	**Lattice Type**	**Difference in Eigenvalues (pcm)**
		40					
		80					
		100					
42	560	0	CON	GE11	3753N	DOM	
		40					
		80					
		100					
43	560	0	CON	GE11	3755N	VAN	
		40					
		80					
		100					
44	560	0	CON	GE14	7099N	DOM	
		40					
		80					
		100					
45	560	0	CON	GE14	7101N	VAN	
		40					
		80					
		100					]]

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Figure 5.2-4 Difference in Eigenvalues for Voided Conditions

Figure 5.2-5 shows the CDOP. Table 5.2-5 contains a list of conditions for every point in this figure. All cases are uncontrolled and represent a change in fuel temperature from 560ºC to 1500ºC.

Table 5.2-5 Doppler Case Conditions for Figure 5.2-5

Case No.	Void (%)	Bundle Type	Lattice No.	Lattice Type	LANCR02 Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs (%)
1	0	GE9	4148C	DOM	[[	
2	40					
3	80					
4	100					
5	0	GE11	3753C	DOM		
6	40					
7	80					
8	100					
9	0	GE11	3755C	VAN		
10	40					
11	80					
12	100					
13	0	GE14	7099C	DOM		
14	40					
15	80					
16	100					
17	0	GE14	7101C	VAN		
18	40					
19	80					
20	100					
21	0	GE9	4148D	DOM		
22	40					
23	80					
24	100					
25	0	GE11	3753D	DOM		
26	40					
27	80					
28	100					
29	0	GE11	3755D	VAN		
30	40					
31	80					
32	100					
33	0	GE14	7099D	DOM		
34	40					
35	80					
36	100					
37	0	GE14	7101D	VAN		
38	40					
39	80					
40	100					
41	0	GE9	4148N	DOM		
42	40					
43	80					
44	100					

Case No.	Void (%)	Bundle Type	Lattice No.	Lattice Type	LANCR02 Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs (%)
45	0	GE11	3753N	DOM		
46	40					
47	80					
48	100					
49	0	GE11	3755N	VAN		
50	40					
51	80					
52	100					
53	0	GE14	7099N	DOM		
54	40					
55	80					
56	100					
57	0	GE14	7101N	VAN		
58	40					
59	80					
60	100					]]

[[

]]

Figure 5.2-5 Difference in CDOP

Figure 5.2-6 is a figure of the difference in rod worth calculated by LANCR02 and MCNP. Table 5.2-6 contains a list of conditions for every point in this figure. All cold cases are represented at a fuel and coolant temperature of 20ºC, and all hot cases are represented at a fuel temperature of 560ºC.

Table 5.2-6 Rod Worth Case Conditions for Figure 5.2-6

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Bundle Type	Lattice No.	Lattice Type	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
1	560	0	Hot	GE9	4148C	DOM	[[	
2	560	40						
3	560	80						
4	560	100						
5	560	0	Hot	GE11	3753C	DOM		
6	560	40						
7	560	80						
8	560	100						
9	560	0	Hot	GE11	3755C	VAN		
10	560	40						
11	560	80						
12	560	100						
13	560	0	Hot	GE14	7099C	DOM		
14	560	40						
15	560	80						
16	560	100						
17	560	0	Hot	GE14	7101C	VAN		
18	560	40						
19	560	80						
20	560	100						
21	560	0	Hot	GE9	4148D	DOM		
22	560	40						
23	560	80						
24	560	100						
25	560	0	Hot	GE11	3753D	DOM		
26	560	40						
27	560	80						
28	560	100						
29	560	0	Hot	GE11	3755D	VAN		
30	560	40						
31	560	80						
32	560	100						
33	560	0	Hot	GE14	7099D	DOM		
34	560	40						
35	560	80						
36	560	100						
37	560	0	Hot	GE14	7101D	VAN		
38	560	40						
39	560	80						
40	560	100						
41	560	0	Hot	GE9	4148N	DOM		
42	560	40						

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Bundle Type	Lattice No.	Lattice Type	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
43	560	80						
44	560	100						
45	560	0	Hot	GE11	3753N	DOM		
46	560	40						
47	560	80						
48	560	100						
49	560	0	Hot	GE11	3755N	VAN		
50	560	40						
51	560	80						
52	560	100						
53	560	0	Hot	GE14	7099N	DOM		
54	560	40						
55	560	80						
56	560	100						
57	560	0	Hot	GE14	7101N	VAN		
58	560	40						
59	560	80						
60	560	100						
1	20	0	Cold	GE9	4148C	DOM		
5	20	0		GE11	3753C	DOM		
9	20	0		GE11	3755C	VAN		
13	20	0		GE14	7099C	DOM		
17	20	0		GE14	7101C	VAN		
21	20	0		GE9	4148D	DOM		
25	20	0		GE11	3753D	DOM		
29	20	0		GE11	3755D	VAN		
33	20	0		GE14	7099D	DOM		
37	20	0		GE14	7101D	VAN		
41	20	0		GE9	4148N	DOM		
45	20	0		GE11	3753N	DOM		
49	20	0		GE11	3755N	VAN		
53	20	0		GE14	7099N	DOM		
57	20	0		GE14	7101N	VAN		]]

[[

]]

Figure 5.2-6 Difference in Rod Worth

Figure 5.2-7 is a plot of the difference in cold eigenvalue calculated by LANCR02 and MCNP. Table 5.2-7 contains a list of conditions for every point in this figure. All cases are represented at a fuel and coolant temperature of 20ºC and there is a single controlled (CON) and uncontrolled (UNC) pair of points for each lattice.

Table 5.2-7 Cold Case Conditions for Figure 5.2-7

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	20	0	UNC	GE9	4148C	DOM	[[
2	20	0		GE11	3753C	DOM	
3	20	0		GE11	3755C	VAN	
4	20	0		GE14	7099C	DOM	
5	20	0		GE14	7101C	VAN	
6	20	0		GE9	4148D	DOM	
7	20	0		GE11	3753D	DOM	
8	20	0		GE11	3755D	VAN	
9	20	0		GE14	7099D	DOM	
10	20	0		GE14	7101D	VAN	
11	20	0		GE9	4148N	DOM	
12	20	0		GE11	3753N	DOM	
13	20	0		GE11	3755N	VAN	
14	20	0		GE14	7099N	DOM	
15	20	0		GE14	7101N	VAN	
1	20	0	CON	GE9	4148C	DOM	
2	20	0		GE11	3753C	DOM	
3	20	0		GE11	3755C	VAN	
4	20	0		GE14	7099C	DOM	
5	20	0		GE14	7101C	VAN	
6	20	0		GE9	4148D	DOM	
7	20	0		GE11	3753D	DOM	
8	20	0		GE11	3755D	VAN	
9	20	0		GE14	7099D	DOM	
10	20	0		GE14	7101D	VAN	
11	20	0		GE9	4148N	DOM	
12	20	0		GE11	3753N	DOM	
13	20	0		GE11	3755N	VAN	
14	20	0		GE14	7099N	DOM	
15	20	0		GE14	7101N	VAN	]]

[[

]]

Figure 5.2-7 Difference in Cold Eigenvalues

5.2.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.2-8. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC), cold uncontrolled (CU), and cold controlled (CC)) and also by plant type (i.e., C-lattice, D-lattice, or N-lattice).

[[

]]

Table 5.2-8 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.2-9. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.2-9 Fission Rate RMS Statistics

Case	**No.**	**AVE (%)**	**STDEV (%)**	**MIN (%)**	**MAX (%)**
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.2-10. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.2-10 Pin Peaking Factor Statistics

Case	**No.**	**AVE (%)**	**STDEV (%)**	**MIN (%)**	**MAX (%)**
[[					
					]]

5.3. Test Suite 3 – Edge Part Length Rods

5.3.1. Purpose

Test the performance of LANCR02 versus MCNP for product lines containing part length rods in edge locations.

5.3.2. Description

A single bundle design from each product line in Table 5.3-1 is analyzed. The analysis includes the DOM, PLE, and VAN zone(s). All bundles are analyzed for a C-lattice plant containing a D100 control blade. Fourteen (14) cases at beginning of life (BOL) are analyzed per lattice. The fourteen cases are: hot (560^{o}C) uncontrolled at 0, 40, 80, and 100% voids; hot (560^{o}C) controlled at 0, 40, 80, and 100% voids; hot uncontrolled for a fuel temperature of 1500^{o}C at 0, 40, 80, and 100% void; cold xenon-free uncontrolled at 20^{o}C; and cold xenon-free controlled at 20^{o}C. Comparisons of k-infinity and the RMS of the pin-by-pin fission density are made.

Table 5.3-1 Edge PLR Test Cases

Bundle Type	Size	Lattices to be Analyzed
GNF1	9x9	DOM; PLE; VAN
GNF2	10x10	DOM; PLE1; VAN1; PLE2; VAN2

5.3.3. Number of Cases

Number of lattices (8) x Number of cases (14) = 112.

5.3.4. Results

Table 5.3-2 contains a list of all lattices analyzed for this test suite. This table also lists the total number of vanishing rods in each lattice and number of vanishing rods at the edges. In the case of plenum regions, rods with zero power are considered vanishing rods.

MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.3-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type	Total Vanishing Rods	Edge Vanishing Rods
GNF1	9x9	N/A	300432	DOM	[[	
			300433	PLE		
			300434	VAN		
GNF2	10x10	2850	6939	DOM		
			6940	PLE1		
			6941	VAN1		
			6942	PLE2		
			6943	VAN2		]]

Figure 5.3-1 through Figure 5.3-7 contain results from all analyses. There is a separate graph for each of the following parameters:

- hot and cold eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates);
- relative pin peaking factor (% difference between LANCR02 and MCNP);
- eigenvalue difference grouped by void (pcm difference between LANCR02P and MCNP);
- CDOP (% difference between LANCR02 and MCNP); and
- rod worth (% difference between LANCR02 and MCNP).

In each graph, data is separated into product line – results to the left of the vertical line are from the GNF1 product line; results to the right of the vertical line are from the GNF2 product line. Results within each product line progress in order from the DOM zone, to the PLE zone, to the VAN zone, and so on.

Table 5.3-3 contains a list of conditions for every point in Figure 5.3-1 through Figure 5.3-3. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. There are no controlled results for the 1500ºC fuel temperature cases.

Figure 5.3-2 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.3-3 Case Conditions for Figure 5.3-1 through Figure 5.3-3

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GNF1	300432	DOM	[[
2	560	0					
3	1500	40					
4	560	40					
5	1500	80					
6	560	80					
7	1500	100					
8	560	100					
9	1500	0	UNC	GNF1	300433	PLE	
10	560	0					
11	1500	40					
12	560	40					
13	1500	80					
14	560	80					
15	1500	100					
16	560	100					
17	1500	0	UNC	GNF1	300434	VAN	
18	560	0					
19	1500	40					
20	560	40					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
21	1500	80					
22	560	80					
23	1500	100					
24	560	100					
25	1500	0	UNC	GNF2	6939	DOM	
26	560	0					
27	1500	40					
28	560	40					
29	1500	80					
30	560	80					
31	1500	100					
32	560	100					
33	1500	0	UNC	GNF2	6940	PLE1	
34	560	0					
35	1500	40					
36	560	40					
37	1500	80					
38	560	80					
39	1500	100					
40	560	100					
41	1500	0	UNC	GNF2	6942	PLE2	
42	560	0					
43	1500	40					
44	560	40					
45	1500	80					
46	560	80					
47	1500	100					
48	560	100					
49	1500	0	UNC	GNF2	6941	VAN1	
50	560	0					
51	1500	40					
52	560	40					
53	1500	80					
54	560	80					
55	1500	100					
56	560	100					
57	1500	0	UNC	GNF2	6943	VAN2	
58	560	0					
59	1500	40					
60	560	40					
61	1500	80					
62	560	80					
63	1500	100					
64	560	100					
2	560	0	CON	GNF1	300432	DOM	
4	560	40					
6	560	80					
8	560	100					
10	560	0	CON	GNF1	300433	PLE	

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
12	560	40					
14	560	80					
16	560	100					
18	560	0	CON	GNF1	300434	VAN	
20	560	40					
22	560	80					
24	560	100					
26	560	0	CON	GNF2	6939	DOM	
28	560	40					
30	560	80					
32	560	100					
34	560	0	CON	GNF2	6940	PLE1	
36	560	40					
38	560	80					
40	560	100					
42	560	0	CON	GNF2	6942	PLE2	
44	560	40					
46	560	80					
48	560	100					
50	560	0	CON	GNF2	6941	VAN1	
52	560	40					
54	560	80					
56	560	100					
58	560	0	CON	GNF2	6943	VAN2	
60	560	40					
62	560	80					
64	560	100					]]

[[

]]

Figure 5.3-1 Difference in Hot Eigenvalues

[[

]]

Figure 5.3-2 Fission Rate RMS

[[

]]

Figure 5.3-3 Difference in Pin Peaking Factor

Figure 5.3-4 is a plot of the same information as Figure 5.3-1, except all of the void cases for each case are plotted together. Table 5.3-4 contains a list of conditions for every point in this figure.

Table 5.3-4 Void Case Conditions for Figure 5.3-4

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GNF1	300432	DOM	[[
		40					
		80					
		100					
2	560	0					
		40					
		80					
		100					
3	1500	0	UNC	GNF1	300433	PLE	
		40					
		80					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
		100					
4	560	0					
		40					
		80					
		100					
5	1500	0	UNC	GNF1	300434	VAN	
		40					
		80					
		100					
6	560	0					
		40					
		80					
		100					
7	1500	0	UNC	GNF2	6939	DOM	
		40					
		80					
		100					
8	560	0					
		40					
		80					
		100					
9	1500	0	UNC	GNF2	6940	PLE1	
		40					
		80					
		100					
10	560	0					
		40					
		80					
		100					
11	1500	0	UNC	GNF2	6942	PLE2	
		40					
		80					
		100					
12	560	0					
		40					
		80					
		100					
13	1500	0	UNC	GNF2	6941	VAN1	
		40					
		80					
		100					
14	560	0					
		40					
		80					
		100					
15	1500	0	UNC	GNF2	6943	VAN2	
		40					
		80					
		100					

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
16	560	0					
		40					
		80					
		100					
17	560	0	CON	GNF1	300432	DOM	
		40					
		80					
		100					
18	560	0	CON	GNF1	300433	PLE	
		40					
		80					
		100					
19	560	0	CON	GNF1	300434	VAN	
		40					
		80					
		100					
20	560	0	CON	GNF2	6939	DOM	
		40					
		80					
		100					
21	560	0	CON	GNF2	6940	PLE1	
		40					
		80					
		100					
22	560	0	CON	GNF2	6942	PLE2	
		40					
		80					
		100					
23	560	0	CON	GNF2	6941	VAN1	
		40					
		80					
		100					
24	560	0	CON	GNF2	6943	VAN2	
		40					
		80					
		100					]]

[[

]]

Figure 5.3-4 Eigenvalue Difference Grouped by Void

Figure 5.3-5 is a plot of CDOP. Table 5.3-5 contains a list of conditions for every point in this figure. All cases are uncontrolled and represent a change in fuel temperature from 560ºC to 1500ºC.

Table 5.3-5 Doppler Case Conditions for Figure 5.3-5

Case No.	Void (%)	Bundle Type	Lattice No.	Lattice Type	LANCR02 Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs (%)
1	0	GNF1	300432	DOM	[[	
2	40					
3	80					
4	100					
5	0	GNF1	300433	PLE		
6	40					
7	80					
8	100					
9	0	GNF1	300434	VAN		
10	40					
11	80					
12	100					
13	0	GNF2	6939	DOM		
14	40					
15	80					
16	100					
17	0	GNF2	6940	PLE1		
18	40					
19	80					
20	100					
21	0	GNF2	6942	PLE2		
22	40					
23	80					
24	100					
25	0	GNF2	6941	VAN1		
26	40					
27	80					
28	100					
29	0	GNF2	6943	VAN2		
30	40					
31	80					
32	100					]]

[[

]]

Figure 5.3-5 Difference in CDOP

Figure 5.3-6 is a plot of the difference in rod worth calculated by LANCR02 and MCNP. Table 5.3-6 contains a list of conditions for every point in this figure. All cold cases are represented at a fuel and coolant temperature of 20ºC, and all hot cases are represented at a fuel temperature of 560ºC.

Table 5.3-6 Rod Worth Case Conditions for Figure 5.3-6

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Bundle Type	Lattice No.	Lattice Type	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
1	560	0	Hot	GNF1	300432	DOM	[[	
2	560	40						
3	560	80						
4	560	100						
5	560	0	Hot	GNF1	300433	PLE		
6	560	40						
7	560	80						
8	560	100						
9	560	0	Hot	GNF1	300434	VAN		
10	560	40						
11	560	80						
12	560	100						
13	560	0	Hot	GNF2	6939	DOM		
14	560	40						
15	560	80						
16	560	100						
17	560	0	Hot	GNF2	6940	PLE1		
18	560	40						
19	560	80						
20	560	100						
21	560	0	Hot	GNF2	6942	PLE2		
22	560	40						
23	560	80						
24	560	100						
25	560	0	Hot	GNF2	6941	VAN1		
26	560	40						
27	560	80						
28	560	100						
29	560	0	Hot	GNF2	6943	VAN2		
30	560	40						
31	560	80						
32	560	100						
1	20	0	Cold	GNF1	300432	DOM		
5	20	0	Cold	GNF1	300433	PLE		
9	20	0	Cold	GNF1	300434	VAN		
13	20	0	Cold	GNF2	6939	DOM		
17	20	0	Cold	GNF2	6940	PLE1		
21	20	0	Cold	GNF2	6942	PLE2		
25	20	0	Cold	GNF2	6941	VAN1		
29	20	0	Cold	GNF2	6943	VAN2		]]

[[

]]

Figure 5.3-6 Difference in Rod Worth

Figure 5.3-7 is a plot in the eigenvalue difference for cold cases calculated by LANCR02 and MCNP. Table 5.3-7 contains a list of conditions for every point in this figure. All cases are represented at a fuel and coolant temperature of 20ºC and there is a single controlled (CON) and uncontrolled (UNC) pair of points for each lattice.

Table 5.3-7 Cold Case Conditions for Figure 5.3-7

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	20	0	UNC	GNF1	300432	DOM	[[
2	20	0		GNF1	300433	PLE	
3	20	0		GNF1	300434	VAN	
4	20	0		GNF2	6939	DOM	
5	20	0		GNF2	6940	PLE1	
6	20	0		GNF2	6942	PLE2	
7	20	0		GNF2	6941	VAN1	
8	20	0		GNF2	6943	VAN2	
1	20	0	CON	GNF1	300432	DOM	
2	20	0		GNF1	300433	PLE	
3	20	0		GNF1	300434	VAN	
4	20	0		GNF2	6939	DOM	
5	20	0		GNF2	6940	PLE1	
6	20	0		GNF2	6942	PLE2	
7	20	0		GNF2	6941	VAN1	
8	20	0		GNF2	6943	VAN2	]]

[[

]]

Figure 5.3-7 Difference in Cold Eigenvalues

5.3.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.3-8. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC), cold uncontrolled (CU), and cold controlled (CC)) and also by plant type (i.e., C-lattice, D-lattice, or N-lattice). The Doppler cases have been included in the HU statistics.

The overall average difference in the LANCR02 and MCNP eigenvalues, for all 111 cases analyzed, is [[ ]], with a standard deviation about the average of [[ ]]. This includes all hot, cold, uncontrolled, and controlled cases. Results are consistent across the three plant types and the statistics are consistent with those from Test Suite 1. No meaningful trends are observed between any subgroup.

Table 5.3-8 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.3-9. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.3-9 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.3-10. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.3-10 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.4. Test Suite 4 – Mixed Oxide

5.4.1. Purpose

Test the ability of LANCR02 to adequately model Mixed Oxide (MOX) bundle designs.

5.4.2. Description

Comparisons of LANCR02 with MCNP are performed to validate the adequacy of modeling Mixed Oxide. Test cases include recycled Pu designs and highly enriched Pu-239 designs for the product lines and lattices in Table 5.4-1. Pu rods do not contain any initial gadolinium. Fourteen (14) cases at beginning of life (BOL) are analyzed per lattice. The fourteen cases are: hot (560^oC) uncontrolled at 0, 40, 80, and 100% voids; hot (560^oC) controlled at 0, 40, 80, and 100% voids; hot uncontrolled for a fuel temperature of 1500^oC at 0, 40, 80, and 100% void; cold xenon-free uncontrolled at 20^oC; and cold xenon-free controlled at 20^oC. Comparisons of k-infinity and the RMS of the pin-by-pin fission density are made.

All bundles are analyzed for a C-lattice plant containing a D100 control blade.

Table 5.4-1 Mixed Oxide Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE9 MOX	8x8	DOM
GE11 MOX	9x9	DOM; VAN

5.4.3. Number of Cases

Number of lattices (3) x Number of cases (14) = 42.

5.4.4. Results

Table 5.4-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.4-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE9	8x8	N/A	90004	DOM
GE11	9x9	N/A	6002	DOM
			6003	VAN

[[

]]

[[

]]

Figure 5.4-1 Enrichment Layouts for MOX Bundles

Figure 5.4-2 through Figure 5.4-8 contain results from all analyses. There is a separate graph for each of the following parameters:

- hot and cold eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (RMS difference between LANCR02 and MCNP pin-wise fission rates);
- relative pin peaking factor (% difference between LANCR02 and MCNP);
- eigenvalue differences arranged by void (pcm difference between LANCR02 and MCNP);
- CDOP (% difference between LANCR02 and MCNP); and
- rod worth (% difference between LANCR02 and MCNP).

In each graph, data is separated into product line – results to the left of the vertical line are from the GE9 (8x8) product line; results to the right of the vertical line are from the GE11 (9x9) product line.

Table 5.4-3 contains a list of conditions for every point in Figure 5.4-2 through Figure 5.4-4. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. There are no controlled results for the 1500ºC fuel temperature cases.

Figure 5.4-3 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.4-3 Case Conditions for Figure 5.4-2 through Figure 5.4-4

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GE9	90004	DOM	[[
2	560	0					
3	1500	40					
4	560	40					
5	1500	80					
6	560	80					
7	1500	100					
8	560	100					
9	1500	0	UNC	GE11	6002	DOM	
10	560	0					
11	1500	40					
12	560	40					
13	1500	80					
14	560	80					
15	1500	100					
16	560	100					
17	1500	0	UNC	GE11	6003	VAN	
18	560	0					
19	1500	40					
20	560	40					
21	1500	80					
22	560	80					
23	1500	100					
24	560	100					
2	560	0	CON	GE9	90004	DOM	
4	560	40					
6	560	80					
8	560	100					
10	560	0	CON	GE11	6002	DOM	
12	560	40					
14	560	80					
16	560	100					
18	560	0	CON	GE11	6003	VAN	
20	560	40					
22	560	80					
24	560	100					]]

[[

]]

Figure 5.4-2 Difference in Hot Eigenvalues

[[

]]

Figure 5.4-3 Fission Rate RMS

[[

]]

Figure 5.4-4 Difference in Pin Peaking Factor

Figure 5.4-5 is a plot of the same data as in Figure 5.4-1, except that all void points are plotted together for the same case. Table 5.4-4 contains a list of conditions for every point in this figure.

Table 5.4-4 Void Case Conditions for Figure 5.4-5

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	GE9	90004	DOM	[[
		40					
		80					
		100					
2	560	0					
		40					
		80					
		100					
3	1500	0	UNC	GE11	6002	DOM	
		40					
		80					
		100					

Case No.	**Fuel Temp (ºC)**	**Void (%)**	**UNC or CON**	**Bundle Type**	**Lattice No.**	**Lattice Type**	**Difference in Eigenvalues (pcm)**
4	560	0					
		40					
		80					
		100					
5	1500	0	UNC	GE11	6003	VAN	
		40					
		80					
		100					
6	560	0					
		40					
		80					
		100					
7	560	0	CON	GE9	90004	DOM	
		40					
		80					
		100					
8	560	0	CON	GE11	6002	DOM	
		40					
		80					
		100					
9	560	0	CON	GE11	6003	VAN	
		40					
		80					
		100					]]

[[

]]

Figure 5.4-5 Eigenvalue Differences Grouped by Void

Figure 5.4-6 is a plot of CDOP. Table 5.4-5 contains a list of conditions for every point in. All cases are uncontrolled and represent a change in fuel temperature from 560ºC to 1500ºC.

Table 5.4-5 Doppler Case Conditions for Figure 5.4-6

Case No.	**Void (%)**	**Bundle Type**	**Lattice No.**	**Lattice Type**	**LANCR02 Doppler Coeffs (pcm/√K)**	**Difference in Doppler Coeffs (%)**
1	0	GE9	90004	DOM	[[	
2	40					
3	80					
4	100					
5	0	GE11	6002	DOM		
6	40					
7	80					
8	100					
9	0	GE11	6003	VAN		
10	40					
11	80					
12	100					]]

[[

]]

Figure 5.4-6 Difference in CDOP

Figure 5.4-7 is a plot of the difference in rod worth calculated by LANCR02 and MCNP. Table 5.4-6 contains a list of conditions for every point in this figure. All cold cases are represented at a fuel and coolant temperature of 20ºC, and all hot cases are represented at a fuel temperature of 560ºC.

Table 5.4-6 Rod Worth Case Conditions for Figure 5.4-7

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Bundle Type	Lattice No.	Lattice Type	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
1	560	0	Hot	GE9	90004	DOM	[[	
2	560	40						
3	560	80						
4	560	100						
5	560	0	Hot	GE11	6002	DOM		
6	560	40						
7	560	80						
8	560	100						
9	560	0	Hot	GE11	6003	VAN		
10	560	40						
11	560	80						
12	560	100						
1	20	0	Cold	GE9	9000	DOM		
5	20	0		GE11	6002	DOM		
9	20	0		GE11	6003	VAN		]]

[[

]]

Figure 5.4-7 Difference in Rod Worth

Figure 5.4-8 is a plot of the difference in cold eigenvalues between LANCR02 and MCNP. Table 5.4-7 contains a list of conditions for every point in the table. All cases are represented at a fuel and coolant temperature of 20ºC and there is a single controlled (CON) and uncontrolled (UNC) pair of points for each lattice.

Table 5.4-7 Cold Case Conditions for Figure 5.4-8

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	20	0	UNC	GE9	90004	DOM	[[
2	20	0		GE11	6002	DOM	
3	20	0		GE11	6003	VAN	
1	20	0	CON	GE9	90004	DOM	
2	20	0		GE11	6002	DOM	
3	20	0		GE11	6003	VAN	]]

[[

]]

Figure 5.4-8 Difference in Cold Eigenvalues

5.4.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.4-8. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC), cold uncontrolled (CU), and cold controlled (CC)) and also by product line (i.e., 8x8 and 9x9). The Doppler cases have been included in the HU statistics.

The overall average difference in the LANCR02 and MCNP eigenvalues, for all 42 cases analyzed, is [[ ]], with a standard deviation about the average of [[ ]] This includes all hot, cold, uncontrolled, and controlled cases. Results are consistent with those from Test Suite 1. No meaningful trends are observed between any subgroups.

Table 5.4-8 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.4-9. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is reasonable.

Table 5.4-9 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.4-10. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.4-10 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.4.6. Comments

[[

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5.5. Test Suite 5 – Reactivity Worth of Depleted Lattice

5.5.1. Purpose

Test the reactivity worth of fission products and actinides of LANCR02 versus MCNP in a depleted lattice. This is accomplished by comparing results from LANCR02 and MCNP for a UOX and MOX lattice depleted to exposures of 40 and 80 GWd/ST.

5.5.2. Description

The lattices in Table 5.5-1 are analyzed with MCNP. Sixteen (16) cases at middle of life (40 GWd/ST) and sixteen cases at End of Life (80 GWd/ST) are analyzed per lattice. The sixteen cases are: hot (560^{o}C) uncontrolled at 0, 40, 80, and 100% voids; hot (560^{o}C) controlled at 0, 40, 80, and 100% voids; hot uncontrolled for a fuel temperature of 1500^{o}C at 0, 40, 80, and 100% void; cold xenon-free uncontrolled at 20^{o}C; cold equilibrium-xenon uncontrolled at 20^{o}C; cold xenon-free controlled at 20^{o}C; and cold equilibrium-xenon controlled at 20^{o}C. All lattices are depleted at 40% voided conditions. Comparisons of k-infinity and the RMS of the pin-by-pin fission density are made.

All bundles are analyzed for a C-lattice plant containing a D100 control blade.

Table 5.5-1 FP and Actinide Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE11 MOX	9x9	DOM
GE14	10x10	DOM

5.5.3. Number of Cases

Number of lattices (2) x Number of exposure points (2) x Number of cases (16) = 64.

5.5.4. Results

Table 5.5-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.5-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE11 MOX	9x9	N/A	6002	DOM
GE14	10x10	2882	7099	DOM

The UOX lattice (7099) is the same as used in Test Suite 1. The MOX lattice (6002) is the same as used in Test Suite 4.

The results from BOL (0 GWd/ST) are also included in the analysis so that any trends with exposure can be determined. The BOL results are taken directly from Test Suite 1 (for lattice 7099) and Test Suite 4 (for lattice 6002).

5.5.5. UOX Results

Figure 5.5-1 through Figure 5.5-7 contain results from all UOX analyses on lattice 7099. There is a separate graph for each of the following parameters:

- hot and cold eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates);
- relative pin peaking factor (% difference between LANCR02 and MCNP);
- eigenvalue differences grouped by void (pcm difference between LANCR02 and MCNP);
- CDOP (% difference between LANCR02 and MCNP); and
- rod worth (% difference between LANCR02 and MCNP).

In each graph, data is separated in terms of exposure – results to the left of the first vertical line are from beginning-of-life; results in between the first and second vertical lines are from the 40 GWd/ST exposure point; results to the right of the second vertical line are from the 80 GWd/ST exposure point. The BOL results have been obtained from Test Suite 1.

Table 5.5-3 contains a list of conditions for every point in Figure 5.5-1 through Figure 5.5-3. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. There are no controlled results for the 1500ºC fuel temperature cases.

Figure 5.5-2 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.5-3 Case Conditions for UOX Lattice Figure 5.5-1 through Figure 5.5-3

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Burn-Up (GWd/ST)	Difference in Eigenvalues (pcm)
1	1500	0	UNC	0	[[
2	560	0			
3	1500	40			
4	560	40			
5	1500	80			
6	560	80			
7	1500	100			
8	560	100			
9	1500	0	UNC	40	
10	560	0			
11	1500	40			
12	560	40			
13	1500	80			
14	560	80			
15	1500	100			
16	560	100			
17	1500	0	UNC	80	
18	560	0			
19	1500	40			
20	560	40			
21	1500	80			
22	560	80			
23	1500	100			
24	560	100			
2	560	0	CON	0	
4	560	40			
6	560	80			
8	560	100			
10	560	0	CON	40	
12	560	40			
14	560	80			
16	560	100			
18	560	0	CON	80	
20	560	40			
22	560	80			
24	560	100			]]

[[

]]

Figure 5.5-1 UOX Difference in Hot Eigenvalues

[[

]]

Figure 5.5-2 UOX Fission Rate RMS

[[

]]

Figure 5.5-3 UOX Difference in Pin Peaking Factor

Figure 5.5-4 is a plot of the same data as Figure 5.5-1, except that the datasets are grouped by void. Table 5.5-4 contains a list of conditions for every point in this figure.

Table 5.5-4 Void Case Conditions for UOX Lattice Figure 5.5-4

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Burn-Up (GWd/ST)	Difference in Eigenvalues (pcm)
1	1500	0	UNC	0	[[
		40			
		80			
		100			
2	560	0	UNC	0	
		40			
		80			
		100			
3	1500	0	UNC	40	
		40			
		80			
		100			
4	560	0	UNC	40	
		40			
		80			
		100			
5	1500	0	UNC	80	
		40			
		80			
		100			
6	560	0	UNC	80	
		40			
		80			
		100			
7	560	0	CON	0	
		40			
		80			
		100			
8	560	0	CON	40	
		40			
		80			
		100			
9	560	0	CON	80	
		40			
		80			
		100			]]

[[

]]

Figure 5.5-4 UOX Eigenvalue Difference Grouped by Void

Figure 5.5-5 is a plot of CDOP. Table 5.5-5 contains a list of conditions for every point in this figure. All cases are uncontrolled and represent a change in fuel temperature from 560ºC to 1500ºC.

Table 5.5-5 Doppler Case Conditions for UOX Lattice Figure 5.5-5

Case No.	Void (%)	Burn-Up (GWd/ST)	LANCR02 Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs (%)
1	0	0	[[	
2	40			
3	80			
4	100			
5	0	40		
6	40			
7	80			
8	100			
9	0	80		
10	40			
11	80			
12	100			]]

[[

]]

Figure 5.5-5 UOX Difference in CDOP

Table 5.5-6 contains a list of conditions for every point in the figure. All cold cases are represented at a fuel and coolant temperature of 20ºC, and all hot cases are represented at a fuel temperature of 560ºC.

Table 5.5-6 Rod Worth Case Conditions for UOX Lattice Figure 5.5-6

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Xenon	Burn-Up (GWd/ST)	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
1	560	0	Hot	No	0	[[	
2	560	40					
3	560	80					
4	560	100					
5	560	0	Hot	No	40		
6	560	40					
7	560	80					
8	560	100					
9	560	0	Hot	No	80		
10	560	40					
11	560	80					
12	560	100					
1	20	0	Cold	No	0		
5	20	0	Cold	No	40		
7	20	0	Cold	Yes	40		
9	20	0	Cold	No	80		
11	20	0	Cold	Yes	80		]]

[[

]]

Figure 5.5-6 UOX Difference in Rod Worth

Figure 5.5-7 is a plot of the cold eigenvalue differences between LANCR02 and MCNP. Table 5.5-7 contains a list of conditions for every point in this figure. All cases are represented at a fuel and coolant temperature of 20ºC and there is a single controlled (CON) and uncontrolled (UNC) pair of points for each lattice.

Table 5.5-7 Cold Case Conditions for UOX Lattice Figure 5.5-7

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Xenon	Burn-Up (GWd/ST)	Difference in Eigenvalues (pcm)
1	20	0	UNC	No	0	[[
2	20	0		No	40	
3	20	0		Yes	40	
4	20	0		No	80	
5	20	0		Yes	80	
1	20	0	CON	No	0	
2	20	0		No	40	
3	20	0		Yes	40	
4	20	0		No	80	
5	20	0		Yes	80	]]

[[

]]

Figure 5.5-7 UOX Difference in Cold Eigenvalues

5.5.6. MOX Results

Figure 5.5-8 through Figure 5.5-14 contain results from all MOX analyses on segment 6002. There is a separate graph for each of the following parameters:

- hot and cold eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates);
- relative pin peaking factor (% difference between LANCR02 and MCNP);
- eigenvalue difference grouped by void (pcm difference between MCNP and LANCR02);
- CDOP (% difference between LANCR02 and MCNP); and
- rod worth (% difference between LANCR02 and MCNP).

In each graph, data is separated in terms of exposure – results to the left of the first vertical line are from beginning-of-life; results in between the first and second vertical lines are from the 40 GWd/ST exposure point; results to the right of the second vertical line are from the 80 GWd/ST exposure point. The BOL results have been obtained from Test Suite 4.

Table 5.5-8 contains a list of conditions for every point in Figure 5.5-8 through Figure 5.5-10. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. There are no controlled results for the 1500ºC fuel temperature cases.

Figure 5.5-9 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.5-8 Case Conditions for MOX Lattice Figure 5.5-8 through Figure 5.5-10

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Burn-Up (GWd/ST)	Difference in Eigenvalues (pcm)
1	1500	0	UNC	0	[[
2	560	0			
3	1500	40			
4	560	40			
5	1500	80			
6	560	80			
7	1500	100			
8	560	100			
9	1500	0	UNC	40	
10	560	0			
11	1500	40			
12	560	40			
13	1500	80			
14	560	80			
15	1500	100			
16	560	100			
17	1500	0	UNC	80	
18	560	0			
19	1500	40			
20	560	40			
21	1500	80			

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Burn-Up (GWd/ST)	Difference in Eigenvalues (pcm)
22	560	80			
23	1500	100			
24	560	100			
2	560	0	CON	0	
4	560	40			
6	560	80			
8	560	100			
10	560	0	CON	40	
12	560	40			
14	560	80			
16	560	100			
18	560	0	CON	80	
20	560	40			
22	560	80			
24	560	100			]]

[[

]]

Figure 5.5-8 MOX Difference in Hot Eigenvalues

[[

]]

Figure 5.5-9 MOX Fission Rate RMS

[[

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Figure 5.5-10 MOX Difference in Pin Peaking Factor

Figure 5.5-11 is a plot of the same data as Figure 5.5-8, except that the data has been grouped by void. Table 5.5-9 contains a list of conditions for every point in the table.

Table 5.5-9 Void Case Conditions for MOX Lattice Figure 5.5-11

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Burn-Up (GWd/ST)	Difference in Eigenvalues (pcm)
1	1500	0	UNC	0	[[
		40			
		80			
		100			
2	560	0			
		40			
		80			
		100			
3	1500	0	UNC	40	
		40			
		80			
		100			
4	560	0			
		40			

Case No.	**Fuel Temp (ºC)**	**Void (%)**	**UNC or CON**	**Burn-Up (GWd/ST)**	**Difference in Eigenvalues (pcm)**
		80			
		100			
5	1500	0	UNC	80	
		40			
		80			
		100			
6	560	0			
		40			
		80			
		100			
7	560	0	CON	0	
		40			
		80			
		100			
8	560	0	CON	40	
		40			
		80			
		100			
9	560	0	CON	80	
		40			
		80			
		100			]]

[[

]]

Figure 5.5-11 MOX Eigenvalue Difference Grouped by Void

Figure 5.5-12 is a plot of CDOP. Table 5.5-10 contains a list of conditions for every point in this table. All cases are uncontrolled and represent a change in fuel temperature from 560ºC to 1500ºC.

Table 5.5-10 Doppler Case Conditions for MOX Lattice Figure 5.5-12

Case No.	Void (%)	Burn-Up (GWd/ST)	LANCR02 Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs (%)
1	0	0	[[	
2	40			
3	80			
4	100			
5	0	40		
6	40			
7	80			
8	100			
9	0	80		
10	40			
11	80			
12	100			]]

[[

]]

Figure 5.5-12 MOX Difference in CDOP

Figure 5.5-13 is a figure of the difference in rod worth calculated by LANCR02 and MCNP. Table 5.5-11 contains a list of conditions for every point in this figure. All cold cases are represented at a fuel and coolant temperature of 20ºC, and all hot cases are represented at a fuel temperature of 560ºC.

Table 5.5-11 Rod Worth Case Conditions for MOX Lattice Figure 5.5-13

Case No.	Fuel Temp (ºC)	Void (%)	Hot or Cold	Xenon	Burn-Up (GWd/ST)	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
1	560	0	Hot		0	[[	
2	560	40					
3	560	80					
4	560	100					
5	560	0	Hot		40		
6	560	40					
7	560	80					
8	560	100					
9	560	0	Hot		80		
10	560	40					
11	560	80					
12	560	100					
1	20	0	Cold	No	0		
5	20	0		No	40		
7	20	0		Yes	40		
9	20	0		No	80		
11	20	0		Yes	80		]]

[[

]]

Figure 5.5-13 MOX Difference in Rod Worth

Figure 5.5-14 is a figure of the cold eigenvalue differences between LANCR02 and MCNP. Table 5.5-12 contains a list of conditions for every point in the figure. All cases are represented at a fuel and coolant temperature of 20ºC and there is a single controlled (CON) and uncontrolled (UNC) pair of points for each lattice.

Table 5.5-12 Cold Case Conditions for MOX Lattice Figure 5.5-14

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Xenon	Burn-Up (GWd/ST)	Difference in Eigenvalues (pcm)
1	20	0	UNC	No	0	[[
2	20	0		No	40	
3	20	0		Yes	40	
4	20	0		No	80	
5	20	0		Yes	80	
1	20	0	CON	No	0	
2	20	0		No	40	
3	20	0		Yes	40	
4	20	0		No	80	
5	20	0		Yes	80	]]

[[

]]

Figure 5.5-14 MOX Difference in Cold Eigenvalues

5.5.7. Statistics for UOX and MOX

A summary of the statistics related to all UOX eigenvalues is presented in Table 5.5-13. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC), cold uncontrolled (CU), and cold controlled (CC)) and also by exposure and void. The Doppler cases have been included in the HU statistics.

[[

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Table 5.5-13 Eigenvalue Statistics for UOX

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions for UOX is presented in Table 5.5-14. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.5-14 Fission Rate RMS Statistics for UOX

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors for UOX is presented in Table 5.5-15. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.5-15 Pin Peaking Factor Statistics for UOX

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all MOX eigenvalues is presented in Table 5.5-16. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC), cold uncontrolled (CU), and cold controlled (CC)) and also by exposure and void. The Doppler cases have been included in the HU statistics.

[[

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Table 5.5-16 Eigenvalue Statistics for MOX

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions for MOX is presented in Table 5.5-17. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.5-17 Fission Rate RMS Statistics for MOX

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors for MOX is presented in Table 5.5-18. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.5-18 Pin Peaking Factor Statistics for MOX

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.6. Test Suite 6 – Alternative Product Lines

5.6.1. Purpose

Test the performance of LANCR02 versus MCNP for traits found in non-GNF product lines.

5.6.2. Description

The lattices in Table 5.6-1 are analyzed with MCNP. Fourteen cases at BOL are analyzed per lattice. The fourteen cases are: hot (560^{o}C) uncontrolled at 0, 40, 80, and 100% voids; hot (560^{o}C) controlled at 0, 40, 80, and 100% voids; hot uncontrolled for a fuel temperature of 1500^{o}C at 0, 40, 80, and 100% void; cold xenon-free uncontrolled at 20^{o}C; and cold xenon-free controlled at 20^{o}C. Comparisons of k-infinity and pin-by-pin fission density are made. All dimensions and locations of alternate product line feature are approximate and based on publicly available information.

These lattices are non-GNF designs. The 9x9 lattice has asymmetric gaps. The 10x10 lattices have symmetric gaps.

Table 5.6-1 Alternative Product Line Test Cases

Bundle Type	Size	Lattices to be Analyzed
Offset Water Box	9x9	DOM
Offset Water Box	10x10	DOM; VAN
Water Wings	10x10	DOM

5.6.3. Number of Cases

Number of lattices (4) x Number of cases (14) = 56.

5.6.4. Results

Table 5.6-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

The location of the water box and water wings for the various lattices analyzed is shown in Figure 5.6-1.

Table 5.6-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
Water Box	9x9	N/A	7782	DOM
Water Box	10x10	N/A	1110	DOM
			1111	VAN
Water Wings	10x10	N/A	33004	DOM

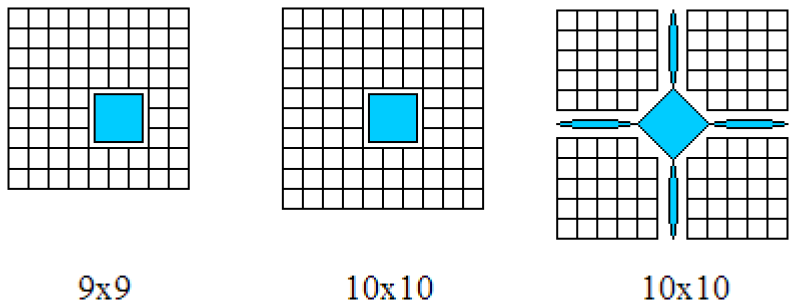

Figure 5.6-1 Location of Water Boxes and Water Wings

Figure 5.6-2 through Figure 5.6-8 contain results from all analyses. There is a separate graph for each of the following parameters:

- hot and cold eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates);
- relative pin peaking factor (% difference between LANCR02 and MCNP);
- eigenvalue differences grouped by void (pcm difference between LANCR02 and MCNP);
- CDOP (% difference between LANCR02 and MCNP); and
- rod worth (% difference between LANCR02 and MCNP).

In each graph, data is separated by bundle type – results to the left of the vertical line are from the 9x9 water box bundle; results to the left of the next vertical line are from the 10x10 water box bundle; results to the far right are from the 10x10 water wing bundle.

All results from LANCR02 are in excellent agreement with those from MCNP. The most important graphs for this test suite are the fission rate RMS graph and the pin peaking factor graph, both of which represent the accuracy with which LANCR02 handles the geometry of the water box and water wings.

Table 5.6-3 contains a list of conditions for every point in Figure 5.6-2 through Figure 5.6-4. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. There are no controlled results for the 1500ºC fuel temperature cases.

Figure 5.6-3 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.6-3 Case Conditions for Figure 5.6-2 through Figure 5.6-4

Case No.	Fuel Temp (°C)	Void (%)	UNC or CON	Bundle Type	Size	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	Water Box	9x9	7782	DOM	[[
2	560	0						
3	1500	40						
4	560	40						
5	1500	80						
6	560	80						
7	1500	100						
8	560	100						
9	1500	0	UNC	Water Box	10x10	1110	DOM	
10	560	0						
11	1500	40						
12	560	40						
13	1500	80						
14	560	80						
15	1500	100						
16	560	100						
17	1500	0	UNC	Water Box	10x10	1111	VAN	
18	560	0						
19	1500	40						
20	560	40						
21	1500	80						
22	560	80						
23	1500	100						
24	560	100						
25	1500	0	UNC	Water Wings	10x10	33004	DOM	
26	560	0						
27	1500	40						
28	560	40						
29	1500	80						
30	560	80						
31	1500	100						
32	560	100						
2	560	0	CON	Water Box	9x9	7782	DOM	
4	560	40						
6	560	80						
8	560	100						
10	560	0	CON	Water Box	10x10	1110	DOM	
12	560	40						
14	560	80						
16	560	100						
18	560	0	CON	Water Box	10x10	1111	VAN	
20	560	40						
22	560	80						
24	560	100						
26	560	0	CON	Water Wings	10x10	33004	DOM	
28	560	40						
30	560	80						
32	560	100						]]

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Figure 5.6-2 Difference in Hot Eigenvalues

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Figure 5.6-3 Fission Rate RMS

[[

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Figure 5.6-4 Difference in Pin Peaking Factor

Table 5.6-4 contains a list of conditions for every point in Figure 5.6-5.

Table 5.6-4 Void Case Conditions for Figure 5.6-5

Case No.	Fuel Temp (°C)	Void (%)	UNC or CON	Bundle Type	Size	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	1500	0	UNC	Water Box	9x9	7782	DOM	[[
		40						
		80						
		100						
2	560	0						
		40						
		80						
		100						
3	1500	0	UNC	Water Box	10x10	1110	DOM	
		40						
		80						
		100						
4	560	0						
		40						
		80						
		100						
5	1500	0	UNC	Water Box	10x10	1111	VAN	
		40						
		80						
		100						
6	560	0						
		40						
		80						
		100						
7	1500	0	UNC	Water Wings	10x10	33004	DOM	
		40						
		80						
		100						
8	560	0						
		40						
		80						
		100						
9	560	0	CON	Water Box	9x9	7782	DOM	
		40						
		80						
		100						
10	560	0	CON	Water Box	10x10	1110	DOM	
		40						
		80						
		100						
11	560	0	CON	Water Box	10x10	1111	VAN	
		40						
		80						
		100						

Case No.	Fuel Temp (°C)	Void (%)	UNC or CON	Bundle Type	Size	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
12	560	0	CON	Water Wings	10x10	33004	DOM	
		40						
		80						
		100						]]

[[

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Figure 5.6-5 Difference in Eigenvalues Grouped by Void

Table 5.6-5 contains a list of conditions for every point in Figure 5.6-6. All cases are uncontrolled and represent a change in fuel temperature from 560ºC to 1500ºC.

Table 5.6-5 Doppler Case Conditions for Figure 5.6-6

Case No.	Void (%)	Bundle Type	Size	Lattice No.	Lattice Type	LANCR02 Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs (%)
1	0	Water Box	9x9	7782	DOM	[[	
2	40						
3	80						
4	100						
5	0	Water Box	10x10	1110	DOM		
6	40						
7	80						
8	100						
9	0	Water Box	10x10	1111	VAN		
10	40						
11	80						
12	100						
13	0	Water Wings	10x10	33004	DOM		
14	40						
15	80						
16	100						]]

[[

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Figure 5.6-6 Difference in CDOP

Table 5.6-6 contains a list of conditions for every point in Figure 5.6-7. All cold cases are represented at a fuel and coolant temperature of 20ºC, and all hot cases are represented at a fuel temperature of 560ºC.

Table 5.6-6 Rod Worth Case Conditions for Lattices Figure 5.6-7

Case No.	Fuel Temp (°C)	Void (%)	Hot or Cold	Bundle Type	Size	Lattice No.	Lattice Type	LANCR02 Rod Worths (pcm)	Difference in Rod Worths (%)
1	560	0	Hot	Water Box	9x9	7782	DOM	[[	
2		40							
3		80							
4		100							
5		0	Hot	Water Box	10x10	1110	DOM		
6		40							
7		80							
8		100							
9		0	Hot	Water Box	10x10	1111	VAN		
10		40							
11		80							
12		100							
13		0	Hot	Water Wings	10x10	33004	DOM		
14		40							
15		80							
16		100							
1	20	0	Cold	Water Box	9x9	7782	DOM		
5		0	Cold	Water Box	10x10	1110	DOM		
9		0	Cold	Water Box	10x10	1111	VAN		
13		0	Cold	Water Wings	10x10	33004	DOM		]]

[[

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Figure 5.6-7 Difference in Rod Worth

Table 5.6-7 contains a list of conditions for every point in Figure 5.6-8. All cases are represented at a fuel and coolant temperature of 20ºC and there is a single controlled (CON) and uncontrolled (UNC) pair of points for each lattice.

Table 5.6-7 Cold Case Conditions for Figure 5.6-8

Case No.	Fuel Temp (°C)	Void (%)	UNC or CON	Bundle Type	Size	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	20	0	UNC	Water Box	9x9	7782	DOM	[[
2	20	0		Water Box	10x10	1110	DOM	
3	20	0		Water Box	10x10	1111	VAN	
4	20	0		Water Wings	10x10	33004	DOM	
1	20	0	CON	Water Box	9x9	7782	DOM	
2	20	0		Water Box	10x10	1110	DOM	
3	20	0		Water Box	10x10	1111	VAN	
4	20	0		Water Wings	10x10	33004	DOM	]]

[[

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Figure 5.6-8 Difference in Cold Eigenvalues

5.6.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.6-8. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC), cold uncontrolled (CU), and cold controlled (CC)) and also by product line (i.e., water box, water cross). The Doppler cases have been included in the HU statistics.

[[

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Table 5.6-8 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.6-9. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is very good.

Table 5.6-9 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.6-10. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.6-10 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.7. Test Suite 7 – Gadolinium Concentration

5.7.1. Purpose

Test the ability of LANCR02 to model gadolinium concentrations up to and including 12 wt%. Enriched Gd is also tested for both Gd-155 or Gd-157 enrichment. The concentration of enriched Gd has a worth equivalent to 12 wt% natural Gd.

5.7.2. Description

Comparisons of LANCR02 with MCNP as a function of gadolinium concentration are performed for the lattices in Table 5.7-1. The gadolinium concentrations shall vary from 0% to 12% for natural gadolinium in increments of 2%, and up to a worth equivalent to 12% natural Gd for enriched Gd. ([[

]]). The standard BOL, controlled and uncontrolled cases at void levels of 0, 40, 80, and 100% are evaluated at a fuel temperature of 560^{o}C. The uncontrolled cases also include evaluation at 1500 ^{o}C.

All bundles are analyzed for a C-lattice plant containing a D100 control blade.

Table 5.7-1 Gd Concentration Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM; VAN

5.7.3. Number of Cases

Number of lattices (2) x Number of Gd loadings (12) x Number of void cases (4) x States(3) = 288.

5.7.4. Results

Table 5.7-2 contains a list of all lattices analyzed for this test suite. [[

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MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.7-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM
			7101	VAN

Figure 5.7-1 to Figure 5.7-5 contain results from all analyses. There is a separate graph for each of the following parameters:

- eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates); and
- relative pin peaking factor (% difference between LANCR02 and MCNP).

In each graph, data is separated by the Gd enrichment case.

All LANCR02 results are consistent with results reported from Test Suite 1. There is no obvious bias in the LANCR02 modeling of different gadolinium concentrations, or in the modeling of gadolinium enriched in Gd-155 or Gd-157 isotopes.

Table 5.7-3 contains a list of conditions for every point in Figure 5.7-1 to Figure 5.7-5. The list pertains to both the dominant zone 7099 (DOM) and vanish zone 7101 (VAN) points in the figures. All cases were run controlled and uncontrolled at a fuel temperature of 560ºC as well as at 1500 ^{o}C for the uncontrolled cases.

Figure 5.7-2 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.7-3 Case Conditions Figures Figure 5.7-1 through Figure 5.7-5

Case No.	Doping (wt%Gd)	Void (%)	Bundle Type	Size
1	0	0	GE14	10x10
2	0	40		
3	0	80		
4	0	100		
5	2	0		
6	2	40		
7	2	80		
8	2	100		
9	4	0		
10	4	40		
11	4	80		
12	4	100		

13	6	0		
14	6	40		
15	6	80		
16	6	100		
17	8	0		
18	8	40		
19	8	80		
20	8	100		
21	10	0		
22	10	40		
23	10	80		
24	10	100		
25	12	0		
26	12	40		
27	12	80		
28	12	100		

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Figure 5.7-1 Hot Uncontrolled Eigenvalue Differences

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Figure 5.7-2 Hot Doppler Eigenvalue Differences

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Figure 5.7-3 Hot Controlled Eigenvalue Differences

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Figure 5.7-4 Hot Uncontrolled Fission Rate RMS

[[

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Figure 5.7-5 Hot Uncontrolled Difference in Pin Peaking Factor

5.7.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.7-4. The statistics have been separated by case type (Nominal, enriched Gd-155, enriched Gd-157), and by Gd enrichment.

[[ ]] The statistics show no trend in Gd concentration and are consistent with those from Test Suite 1.

Table 5.7-4 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.7-5. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.7-5 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.7-6. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.7-6 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.8. Test Suite 8 – Gadolinium Pin Placement

5.8.1. Purpose

Test the ability of LANCR02 to model gadolinium placements of lumped collections of Gd pins and Gd pins residing along the edge of the bundle and in the corner location.

5.8.2. Description

Comparisons of LANCR02 with MCNP as a function of gadolinium pin placement are performed for the lattice in Table 5.8-1. The gadolinium pin locations shall include lumped collections in the interior of the bundle, and Gd locations along the edge of the bundle and in the bundle corners. The standard BOL, uncontrolled cases at void levels of 0, 40, 80, and 100% are evaluated at a fuel temperature of 560^{o}C.

All bundles are analyzed for a C-lattice plant containing a D100 control blade.

Table 5.8-1 Gd Placement Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM; VAN

5.8.3. Number of Cases

Number of lattices (2) x Number of Gd placements (5) x Number of voids (4) = 40.

5.8.4. Results

Table 5.8-2 contains a list of all lattices analyzed for this test suite. Lattices 7099 and 7101 from Test Suite 8 were used as a baseline. Both lattices contained 12 pins of 8 wt% Gd_2O_3 evenly distributed throughout the bundle. These pins were then rearranged to form the bundle variations for the Test Suite 9 parametric study. The various Gd pin locations are illustrated in Figure 5.8-1 for the DOM zone, and Figure 5.8-2 for the VAN zone. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.8-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM
			7101	VAN

[[

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Figure 5.8-1 Location of Gd Pins in DOM Zone

[[

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Figure 5.8-2 Location of Gd Pins in VAN Zone

Figure 5.8-4 through Figure 5.8-7 contain results from all analyses. There is a separate graph for each of the following parameters:

- eigenvalue (pcm difference between LANCR02 and MCNP);
- fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates); and
- relative pin peaking factor (% difference between LANCR02 and MCNP).

In each graph, the data is separated by type of Gd pin placement.

Table 5.8-3 contains a list of conditions for every point in Figure 5.8-4 through Figure 5.8-6. The list pertains to both the dominant zone 7099 (DOM) and vanish zone 7101 (VAN) points in the figures. All cases were run uncontrolled at a fuel temperature of 560ºC.

Figure 5.8-5 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.8-3 Case Conditions Figures Figure 5.8-4 through Figure 5.8-6

Case No.	Gd Pin Placement	Void (%)	Lattice Number	Lattice Type	Difference in Eigenvalues (pcm)
1	Nominal	0	7099	DOM	[[
2	Nominal	40			
3	Nominal	80			
4	Nominal	100			
5	Corner	0			
6	Corner	40			
7	Corner	80			
8	Corner	100			
9	Edge	0			
10	Edge	40			
11	Edge	80			
12	Edge	100			
13	Lumped	0			
14	Lumped	40			
15	Lumped	80			
16	Lumped	100			
17	Lumped Corner	0			
18	Lumped Corner	40			
19	Lumped Corner	80			
20	Lumped Corner	100			
1	Nominal	0	7101	VAN	
2	Nominal	40			
3	Nominal	80			
4	Nominal	100			
5	Corner	0			
6	Corner	40			
7	Corner	80			
8	Corner	100			
9	Edge	0			
10	Edge	40			
11	Edge	80			
12	Edge	100			
13	Lumped	0			
14	Lumped	40			
15	Lumped	80			
16	Lumped	100			
17	Lumped Corner	0			
18	Lumped Corner	40			
19	Lumped Corner	80			
20	Lumped Corner	100			]]

[[

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Figure 5.8-3 LANCR02P Eigenvalues (Eigenvalues decrease with void)

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Figure 5.8-4 Eigenvalue Differences

[[

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Figure 5.8-5 Fission Rate RMS

[[

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Figure 5.8-6 Difference in Pin Peaking Factor

Table 5.8-4 contains a list of conditions for every point in Figure 5.8-7. All cases were run uncontrolled at a fuel temperature of 560ºC.

Table 5.8-4 Void Case Conditions for Figure 5.8-7

Case No.	Gad Pin Placement	Void (%)	Bundle Type	Size	Lattice No.	Lattice Type	Difference in Eigenvalues (pcm)
1	Nominal	0	GE14	10x10	7099	DOM	[[
		40					
		80					
		100					
2	Corner	0					
		40					
		80					
		100					
3	Edge	0					
		40					
		80					
		100					
4	Lumped	0					
		40					
		80					
		100					
5	Lumped Corner	0					
		40					
		80					
		100					
6	Nominal	0	GE14	10x10	7101	VAN	
		40					
		80					
		100					
7	Corner	0					
		40					
		80					
		100					
8	Edge	0					
		40					
		80					
		100					
9	Lumped	0					
		40					
		80					
		100					
10	Lumped Corner	0					
		40					
		80					
		100					]]

[[

]]

Figure 5.8-7 Difference in Eigenvalues by Void

5.8.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.8-5. The statistics have been separated by case type (Nominal, corner, edge, lumped, lumped corner), and by lattice type (DOM and VAN).

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Table 5.8-5 Eigenvalue Statistics

Case	No.	Ave (pcm)	St Dev (pcm)	Min (pcm)	Max (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.8-6. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.8-6 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.8-7. Only hot cases are considered in the table. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.8-7 Peak Pin Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.9. Test Suite 9 – Enrichment

5.9.1. Purpose

Test the ability of LANCR02 to model U-235 enrichments up to and including 10 wt%.

5.9.2. Description

Comparisons of LANCR02 with MCNP as a function of U-235 enrichment are performed for the lattices in Table 5.9-1. The enrichment varies from 2% to 10% in increments of 2%. The standard BOL, uncontrolled cases at void levels of 0, 40, 80, and 100% are evaluated at a fuel temperature of 560°C.

The lattice analyzed is for a C-lattice plant containing a D100 control blade.

Table 5.9-1 Enrichment Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM

5.9.3. Number of Cases

Number of lattices (1) x Number of enrichments (5) x Number of cases (4) = 20.

5.9.4. Results

Table 5.9-2 contains a list of all lattices analyzed for this test suite. All lattices were of a uniform enrichment for all cases and contained no Gd pins. Enrichment per case was changed in increments of 2 wt% U-235. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.9-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

Figure 5.9-2 through Figure 5.9-3 contain results from all analyses. There is a separate graph for each of the following parameters:

- eigenvalue (pcm difference between LANCR02 and MCNP); and
- fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates).

In each graph, data is separated by the enrichment case. All LANCR02 results are consistent with results reported from Test Suite 1. [[
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Table 5.9-3 contains a list of conditions for every point in Figure 5.9-2 through Figure 5.9-3. All cases were run uncontrolled at a fuel temperature of 560ºC.

Figure 5.9-3 is a summary of fission rate RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.9-3 Enrichment Case Conditions for Figure 5.9-2 through Figure 5.9-3

Case No.	Enrichment (wt%U-235)	Void (%)	Bundle Type	Size	Lattice No.	Lattice Type
1	2	0	GE14	10x10	7099	DOM
2		40				
3		80				
4		100				
5	4	0				
6		40				
7		80				
8		100				
9	6	0				
10		40				
11		80				
12		100				
13	8	0				
14		40				
15		80				
16		100				
17	10	0				
18		40				
19		80				
20		100				

[[

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Figure 5.9-1 LANCR02 Eigenvalues (eigenvalues increase with enrichment)

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Figure 5.9-2 Difference in Eigenvalues

[[

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Figure 5.9-3 Fission Rate RMS

5.9.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.9-4. Separate statistics are included for each enrichment group.

[[

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Table 5.9-4 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.9-5. Overall agreement between LANCR02 and MCNP is very good over all enrichments.

Table 5.9-5 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.9-6. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.9-6 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.10. Test Suite 10 – Borated Lattices

5.10.1. Purpose

Test the ability of LANCR02 to adequately model borated lattice designs over the design range of boron concentration (ppm) and moderator temperature.

5.10.2. Description

Comparisons of LANCR02 with MCNP are performed for the lattices in Table 5.10-1 to validate the adequacy of modeling borated lattices. Test cases include 0, 1000, and 2000 ppm at coolant/fuel temperatures of 20°C, 100°C, and 286°C (HSB).

All bundles are analyzed for a C-lattice plant containing a D100 control blade.

Table 5.10-1 Borated Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM; VAN

5.10.3. Number of Cases

Number of lattices (2) x Number of boron levels (3) x Number of temps (3) = 18.

5.10.4. Results

Table 5.10-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.10-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM
			7101	VAN

Figure 5.10-1 contains results from all analyses. The graph contains the difference in eigenvalue between LANCR02 and MCNP expressed in pcm. Data is separated by coolant temperature. For each temperature, the first data point is the 0 ppm case; the second data point is the 1000 ppm case; and the third data point is the 2000 ppm case.

Fission rate results were not analyzed for this test suite.

Table 5.10-3 contains a list of conditions for every point in Figure 5.10-1. All cases were run uncontrolled.

Table 5.10-3 Case Conditions for Borated Test Cases Figure 5.10-1

Case No.	Coolant Temp (ºC)	Bundle Type	Size	Lattice No.	Lattice Type
1	20	GE14	10x10	7099	DOM
2	100				
3	286				
4	20	GE14	10x10	7101	VAN
5	100				
6	286				

[[

]]

Figure 5.10-1 Difference in Cold Eigenvalues

5.10.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.10-4. The statistics have been separated into groups by case type (0, 1000, 2000 pcm), and by lattice type.

[[

]]

Table 5.10-4 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

5.11. Test Suite 11 – Alternative Control Blade Designs

5.11.1. Purpose

Test the ability of LANCR02 to adequately model various control blade designs.

5.11.2. Description

Comparisons of LANCR02 with MCNP are performed for the lattices in Table 5.11-1. The standard BOL controlled cases at void levels of 0, 40, 80, and 100% are evaluated at a fuel temperature of 560°C. Control blade designs to be tested are those included in Table 5.11-2 and illustrated in Figure 5.11-1.

All bundles are analyzed for a C-lattice, except for the cases for blade type D230, which corresponds to a D-lattice type. Original Equipment Manufacturer (OEM) control blade types are conventional B4C control blades comprised of multiple vertical absorber rods contained within a stainless steel sheath. An example of this type of blade is the standard Duralife D100 model. Asea Brown Boveri (ABB) control blade types consist of a solid bar of stainless steel containing horizontal holes filled with B4C.

Table 5.11-1 Test Cases to be Analyzed

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM

Table 5.11-2 Alternative Control Blade Test Cases

Lattice Type	Blade to be Tested
[[	
	]]
[[ ]]	Horizontal B4C holes drilled in a solid bar of SS304 (ABB)
[[	
	]]

[[

]]

Figure 5.11-1 Various Control Blade Designs Analyzed

5.11.3. Number of Cases

Number of lattices (1) x Number of control blade designs (9) x Number of cases (4) = 36.

5.11.4. Results

Table 5.11-3 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.11-3 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

Figure 5.11-2 through Figure 5.11-4 contain results from all analyses. There is a separate graph for each of the following parameters: hot eigenvalue (pcm difference between LANCR02 and MCNP); fission rate RMS (% RMS difference between LANCR02 and

MCNP pin-wise fission rates); and relative pin peaking factor (% difference between LANCR02 and MCNP).

Table 5.11-4 contains a list of conditions for every point in Figure 5.11-2 through Figure 5.11-4. All cases were run at a fuel temperature of 560ºC.

Table 5.11-4 Case Conditions for Alternate Control Blades

Case No.	Void (%)	Blade Type
1	0	[[ ]]
2	40	
3	80	
4	100	
5	0	Horizontal B4C holes drilled in a solid bar of SS304 (ABB)
6	40	
7	80	
8	100	
9	0	[[
10	40	
11	80	
12	100	
13	0	
14	40	
15	80	
16	100	
17	0	
18	40	
19	80	
20	100	
21	0	
22	40	
23	80	
24	100	
25	0	
26	40	
27	80	
28	100	
29	0	
30	40	
31	80	
32	100	
33	0	
34	40	]]
35	80	
36	100	

[[

]]

Figure 5.11-2 Eigenvalue Differences

[[

]]

Figure 5.11-3 Fission Rate RMS

[[

]]

Figure 5.11-4 Difference in Pin Peaking Factor

5.11.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.11-5. The statistics have been separated into groups by control blade type.

[[

]]

Table 5.11-5 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.11-6. Overall agreement between LANCR02 and MCNP is very good for all blades.

Table 5.11-6 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.11-7. Overall agreement is consistent with the controlled cases from Test Suite 1.

Table 5.11-7 Pin Peaking Factors Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.12. Test Suite 12 – Alternate Doppler Analysis

5.12.1. Purpose

Test the ability of LANCR02 to adequately model changes in fuel temperature from off nominal conditions, such as hot standby and cold.

5.12.2. Description

Comparisons of LANCR02 with MCNP are performed for the lattices in Table 5.12-1. Doppler branches are performed from the base temperature to 1500°C and 2300°C. Base temperatures are 560°C (hot), 286°C (hot standby), and 20°C (cold). All cases are tested at BOL, uncontrolled, 0% void conditions.

The lattice analyzed is for a C-lattice plant containing a D100 control blade.

Table 5.12-1 Alternate Doppler Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM

5.12.3. Number of Cases

Number of lattices (1) x Number of coolant temps (2) x Number of fuel temps (3) = 6 CDOPs. This corresponds to 7 cases.

5.12.4. Results

Table 5.12-2 contains a list of all lattices analyzed for this test suite. The base temperature cases for 20°C and 560°C were obtained from Test Suite 1. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.12-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

Table 5.12-3 contains the eigenvalues for each case used to calculate the CDOPs.

Table 5.12-3 Eigenvalue Results for Alternate Doppler Calculation

Case No.	Coolant Temp (ºC)	Fuel Temp (ºC)	MCNP Eigenvalue	LANCR02P Eigenvalue	Eigenvalue Difference (pcm)
1	20	20	[[		
2	20	1500			
3	20	2300			
4	286	286			
5	286	560			
6	286	1500			
7	286	2300			]]

Figure 5.12-1 contains the CDOP results. The graph contains the difference in CDOPs expressed in percent of the MCNP value. Data is separated by coolant temperature. For each temperature, the first data point is the branch to a fuel temperature of the 1500^{o}C case, and the second data point is the branch to a fuel temperature of the 2300^{o}C case. All LANCR02 results are in excellent agreement with the MCNP results. Table 5.12-4 contains a list of conditions for every point in this figure. All cases were run uncontrolled.

Table 5.12-4 Case Conditions for Alternate Doppler

Case No.	Coolant Temp (ºC)	Initial Fuel Temp (ºC)	Final Fuel Temp (ºC)	LANCR02P Doppler Coeffs (pcm/√K)	Difference in Doppler Coeffs(%)
1	20	20	1500	[[	
2	20	20	2300		
3	20	286	1500		
4	286	286	2300		
5	286	560	1500		
6	286	560	2300		]]

[[

]]

Figure 5.12-1 CDOP Differences

5.12.5. Statistics

The CDOP statistics are included in Table 5.12-5. [[

]]

Table 5.12-5 CDOP Statistics

Case	No.	Ave Diff (%)	St Dev Diff (%)	Min Diff (%)	Max Diff (%)
[[					]]

5.13. Test Suite 13 – Off-Nominal Voiding

5.13.1. Purpose

Test the ability of LANCR02 to adequately model voiding in the bypass and water rods, and changes in the in-channel moderator density at cold conditions (for rod drop accident analysis support).

5.13.2. Description

Comparisons of LANCR02 with MCNP are performed for the lattices in Table 5.13-1. [[

]]

The lattice analyzed is for a C-lattice plant containing a D100 control blade.

Table 5.13-1 Off-Nominal Voiding Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM

5.13.3. Number of Cases

Number of lattices (1) x [Number of in-channel voids (2) x Number of bypass/water rod voids (2) + Number of cold temps (1) x Number of sub-cooled void temps (2)] = 6.

5.13.4. Results

Table 5.13-2 contains the lattice analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.13-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

Figure 5.13-1 through Figure 5.13-3 contain results from all analyses. There is a separate graph for each of the following parameters: eigenvalue (pcm difference between LANCR02 and MCNP); fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates); and relative pin peaking factor (% difference between LANCR02 and MCNP). Data is separated by coolant temperature in the bypass region.

Table 5.13-3 contains a description of the cases in each figure.

Table 5.13-3 Case Conditions Figure 5.13-1 through Figure 5.13-3

Case No.	Bypass Temp (°C)	Bypass Void (%)	Water Rod Temp (°C)	Water Rod Void (%)	In-Channel Temp (°C)	In-Channel Void (%)	Eigenvalue Difference (pcm)
1	20	0	20	0	100	0	[[
2	20	0	20	0	286	0	
3	286	5	286	10	286	100	
4	286	20	286	40	286	100	
5	286	5	286	10	286	80	
6	286	20	286	40	286	80	]]

[[

]]

Figure 5.13-1 Difference in Reactivity

[[

]]

Figure 5.13-2 Fission Rate RMS

[[

]]

Figure 5.13-3 Difference in Pin Peaking Factor

5.13.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.13-4.

[[

]]

Table 5.13-4 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					

A summary of the statistics related to all fission rate distributions is presented in Table 5.13-5. Overall agreement between LANCR02 and MCNP is very good over all cases.

Table 5.13-5 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.13-6. Overall agreement between LANCR02 and MCNP is excellent.

Table 5.13-6 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.14. Test Suite 14 – Channel Bowing

5.14.1. Purpose

Test the ability of LANCR02 to adequately model the effects of channel bow.

5.14.2. Description

Comparisons of LANCR02 with MCNP are performed for the lattice in Table 5.14-1. Cases are analyzed that produce asymmetric water gaps around the bundle. The standard BOL, uncontrolled and controlled cases at void levels of 0, 40, 80, and 100% are evaluated at a fuel temperature of 560°C.

The lattice analyzed is for a C-lattice plant containing a D100 control blade.

Table 5.14-1 Channel Bow Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM

5.14.3. Number of Cases

Number of lattices (1) x Number of channel bows (1) x Number of cases (8) = 8.

5.14.4. Results

The bundle was bowed 2 mm towards the west side water gap as shown in Figure 5.14-1. Note that this problem exhibits no diagonal symmetry and the LANCR02 case was calculated in full-symmetry. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

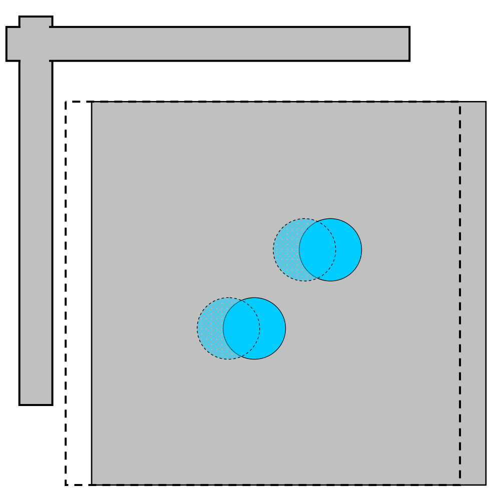

Figure 5.14-1 Bowing Description

Table 5.14-2 contains the lattice analyzed for this test suite.

Table 5.14-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

Figure 5.14-2 through Figure 5.14-4 contain results from all analyses. There is a separate graph for each of the following parameters: eigenvalue (pcm difference between LANCR02 and MCNP); fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates); and relative pin peaking factor (% difference between LANCR02 and MCNP). Data is separated by control blade placement (uncontrolled vs. controlled).

Table 5.14-3 contains a list of conditions for every point in Figure 5.14-2 through Figure 5.14-4. All cases were run uncontrolled. The "unbowed" results are copied directly from Test Suite 1, and are included to determine if there is any trend with bow.

Table 5.14-3 Case Conditions Figure 5.14-2 to Figure 5.14-4

Case No.	Void (%)	Bow (mm)	Direction	Bundle Type	Size	Lattice No.	Lattice Type
1	0	0	--	GE14	10x10	7099	DOM
2	40	0	--				
3	80	0	--				
4	100	0	--				
5	0	2	West				
6	40	2	West				
7	80	2	West				
8	100	2	West				

[[

]]

Figure 5.14-2 Reactivity Difference

[[

]]

Figure 5.14-3 Fission Rate RMS

[[

]]

Figure 5.14-4 Difference in Pin Peaking Factor

5.14.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.14-4. Separate statistics are included for cold and uncontrolled cases.

The overall average difference in the LANCR02 and MCNP eigenvalues, for the [[

]].

Table 5.14-4 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.14-5. Overall agreement between LANCR02 and MCNP is very good over all cases.

Table 5.14-5 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.14-6. Overall agreement between LANCR02 and MCNP is very good and consistent with Test Suite 1.

Table 5.14-6 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.15. Test Suite 15 – Fuel Rod Variations

5.15.1. Purpose

Test the ability of LANCR02 to adequately model the effects of different fuel rod variations.

5.15.2. Description

Comparisons of LANCR02 with MCNP are performed to validate the adequacy of modeling the fuel rod variations identified in Table 5.15-1. These tests are performed at BOL conditions only. Ten (10) cases at BOL are analyzed per lattice. The ten cases are: hot (560°C) uncontrolled at 0, 40, 80, and 100% voids; hot (560°C) controlled at 0, 40, 80, and 100% voids; cold xenon-free uncontrolled at 20°C; and cold xenon-free controlled at 20°C.

The lattice analyzed is for a C-lattice plant containing a D100 control blade.

Table 5.15-1 Secondary Variable Test Cases

Secondary Variable	Type
[[	DOM
	DOM
]]	DOM

5.15.3. Number of Cases

Number of lattices (1) x Number of variables (3) x Number of cases (10) = 30.

5.15.4. Results

Table 5.15-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.15-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

For this test suite, [[

]] This is illustrated in Figure 5.15-1.

[[

]]

Figure 5.15-1 Different Lattice Designs of Varying Rod Sizes

[[

]]

Figure 5.15-2 and Figure 5.15-3 contain results from all analyses. There is a separate graph for each of the following parameters: eigenvalue (pcm difference between LANCR02 and MCNP); fission rate RMS (% RMS difference between LANCR02 and MCNP pin-wise fission rates); and relative pin peaking factor (% difference between LANCR02 and MCNP). In the figures, data is separated by control blade position (uncontrolled vs. controlled).

Table 5.15-3 contains a list of conditions for every point in Figure 5.15-2 and Figure 5.15-3. The list pertains to lattices analyzed for the test suite, plus the baseline lattice. The first two cases in the figures represent results from the two cold cases (controlled and uncontrolled, respectively); cases 3 through 6 represent results from the hot controlled cases at the four different void levels (0%, 100%, 40%, and 80%, respectively); and cases 7 through 10 represent results from the hot uncontrolled cases at the four different void levels (0%, 100%, 40%, and 80%, respectively). In the figures, the baseline results have been taken from Test Suite 1.

Table 5.15-3 Case Conditions for Figure 5.15-2 and Figure 5.15-3

Case No.	Fuel Temp (ºC)	Void (%)	Rod Change	Bundle Type	Size	Lattice No.	Lattice Type
1	20	0	In	GE14	10x10	7099	DOM
2	20	0	Out				
3	560	0	In				
4	560	40	In				
5	560	80	In				
6	560	100	In				
7	560	0	Out				
8	560	40	Out				
9	560	80	Out				
10	560	100	Out				

[[

]]

Figure 5.15-2 Hot Eigenvalue Differences

[[

]]

Figure 5.15-3 Fission Rate RMS

5.15.5. Statistics

A summary of the statistics related to all eigenvalues is presented in Table 5.15-4. Separate statistics are included for baseline, [[ ]].

[[ ]]

[[ ]]

Table 5.15-4 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

A summary of the statistics related to all fission rate distributions is presented in Table 5.15-5. Overall agreement between LANCR02 and MCNP is very good for all cases.

Table 5.15-5 Fission Rate RMS Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

A summary of the statistics related to all pin peaking factors is presented in Table 5.15-6. Overall agreement between LANCR02 and MCNP is very good and consistent with Test Suite 1.

Table 5.15-6 Pin Peaking Factor Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

5.16. Test Suite 16 – Neutron Balance

5.16.1. Purpose

Test the ability of LANCR02 to calculate three-group neutron balances.

5.16.2. Description

Comparisons of LANCR02 and MCNP three-group neutron balances are performed for the lattice in Table 5.17-1 for four different void cases. The analysis only includes the DOM zone at BOL. The four cases are: hot (560°C) uncontrolled at 0, 40, 80, and 100% voids.

The lattice analyzed is for a C-lattice plant containing a D100 control blade. This lattice is part of Test Suite 1.

Table 5.16-1 Neutron Balance Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM

5.16.3. Number of Cases

Number of lattices (1) x Number of cases (4) = 4.

5.16.4. Results

Table 5.17-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 10 million neutron particle histories per calculation, with the first 2 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of less than 30 pcm.

Table 5.16-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

Table 5.16-3 through Table 5.16-6 contain results from all analyses. There is a separate table for each void condition. The neutron balance is normalized so that the total absorption is equal to 1.0 and the total production is equal to the eigenvalue.

Results are not shown for the minor isotopes U-234, Gd-154, Gd-156, Gd-158, Gd-160 and O (in the fuel). These minor isotopes do not contribute significantly to the neutron balance.

Table 5.16-3 Three-Group Neutron Balance for 0% Void Case

Nuclide	Value	Absorption				Production			
		1	2	3	Total	1	2	3	Total
U-235	[[								
U-238									
Gd-155									
Gd-157									
H_2O									
Zr									
Total									]]

Table 5.16-4 Three-Group Neutron Balance for 40% Void Case

Nuclide	Value	Absorption				Production			
		1	2	3	Total	1	2	3	Total
U-235	[[								
U-238									
Gd-155									
Gd-157									
H2O									
Zr									
Total									]]

Table 5.16-5 Three-Group Neutron Balance for 80% Void Case

Nuclide	Value	Absorption				Production			
		1	2	3	Total	1	2	3	Total
U-235	[[								
U-238									
Gd-155									
Gd-157									
H2O									
Zr									
Total									]]

Table 5.16-6 Three-Group Neutron Balance for 100% Void Case

Nuclide	Value	Absorption				Production			
		1	2	3	Total	1	2	3	Total
U-235	[[								
U-238									
Gd-155									
Gd-157									
H2O									
Zr									
Total									]]

5.17. Test Suite 17 – Gamma Transport Solution

5.17.1. Purpose

Test the performance of LANCR02 gamma transport model versus MCNP.

5.17.2. Description

The lattices in Table 5.17-1 are analyzed with LANCR02 and MCNP to validate the gamma energy deposition calculations in LANCR02. The MCNP cases were run in coupled neutron/photon mode in order to get the gamma deposition.

The analysis only includes DOM and VAN zones. Eight (8) cases at beginning of life (BOL) are analyzed per lattice. The eight cases are: hot (560^{o}C) uncontrolled at 0, 40, 80, and 100% voids; hot (560^{o}C) controlled at 0, 40, 80, and 100% voids. Comparisons of the gamma deposition energy in the different materials of the lattice are given. Results are also given for the RMS difference in the energy gamma deposition in the fuel pins.

All bundles are analyzed for a C-lattice plant containing a D100 control blade.

Table 5.17-1 Gamma Transport Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM; VAN

5.17.3. Number of Cases

Number of lattices (2) x Number of cases (8) = 16.

5.17.4. Results

Table 5.17-2 contains a list of all lattices analyzed for this test suite. MCNP was used to model 5 million neutron particle histories per calculation, with the first 1 million histories of each calculation being omitted from the statistics. MCNP had a reported 1σ uncertainty associated with each eigenvalue of no greater than 50 pcm.

Table 5.17-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM
			7101	VAN

Figure 5.17-1 through Figure 5.17-5 contain results from all analyses. There is a separate graph for each of the following parameters:

- Gamma energy deposition in different lattice regions from LANCR02 (uncontrolled and controlled)
- Difference in gamma energy deposition between LANCR02 and MCNP (uncontrolled and controlled)

- Gamma energy deposition RMS in fuel pins (%RMS difference between LANCR02 and MCNP pin-wise energy deposition);

In each graph, data is separated into lattice type – results to the left of the vertical line are from the DOM zone lattice; results to the right of the vertical line are from the VAN zone lattice.

Table 5.17-3 contains a list of conditions for every point in Figure 5.17-1 through Figure 5.17-5. The list pertains to both the uncontrolled (HOTUNC) and controlled (HOTCON) points in the figures. Figure 5.17-5 shows gamma energy deposition RMS from each LANCR02 solution compared against each MCNP solution.

Table 5.17-3 Case Conditions for Figure 5.17-1 through Figure 5.17-5

Case No.	Fuel Temp (ºC)	Void (%)	UNC or CON	Bundle Type	Lattice No.	Lattice Type	LANCR02 Total Gamma Energy Dep (MeV)	Difference in Total Gamma Energy Dep (MeV)
1	560	0	UNC	GE14	2882	DOM	[[	
2	560	100						
3	560	40						
4	560	80						
5	560	0				VAN		
6	560	100						
7	560	40						
8	560	80						
1	560	0	CON			DOM		
2	560	100						
3	560	40						
4	560	80						
5	560	0				VAN		
6	560	100						
7	560	40						
8	560	80						]]

[[

]]

Figure 5.17-1 LANCR02 Uncontrolled Gamma Energy Deposition

[[

]]

Figure 5.17-2 Difference in Uncontrolled Gamma Energy Deposition

[[

]]

Figure 5.17-3 LANCR02 Controlled Gamma Energy Deposition

[[

]]

Figure 5.17-4 Difference in Controlled Gamma Energy Deposition

[[

]]

Figure 5.17-5 Gamma Energy Deposition RMS in Fuel Pins

5.17.5. Statistics

A summary of the statistics related to all gamma energy depositions are presented in Table 5.17-4. The statistics have been separated by case type (i.e., hot uncontrolled (HU), hot controlled (HC)) and also by material type (e.g., fuel, clad, channel, coolant and moderator (C&M) control blade (CBLADE)).

The overall average difference in the LANCR02 and MCNP total gamma energy deposition, for all 16 cases analyzed, is [[ ]], with a standard deviation of [[ ]].

Table 5.17-4 Gamma Energy Deposition Statistics

Case	No.	AVE (MeV)	STDEV (MeV)	MIN (MeV)	MAX (MeV)
[[					

Case	No.	AVE (MeV)	STDEV (MeV)	MIN (MeV)	MAX (MeV)
					]]

A summary of the statistics related to all gamma energy deposition distributions in the fuel pins is presented in Table 5.17-5. Overall agreement between LANCR02P and MCNP5 is excellent.

Table 5.17-5 Gamma Energy Deposition in Fuel Pins Distribution Statistics

Case	No.	AVE (%)	STDEV (%)	MIN (%)	MAX (%)
[[					
					]]

6. Depletion Test Cases

This section describes the test cases used to validate the depletion modules in LANCR02. To validate the results, the results from LANCR02 depletions are compared against results from MONTEBURNS. MONTEBURNS [Ref. 5] is an independent code that links stationary MCNP calculations with an ORIGEN depletion calculation.

In the LANCR02 depletion test cases, the infinite flux spectrum was used in the burnup calculation. This is the NLOP=1 option (no leakage correction). This option was used to be consistent with the MONTEBURN calculations.

6.1. Depletion Test Suite

6.1.1. Purpose

Test the performance of the depletion modules in LANCR02.

6.1.2. Description

This test suite tests the depletion modules in LANCR02P by comparing results with the alternate depletion methods in MONTEBURNS. LANCR02 and MONTEBURNS depletions are performed for the single lattice listed in Table 6.1-1 at three different historical voids (0, 40, and 80% void). The case is depleted uncontrolled at a fuel temperature of 560^{o}C.

The lattice analyzed is for a C-lattice plant containing a D100 control blade.

Table 6.1-1 Lattice Depletion Test Cases

Bundle Type	Size	Lattices to be Analyzed
GE14	10x10	DOM

6.1.3. Number of Cases

Number of lattices (1) x Number of void histories (3) x Number of exposure points per depletion (42) = 126.

6.1.4. Results

Table 6.1-2 contains the information related to the lattice analyzed for this test suite. MONTEBURNS uses the MCNPX Monte Carlo solver. [Ref. 6]. MCNPX was used to model 4.5 million neutron particle histories per calculation, with the first 500,000 histories of each calculation being omitted from the statistics. MCNPX had a reported 1σ uncertainty associated with each eigenvalue of no greater than 50 pcm.

Table 6.1-2 Lattices Analyzed

Bundle Type	Size	Bundle No.	Lattice No.	Lattice Type
GE14	10x10	2882	7099	DOM

A schematic of gadolinium pin placements in the lattice is contained in Figure 6.1-1. In the figure, the 8 wt% Gd_2O_3 pins are represented by a burgundy square, while the 7 wt% Gd_2O_3 pins are represented by an orange square.

[[

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Figure 6.1-1 Location of Gd Pins in Lattice 7099

Results from LANCR02 are compared against those from MONTEBURNS in Figure 6.1-2 to Figure 6.1-4. The depletion was carried out to a lattice-averaged burnup of approximately 54 GWd/ST.

The MONTEBURN calculations are very time-consuming to run. Each depletion takes approximately 210 to 350 cpu-days to run. The cases with larger void fractions take longer to run because each particle typically has more interactions before it is absorbed.

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Figure 6.1-2 Lattice Depletion at 0% Void

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Figure 6.1-3 Lattice Depletion at 40% Void

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Figure 6.1-4 Lattice Depletion at 80% Void

6.1.5. Statistics

Table 6.1-3 summarizes differences between eigenvalues from LANCR02 and MONTEBURNS. [[ ]] This represents excellent agreement between the two codes, attributed primarily to the large number of particle histories modeled in MCNP, which are needed to accurately deplete the gadolinium isotopes.

Table 6.1-3 Eigenvalue Statistics

Case	No.	AVE (pcm)	STDEV (pcm)	MIN (pcm)	MAX (pcm)
[[					
					]]

6.2. Discussion

The results of this section show that the LANCR02 depletion results give excellent results when compared to MONTEBURNS. No trend is observed with exposure. This section validates the LANCR02 depletion methods.

7. Conclusion

This report describes the methods and results used to validate LANCR02. The LANCR02 results are validated in three ways.

The first set of validation cases are critical experiments run with MCNP using the ENDF/B-VII.0 data library. The purpose of these cases is to validate the basic cross section library used in LANCR02. The results for these critical experiments show that ENDF/B-VII.0 data library gives excellent results when modeling critical experiments and is applicable to BWR analysis.

The second set of validation cases models over 1000 single BWR lattices with LANCR02 and compares the results to MCNP. This set of cases validates the cross section library and transport solution (neutron and gamma) used in LANCR02 over a broad range of geometric and compositional variables. The results show excellent agreement.

The third set of validation cases depletes a BWR lattice with LANCR02 and compare the results with the independent code MONTEBURNS. The purpose of this test is to validate the depletion models in LANCR02. Again, excellent agreement was observed with the standard deviation between LANCR02 and MONTEBURNS less than [[ ]].

The results show that LANCR02 is a high fidelity predictive tool for BWR lattice analysis applications.

8. References

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[Ref. 8] S. Sitaraman, "MCNP: Light Water Reactor Critical Benchmarks," General Electric, NEDO-32028 (March 1992).

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Appendix: Summary of lattice compositions

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction
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Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction

Test suite	GNF Plant Type	ID	Type	Size	Cell Type	UO2 Fuel Rods	U-235 Enrichment	Gd Weight Fraction	Pu Weight Fraction
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