THERMAL-HYDRAULIC ANALYSIS OF SEED-BLANKET UNIT

DUPLEX FUEL ASSEMBLIES WITH VIPRE-01

A Thesis

by

PATRICK BRIAN MCDERMOTT

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Approved by:

Co-Chairs of Committee,	Karen Vierow
	Jean Ragusa
Committee Member,	Miladin Radovic
Head of Department,	Yassin Hassan

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ABSTRACT

One of the greatest challenges facing the nuclear power industry is the final disposition of nuclear waste. To meet the needs of the nuclear power industry, a new fuel assembly design, called DUPLEX, has been developed which provides higher fuel burnups, burns transuranic waste while reducing minor actinides, reduces the long term radiotoxicity of spent nuclear fuel, and was developed for use in current light water reactors. The DUPLEX design considered in this thesis is based on a seed and blanket unit (SBU) configuration, where the seed region contains standard UO_2 fuel, and the blanket region contains an inert matrix $(Pu,Np,Am)O_2$-MgO-ZrO_2 fuel.

The research efforts of this thesis are first to consider the higher burnup effects on DUPLEX assembly thermal-hydraulic performance and thermal safety margin over the assembly's expected operational lifetime. In order to accomplish this, an existing burnup-dependent thermal-hydraulic methodology for conventional homogeneous fuel assemblies has been updated to meet the modeling needs specific to SBU-type assemblies. The developed framework dramatically expands the capabilities of the latest thermal-hydraulic evaluation framework such that the most promising and unique DUPLEX fuel design can be evaluated. As part of this updated methodology, the posed DUPLEX design is evaluated with respect to the minimum departure from nucleate boiling ratio, peak fuel temperatures for both regions, and the peak cladding temperatures, under ANS Condition I, II, and III transient events with the thermal-hydraulic code VIPRE-01.

Due to difficulty in the fabrication and handling of minor actinide dioxides, documented thermal conductivity values for the considered IMF design are unavailable. In order to develop a representative thermal conductivity model for use in VIPRE-01, an extensive literature survey on the thermal conductivity of $(Pu,Np,Am)O_2$-MgO-ZrO_2 component materials and a comprehensive review of combinatory models was performed.

Using the updated methodology, VIPRE-01 is used to perform steady-state and transient thermal hydraulic analyses for the DUPLEX fuel assembly. During loss-of-flow accident scenarios, the DUPLEX design is shown to meet imposed safety criteria. However, using the most conservative thermal conductivity modeling approach for $(Pu,Np,Am)O_2$-MgO-ZrO_2, the blanket region fuel temperatures remain only slightly below the design limit.

DEDICATION

TO MY PARENTS, DAN & BECKY McDERMOTT

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NOMENCLATURE

ABBREVIATIONS

ADS	accelerator driven systems
AEC	Atomic Energy Commission
AFA	advanced fuel assembly
AFCI	Advanced Fuel Cycle Initiative
AFTRA	Advanced Fuels for TRAnsmutation system
ALWR	Advance Light Water Reactor
Am	americium
AMOX	advanced mixed-oxide
ANS	American Nuclear Society
AOO	Anticipated Operational Occurrence
BOL	beginning-of-life
BWR	boiling water reactor
CERCER	CERamic matrix-CERamic host phase
CERMET	CERamic matrix-METal host phase
CFR	Code of Federal Regulations
CHF	critical heat flux
CLOFA	complete loss-of-flow accident
Cm	curium
CONFU	Combined NonFertile and Uranium
CPNPP	Comanche Peak Nuclear Power Plant

CPR	critical power ratio
DBC	design basis condition
DEC	design extension condition
DNB	departure from nucleate boiling
DNBR	departure from nucleate boiling ratio
EFIT	European Facility for Industrial Transmutation
EMT	Effective Medium Theory
EOL	end-of-life
EURO-TRANS	EUROpean research program for the TRANSmutation of high level nuclear waste in ADS
EPRI	Electric Power Research Institute
FSAR	final safety analysis report
HM	heavy metal
HS	Hashin-Shtrikman
HEM	homogeneous equilibrium model
IMF	inert matrix fuel
INL	Idaho National Laboratory
LHGR	linear heat generation rate
LOFA	loss-of-flow accident
LWR	light water reactor
MA	minor actinides
ME	Maxwell-Eucken

MDNBR	minimum departure from nucleate boiling ratio
MNFI	modified Nuclear Fuels Industries
Mo	molybdenum
MOX	mixed-oxide
M-R	multi-recycling
NFI	Nuclear Fuels Industries
Np	neptunium
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NRML	normalized mass loss rate
PCT	peak cladding temperature
PFT	peak fuel temperature
PLOFA	partial loss-of-flow accident
Pu	plutonium
PWR	pressurized water reactor
R&D	research and development
RCS	reactor coolant system
RCP	reactor coolant pump
RTF	Radkowsky Thorium Fuel
SAR	safety analysis report
SBU	Seed-Blanket Unit
SOP	standard operating procedure

SNF	spent nuclear fuel
TD	theoretical density
TRU	transuranic elements
TRUOX	transuranic oxide fuel
UOX	uranium oxide fuel
WASB	Whole Assembly Seed and Blanket
XRD	X-ray diffraction
Zr	zirconium

SYMBOLS

A	area
C_p	specific heat
F_Q	heat flux hot channel factor
F_A^N	assembly relative radial power factor
h	enthalpy
ħ	Plank's constant: $6.626068 \times 10^{-34}\ \left(\frac{m^2 \cdot kg}{s}\right)$
k	thermal conductivity
K	thermal conductance (1/R)
k_B	Boltzmann constant: $1.3806503 \times 10^{-23}\ \left(\frac{m^2 \cdot kg}{s^2 \cdot {}^\circ K}\right)$
K_{ij}	cross-flow resistance factor
M	mass

N	number of atoms
$PuCon$	PuO_2 content
r	radius
R	thermal resistance to heat flow ($\Delta r/kA_s$)
Q	heat transfer
Q'''	volumetric heat generation rate
q''	surface heat flux
t	time
T	temperature
T_{melt}	fuel melting temperature
u	axial velocity
v	lateral velocity
V	volume
p	porosity
P_W	channel wetted perimeter
P_H	channel heated perimeter
z_{Am}	americium content
z_{Np}	neptunium content
$\frac{\partial}{\partial t}$	partial derivative with respect to time

Greek Symbols:

ρ	density

Subscripts:

s	surface
th	theoretical

VIPRE: FLOW-FIELD MODEL

A	channel flow area perpendicular to axial flow
$\underline{F}$	fluid component of the fluid/wall interface
$\vec{g}$	gravity vector
ℓ	distance between centroids of adjacent cells
$\vec{n}$	unit outward normal vector
P	hydrostatic pressure component of the stress tensor
$\vec{q}$	heat flux vector
$\dot{r}$	rate of internal heat generation per unit mass
S	gap width
U	axial flow velocity
$\overline{\mathrm{U}}$	cell average axial flow velocity
$\vec{U}$	fluid velocity vector
v	lateral flow velocity
$\underline{V}$	eulerian control volume (fluid)

$\underline{W}$	solid wall component of the fluid/wall interface
ΔX	subchannel cell axial height

Greek symbols:

$\vec{\pi}$	shear tensor component of the stress tensor

VIPRE: HEAT TRANSFER MODEL

H	surface heat transfer coefficient

Greek Symbols:

ϕ	fraction of rod's heated perimeter connected to a subchannel

Subscripts:

$i, i-1$	"from" heat node $i-1$ "to" heat node i
$i, i+1$	"from" heat node $i+1$ "to" heat node i
$i-1, i$	"from" node $i-1$ "to" node i
$i+1, i$	"from" node $i+1$ "to" node i
b	bulk fluid
n	rod indice

CLASSICAL PHONON TRANSPORT HEAT CONDUCTION MODEL

A	lattice defect thermal resistivity
B	intrinsic lattice thermal resistivity

Greek Symbols:

α	thermal diffusivity

EFFECTIVE THERMAL CONDUCTIVITY MODELS

d	number of dimensions involved in heat transfer
v	volume fraction

Subscripts:

eff	effective
m	matrix
f	fuel

ANALYTICAL HEAT CONDUCTION MODEL

a	lattice parameter of the material
a_0	effective crystallite size
B_{T0}	bulk elastic modulus of the solid at T=0 K
b_U	takes into account the fraction of phonons that can participate in the U-processes
$\bar{M}$	mean atomic mass

u	sound velocity

Greek Symbols:

$\bar{\theta}$	mean characteristic temperature of acoustic phonons
μ	Poisson ratio
ω	phonon angular frequency
γ_G	Grüneisen bulk constant

Subscripts:

A	acoustic
L	longitudinal
T	transverse
gb	crystalline grain boundaries
pd	point defects
ph	phonons-phonon
U	Umklapp process (inelastic phonon-phonon scattering)

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1. INTRODUCTION

The closing of the Yucca Mountain Project has led to re-examining the U.S. final nuclear waste repository plan. Spent Nuclear Fuel (SNF) discharged from light water reactors (LWR) contains high level radioactive wastes in the form of transuranic elements (TRU) and minor actinides (MA). MA pose the main radiotoxic risk at longer time scales. In the U.S., around 2000 tonnes of heavy metal in the form of SNF is produced each year from civilian uses [1]. The combination of high levels of radiation, long half-lives, radiotoxicity, and proliferation concerns associated with SNF, requires the adoption of a safe long-term storage program with the ability to contain radiological wastes over geological time periods. However, the current U.S. inventory of SNF is already exceeding storage capacity. Transmutation in nuclear reactors is one proposed method for reducing the radiotoxic inventory. According to Calabrese et al. [2], plutonium recycling in future fast reactor fuel cycle systems and accelerator-driven sub-critical systems, along with MA transmutation in dedicated nuclear systems, could reduce the long-term radiotoxicity of nuclear waste by two orders of magnitude in comparison with the current once-through strategy in which fuel is discarded after operation in a reactor. This method proposes the separation of MA from fission products in reprocessed fuel and reused as a fuel material component [3]. Reducing the amount of TRUs requiring permanent storage would significantly decrease the long term heat and radiological loads to a repository, which would in turn increase both the capacity and lifetime. As a result, considerable effort has been focused on the development of methods by which the long-lived isotopes that are contained within SNF can be transmuted into more benign forms [1].

One possible method is through the use of ZrO_2 based inert matrix fuels (IMF), for which analysis has shown a 75% reduction in the radiological and integrated thermal output is achievable in a single recycle using IMF, when compared to the current once-through method of directly disposing an energy equivalent spent uranium oxide fuel (UOX) [1]. In order to decrease the burden on storage requirements, new and innovative fuel and core designs have been improved upon and developed that will provide higher fuel burn-ups, burn TRU while reducing MA, and reduce the long term radiotoxicity of SNF all while utilizing existing LWR and future Advanced Light Water Reactors (ALWR) [4]. For over the past 20 years several European countries have recycled SNF, and extracted plutonium to make mixed oxide (MOX) fuel [5], which is a blend of uranium dioxide and plutonium dioxide, for use in commercial nuclear reactors [6]. While this process does aid in the disposition of plutonium, it does not address the issue of minor actinides.

As a part of the effort to further reduce the radiotoxicity and waste from SNF, advanced mixed oxide (AMOX) fuels and inert matrix fuels (IMF) have been proposed. IMF is a nuclear reactor fuel concept that consists of an inert, or neutron-transparent (low neutron absorption cross-section), matrix with a fissile phase (to be burned) either dissolved in the matrix or incorporated as macroscopic inclusions [7]. The leading IMF designs are those that do not contain uranium, which prevents the production of plutonium in spent nuclear fuel. IMFs, due to their fertile-free matrices, could be an ideal method of using current LWR for the reduction of plutonium and other transuranics (neptunium, curium, americium) contained within spent UOX [1]. Previous investigations into IMF designs have shown IMF to have greater plutonium burnup efficiency than MOX and have the added advantage of transmuting MA at the same time. Thus, IMF is an attractive option for solving many SNF storage related issues.

Although AMOX and IMF fuels have been studied in depth from a neutronics perspective [8], thermal-hydraulic analysis is needed to further ensure the safe and reliable operation of each particular assembly design such that the health and safety of the public is maintained. Furthermore, the U.S. Nuclear Regulatory Commission (NRC) requires a thermal-hydraulic analysis of all newly designed fuels before licensing can be approved. In order to determine the operating temperature distribution in nuclear fuel within a nuclear reactor, the neutron flux distribution, coolant flow rate and temperature, heat-transfer coefficient, fuel-element geometry, and the physical properties of the material that influence the temperature under both steady-state and transient conditions must be known [9]. Previous analyses of AMOX and IMF designs have been focused on neutronic aspects of safety and have neglected the thermal-hydraulic safety aspects in the design process. Material-specific thermophysical properties are affected by various neutronic design parameters such as fuel burnup, enrichment, porosity, and loading which can affect the limits of the respective neutronic design parameters. The effect of neutronics parameters on material-specific thermophysical properties was one of the topics under investigation by Bingham [4]. The investigation revealed that much of the work that has considered material and thermal-hydraulic factors has only done so in a simplified steady-state or limited transient analysis manner. The full-scale, whole-core, effect of material thermophysical property degradation and variation over the fuel assembly's life on thermal-hydraulic safety parameters has traditionally been overlooked in advanced fuel assembly (AFA) designs.

Most thermal-hydraulic evaluations of AFA designs have focused on simplified steady-state analysis as a secondary consideration in the design process. Although the nuclear power industry in the U.S. typically operates at high capacity factors with limited interruptions, the reactors are expected to undergo Anticipated Operational Occurrences (AOO), or transients, during any given operating cycle. Thus, it is a necessary part of the thermal-hydraulic analysis to simulate the thermal performance and response of reactor systems under such transients [4].

1.1. Technical Objectives

The work included in this thesis study will be the first thermal hydraulic evaluation of SBU-type fuel assemblies utilizing the latest state-of-the-art thermal hydraulic methodology [4]. This methodology includes the evaluation of fuel assemblies both under steady-state and transient conditions for a $1/8^{th}$ core subchannel analysis. The developed framework for SBU-type assemblies will serve to unify neutronic, thermal-hydraulic, and materials considerations in a full-core analysis. It is of critical importance, as a part of this methodology, to more accurately determine the thermophysical properties and limits of the innovative DUPLEX IMF fuels than what has been used with basic assumptions in previous work [10]. The considered fuel assembly designs are of the 17x17 fuel pin variety, and are to be used in existing pressurized water reactor (PWR) cores without the need for major modifications to plant systems. The SBU fuel assembly design to be analyzed is the UO_2 (seed) and IMF (blanket) fuel system.

The developed framework will also allow for the combination of any fuel type presented here and in previous work by Bingham [4]. This will dramatically expand the capabilities of the latest thermal-hydraulic evaluation framework such that the most promising and unique DUPLEX fuel design can be evaluated. In addition to analyzing nominal specification designs, this extension to the framework will allow for variations in fuel geometry characteristics in different segments of the fuel assembly (seed and blanket regions). Variations in seed region dimensions and blanket region dimensions will be investigated for thermal-hydraulic effects. Also, due to the variability of thermal conductivity models and the limited availability of data from related experiments, an in-depth analysis will be performed on the thermal conductivity of the IMF fuel in the blanket region in order to determine the degree of accuracy needed in thermal conductivity data for successful evaluation of such a fuel. The following are the main objectives of this thesis:

- To enhance and expand upon previous methodology for analyzing advanced fuel designs, which accounted for the effects of burnup on neutronic and thermal-hydraulic operational parameters, such that the analysis of advanced fuel assembly and IMF designs are also possible

- To review, select, and propose methods for estimating thermophysical properties of advanced and complex fuel designs for which little or no data is available, since there is currently no standardized process for analyzing untested fuel
- To perform both steady-state and transient thermal-hydraulic analyses for proposed fuel assembly and fuel designs
- To investigate and develop modeling techniques of SBU-type fuel assemblies
- To investigate the possibility of improving thermal-hydraulic characteristics of advanced fuel assembly designs through the use of the enhanced interface.

1.2. Inert Matrix Fuel (IMF) Background

Oxide fuels have traditionally been used in LWRs for many reasons, such as the ability to operate at high temperatures. A drawback to the use of fissile materials in oxide forms, however, is their low thermal conductivity. For minor actinide oxides this issue is even greater. Also most oxide forms of minor actinides further compound the problem by requiring lower operational temperature limits due to generally lower melting temperatures than standard UO_2. Thus, in order to meet plutonium and minor actinides disposition needs in current U.S. LWRs, the more restrictive thermal limits inherent to minor actinide dioxides must be offset through some means. The restrictive limits have kept minor actinide concentrations in fuels such as MOX and AMOX low.

MOX has been proposed for the disposition of plutonium coming from SNF and surplus weapons-grade material stockpiles. However, burnup efficiency of plutonium by

MOX is low and the minor actinide issue is ignored. AMOX designs attempt to address the minor actinide issue by adding small amounts of minor actinides to MOX fuel for transmutation. MOX and AMOX designs do not completely meet industry needs since not enough material can be transmuted at one time and efficiently. Also, since uranium dioxide is a component in MOX and AMOX designs, nuclear waste is still generated.

The IMF concept was developed to allow for greater transmutation of actinides and improve thermal performance over other transmutation concepts. It also provides the ability to target both the long term radiotoxicity and proliferation risks of SNF at the same time.

1.3. Recycling Background

The idea of recycling of plutonium and minor actinides has been around for decades. Since the beginnings of the nuclear power industry many technologies were pursued, some of which involved the recycling of plutonium using inert matrix fuels.

For the past 20 years several European countries have been reprocessing SNF to produce MOX fuel, while the U.S. has not. Under agreements between the U.S. and Russia to reduce each country's own surplus weapons-grade fissile stockpile into more benign forms that are unsuitable for use in nuclear weapons, the U.S. has begun steps to fabricate MOX fuel for possible use in current U.S. LWRs. While the U.S.' disposition of surplus weapons-grade plutonium will serve global and national security needs, it will also serve as a test of reprocessing techniques which will be needed as a basis for possible future minor actinide recycling.

1.4. DUPLEX FA: Seed Blanket Unit (SBU) Design and LWR-2-E Fuel

A detailed neutronics analysis of various multi-recycling (M-R) strategies has been performed by Zhang [8]. The optimized design and results of the neutronics analysis, which are briefly described below, are the basis for the thermal-hydraulic analysis to be performed. The study compared five advanced TRU-burning fuel assembly designs in terms of TRU mass balance, radiotoxicity, and decay heat: MOX once-through cycle (standard), MOX M-R, Am-coated MOX (AMOX) M-R, DUPLEX with UOX inner zone M-R (IMF-UOX), and DUPLEX with MOX inner zone M-R (IMF-MOX). The IMF-UOX design was chosen as the most promising design to achieve TRU disposition and enhanced long-term safety goals, due to its high energy/waste efficiency, reduced radiotoxicity, and reduced decay heat [8].

Conventional PWR fuel assemblies employ a homogeneous scheme where all fuel pins, typically UOX, are of the same type and dimension. For the IMF concept, the homogeneous scheme is not ideal due to violations of several reactor physics safety criteria. The removal of Uranium from the assembly results in a hardened neutron spectrum, thus reducing the void reactivity coefficient, soluble poison worth, control rod worth, etc [8]. In addition to safety issues, performance issues are also presented when the use of UOX fuel is abandoned. UOX fuels contain fertile fuel (most notably Uranium-238), which produce fissile nuclides as fuel burnup increases. As Uranium-238 transmutes into Plutonium-239, the reactivity reduction due to the depletion of Uranium-235 is slightly offset, allowing the core to main criticality for an extended period of time (core reactivity decreases at a slower rate). In a sense, as UOX fuel depletes, it also produces a small amount of additional fuel in the form of transuranics, which actually help produce power near the end of life (EOL) of each fuel resulting in an increase of fuel utilization. Maintaining these extended periods of operation translates into significant economic value. However, in a homogeneous fuel assembly composed only of IMF fuel, the reactivity decreases at a greater rate than experienced by UOX fuels. Therefore, a heterogeneous fuel assembly design must be adopted.

SBU-type fuel assemblies consist of two regions of fuel: the inner fuel region ("seed"), and the outer fuel region ("blanket"). The adopted design was derived from the findings of two previous designs: one proposed by MIT, the Combined Non-Fertile and Uranium (CONFU) design, which replaced 60 UOX pins on the periphery of a 17x17 assembly with IMF pins; and a French design, named DUPLEX, which replaced 84 UOX pins on the periphery instead. The CONFU design was deemed inadequate for multi-recycling beyond 3 recycling cycles, or "generations". On the other hand, the additional 24 IMF pins included in the DUPLEX design allowed for the achievement of up to 7 generations [8]. The DUPLEX IMF-UOX design is depicted in Figure 1.

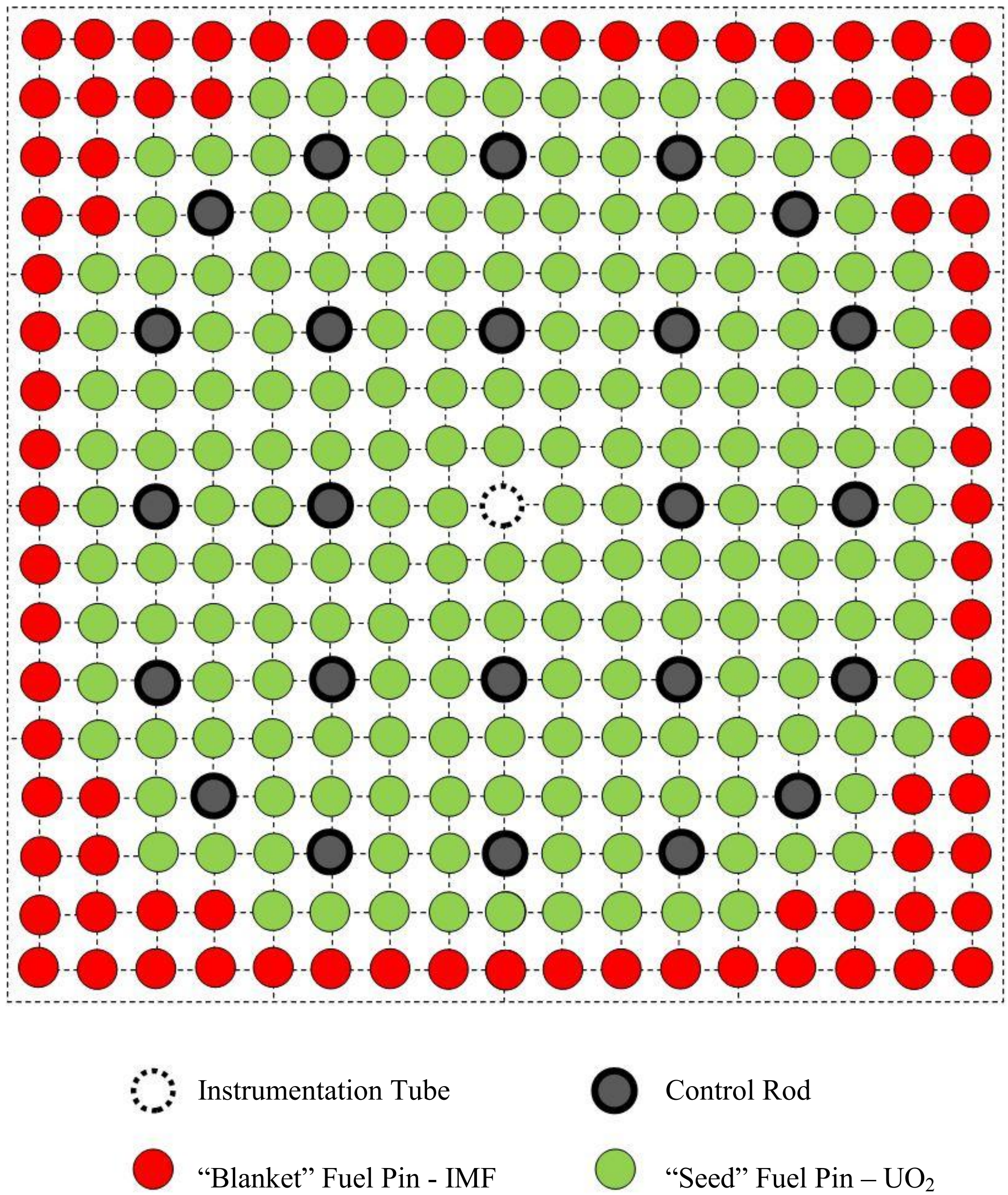


Figure 1. DUPLEX IMF-UOX fuel assembly geometry

The IMF fuel designated as the blanket component of the SBU-type DUPLEX FA was proposed under the Advanced Fuels Cycle Initiative (AFCI) LWR transmutation program. The IMF fuel consists of an inert matrix, MgO-ZrO_2, combined with a fissile phase, transuranic oxide (TRUOX). The inert matrix is used primarily to increase the thermal conductivity of transuranics to be burned (due to the relatively low estimated thermal conductivity of transuranic oxides), while yielding a net decrease in overall transuranic inventory (i.e. not produce any further waste). Transuranics used in the fissile phase of IMF fuel come from discharged legacy UOX fuels (i.e. SNF). Instead of recycling just Plutonium, as in MOX fuel, TRUOX also includes recycled Am, Np, and possibly Cm. The proposed DUPLEX design [8] includes the use of a specific IMF fuel, called “LWR-2-E”, which consist of a ceramic fissile component, $(Pu,Np,Am)O_2$, uniformly dispersed throughout an inert ceramic matrix, MgO-ZrO_2. The inert matrix is configured such that there is an equal weight distribution between the MgO (magnesia) and ZrO_2 (zirconia) (50/50 wt.%).

As mentioned previously, the fuel reactivity decreases over time due to a reduction in the amount of fissile material, even more so in the case of IMF fuel. This issue is further extended for multi-recycling strategies, as IMF fissile inventory decreases over multiple burnup cycles. In order to maintain the desired campaign length equivalent to that of legacy UOX, research has shown that increasing and fixing the U-235 enrichment to the maximum allowable value of 5 wt.% (for commercial nuclear power plants) and blending in fresh TRUs in IMF pins between successive cycles is sufficient, and also keeps the TRU percentage in IMF pins to a reasonably low value throughout each generation of recycled fuel. A reasonably low percentage of TRU is ideal since the thermal conductivity of IMF decreases as the percent of TRU increases and percentages in excess of 40% result in manufacturing difficulties [8]. Neutronics analysis also yielded a unique geometrical characteristic in order to maximize TRU utilization in the DUPLEX IMF-UOX design (referred to hereafter as DUPLEX). Unlike typical legacy UOX fuel assemblies, the optimized DUPLEX design requires the increase of the blanket (IMF) pins' radii by ~10% compared to legacy UOX pins radii, while retaining nominal dimensions for the seed (UOX) pins. Therefore, the final design has two very distinct sections within each fuel assembly. Both the geometry and material properties of these sections vary greatly from each other: a deviation from standard practice and from what is found in current civilian nuclear reactors around the world.

1.5. Overview of Technical Approach

In order to fully analyze the thermal-hydraulic safety of the proposed advanced heterogeneous fuel assembly, thermal-hydraulic analyses are performed over its entire operational lifetime, up to 68 GWd/tHM of burnup. Analyses include the evaluation of each design under both nominal and licensing-based conditions. The licensing-based conditions consist of overpower steady-state and transient conditions deemed Anticipated Operational Occurrences suggested by NUREG-0800 [11].

The three primary figures of merit by which each design will be evaluated are the minimum departure from nucleate boiling ratio (MDNBR), maximum fuel centerline temperatures, and peak cladding temperatures (PCT). The design limit for the MDNBR is plant-specific. For CPNPP a standard limit of 1.3 for the W3-L critical heat flux (CHF) correlation is used. The departure from nucleate boiling ratio (DNBR) is simply the ratio of the calculated CHF to the actual local heat flux. The CHF is the heat flux required to induce a departure from nucleate boiling (DNB) heat transfer at the cladding surface. Departure from nucleate boiling is undesirable because under such a condition the cladding heated surface becomes vapor-blanketed and a temperature excursion may occur, resulting in damage to the fuel rods.

Limits on peak temperatures are imposed based on suggestions from the available open literature and NUREG-0800 regulations. While UOX and MOX fuel limits are widely known, limits on TRUOX fuels (such as LWR-2-E) are not well distinguished due to the early nature of their development and experimentation. Thus, a combination of standardized regulations on the thermal limits of UOX and MOX are used along with additional suggested limits on advanced TRUOX fuels from the available literature. In the end, two different sets of thermal limits are imposed on two different fuel regions within the fuel assembly. This is not typical of normal thermal-hydraulic analyses and requires more in-depth tracking of each individual fuel rod, not just the hottest fuel rod. The negative effects of burnup are only considered in detail with the standard components of the DUPLEX fuel assembly design located within the seed region (UOX/MOX). Due to the complexity of the burnup phenomenon in fuel, it is not accounted for in LWR-2-E fuel since experimental data to base any type of correction factor is not available.

The primary figures of merit of each design are extracted from the thermal-hydraulic analysis results and compared against those from a prototypic UO_2 loaded reference core. VIPRE is be used to perform the detailed thermal-hydraulic analyses which yield core and fuel assembly results. MELCOR is used as a severe accident code to model the entire primary side of the power plant during simulated transient events to generate time-dependent system pressure, inlet temperature, inlet flow, and core power curves as input into VIPRE boundary conditions (temporal forcing functions to induce reactor operating parameter changes with time). Simulated transients include both partial and complete loss-of-flow-accidents in which one or all reactor coolant pumps are tripped offline. Transient simulations tend to be computationally intensive, and due to the overwhelming number of possible analyses for each fuel design over the entire operating lifetime and recycling schemes, a steady state scoping study is used to screen out all but the most limiting cases for transient analysis.

The thermal-hydraulic analysis is a post-neutronics analysis, taking from neutronic analysts the fuel design characteristics, fuel concentrations, and burnup-dependent axial and radial power profiles. A script-based interface is be used to communicate neutronics data to VIPRE input. Core power is also iterated within the VIPRE analysis framework to achieve equivalent power as the reference core (CPNPP) during simulations.

In order to achieve the aforementioned technical objectives, the following tasks have been performed:

- A comprehensive literature survey to investigate previous and current work in the area of modeling heterogeneous fuel assembly designs and recommendations as to appropriate analysis techniques. Drawing from standard analysis techniques and recommendations of traditional fuel design analysis, results from the literature survey of advanced fuel assembly analysis have been utilized to help create an appropriate design methodology of heterogeneous fuel assemblies.
- An extensive literature survey in regards to the thermophysical properties of proposed TRUOX-containing IMF fuel materials have been carried out. However, due to the exotic nature of such fuels, the limited amount of available data does not include burnup-dependencies. Simplified models for evaluating thermophysical properties of the proposed fuel materials have been developed along with suggestions for more advanced models in possible future research. Where there is large uncertainty, conservative assumptions have been made to ensure that safe operation of each fuel design is maintained under all proposed AOOs.
- An existing script-based interface for coupling neutronic and thermal-hydraulic information between respective codes is modified and improved upon to allow for heterogeneous fuel assembly evaluation. In the current framework, each channel of the hottest fuel assembly is modeled on a subchannel basis, but moving away from the hot assembly, lumped fuel rods and channels are used. Due to the homogeneous fuel designs for which this framework was developed, many simplifying assumptions were allowed since the nuclear fuel was all of the

same type. However, these assumptions are no longer valid due to the multi-fuel type characteristic of heterogeneous assembly's which requires an extensive overhaul of the framework, but the general methodology stays the same. All assumptions of each component of the existing framework have been reinvestigated for applicability to heterogeneous fuel assembly designs. Where assumptions are no longer valid, changes have been made. Also, where additional information is needed for VIPRE, PERL scripts have been created such that all previous functionality of the thermal-hydraulic interface is maintained along with upgraded features.

- Fuel assembly designs are analyzed in VIPRE over their entire operational lifetime and for multiple recycling generations. VIPRE steady-state, single-pass hot channel thermal-hydraulic analyses are performed with 1/8th core symmetry at 118% core power to simulate a pseudo-transient and verify that all safety criteria are satisfied. The 118% core power assumption is based off the 112% maximum overpower limit for U.S. PWRs and an additional 6% power to account for transient conditions while using steady-state analysis techniques [4]. The Westinghouse W-3L critical heat flux correlation is used to quantify an assembly's DNBR performance, more specifically the minimum DNBR such that safety criteria are met. Thermal-hydraulic analyses are performed with a core axial power profile modeled by a 1.55 peak chopped cosine curve, which is standard practice in licensing calculations and yields conservative results. Neutronic power maps of relative rod power in the hottest fuel assembly, supplied from neutronic simulations, are also included. The fuel assembly's relative power factor is modified such that the hottest rod in the hot assembly will have the same peaking factor as in the reference core.

- Full-core transients which will be modeled include partial loss-of-flow-accidents (PLOFA) and complete loss-of-flow-accidents (CLOFA). Boundary conditions from MELCOR are supplied to VIPRE to simulate each type of transient. Transient analysis is performed at 112% power, and only on the most limiting cases from steady-state analyses. For transient heat transfer correlations, appropriate closure values are used from the literature such that designs are successfully modeled throughout the entire transient event.

1.6. Thesis Organization

This thesis is organized in a comprehensive manner in order to support the posed technical objectives listed in Section 1.1. Modern thermal-hydraulic codes are reviewed in Section 2 for their applicability to the current research effort, along with an overview of modifications needed to the most recent coupling method for integrated neutronic and thermal-hydraulic calculations. A comprehensive literature review of current thermal-hydraulic analysis techniques is given in Section 3. The prescribed thermal-hydraulic modeling approach for achieving the posed technical objectives is also presented in Section 3. A comprehensive review of fuel theoretical thermophysical property modeling techniques and available experimentally-based models is given Section 4. The developed thermal conductivity model for $(Pu,Np,Am)O_2$-MgO-ZrO_2 is also presented in Section 4.

The description of the DUPLEX UOX-IMF geometry formulation within VIPRE is presented in Section 5. The thermal-hydraulic analysis results of the proposed DUPLEX assembly, along with the results of a fuel rod diameter variation analysis, are given in Section 6. Finally, conclusions and future work recommendations are given in Section 7.

2. THERMAL-HYDRAULIC ANALYSIS TOOLS

Due to the increased capabilities of computational resources throughout the years, the nuclear industry has been able to utilize a ‘subchannel’ approach with greater refinement to the thermal-hydraulic evaluation of core, bundle, or other flow path regions using state-of-the-art codes which evaluate thermal-hydraulic parameters for each individual flow path or channel. This method has been popular in the nuclear industry since it allows for the simulation of complex three-dimensional geometries to be performed easily and accurately [12]. The reactor core or section of symmetry is defined as an array of parallel flow channels with lateral connections, or ‘gaps’, between adjacent channels [13]. A lateral connection is defined mathematically by the distance between subchannel centroids and its width. In this type of analysis, the region being modeled is divided into quasi-one-dimensional flow paths, described mathematically by a flow area and wetted perimeter (the exact channel shape is not important). A channel may represent a true subchannel within a closed tube, a rod bundle, or even a larger flow area representing multiple subchannels or rod bundles.

There are many advantages to this type of modeling over system codes such as MELCOR [14], RELAP [15], and RETRAN [16], for fuel assembly design analysis since subchannel codes, such as VIPRE-01 [12] and COBRA-IIIC/MIT [17], are able to model the thermal-hydraulic phenomena within individual flow channels of assemblies while simultaneously accounting for the coupled feedback effects of the entire reactor core. For this reason, the subchannel modeling philosophy has been popular in the nuclear industry for several years.

2.1. Thermal-Hydraulic Modeling Approach

Subchannel codes are more widely used for the thermal-hydraulic analysis of fuel assembly and core designs over system codes due to their ability to provide more detailed information about the thermal-hydraulic phenomena that occur within individual subchannels, mainly those located between adjacent rods within a fuel assembly, while also being able to simulate larger channels representing "lumped" components of the reactor core. The subchannel approach allows for the accounting of localized thermal-hydraulic behavior around fuel pins within an assembly, which cannot be performed by system codes such as MELCOR or RELAP. System codes group multiple fuel assemblies together, thus they are only able to yield average results for the lumped components, which is not suitable for calculating key parameters of interest needed to quantify important performance characteristics of a particular assembly design, such as its corresponding thermal margin.

In modern subchannel codes, such as VIPRE-01 and COBRA-IIIC/MIT, the size and shape of the individual channels and their connections are essentially arbitrary [18]. Thus, the user has a great deal of flexibility when modeling reactor cores or any other fluid flow geometry. This capability is a significant advantage over system codes since it allows for the simultaneous calculations of the flow, and enthalpy, distributions of individual coolant channels between four adjacent rods and the distributions over the entire core by using subchannels that are the size of fuel assemblies and larger. Therefore, it is possible to conduct both a detailed assembly and core-wide analysis at the same time [4]. By performing simulations efficiently and accurately, subchannel codes such as VIPRE-01 can be a valuable aid in determining setpoints of safety systems and preparing licensing submittals, as well as normal day-to-day thermal-hydraulic reactor core calculations [12].

Subchannel codes are widely used throughout the nuclear industry for both fuel assembly and core design analyses which simulate a list of postulated conditions for both safety and performance characteristics as part of the design process. The U.S. nuclear industry has used the NRC-approved thermal-hydraulics subchannel analysis code VIPRE-01 extensively to model fuel assemblies and core designs for the current fleet of U.S. PWRs, as well as numerous advanced fuel assembly designs [4]. It has recently been used by Westinghouse Nuclear as their primary tool for thermal-hydraulic analyses involving various fuel designs in their AP1000 nuclear reactor [19]. One of the main reasons for the success of VIPRE-01 in the nuclear industry as a design tool in the past and present is the subchannel method's capability of maintaining a balance of detailed analysis and computational speed.

Even with the advent of increasingly detailed computational analysis techniques, such as computational fluid dynamics (CFD), subchannel codes are still widely used as a primary tool due to their more than 30 years of development, fine-tuning, and use, which has molded these subchannel codes into efficient, yet accurate tools for use as part of the fuel assembly and core design process. The design process can take numerous iterations to converge to a suitable design making the CFD approach impractical due to the computational resources needed for such an approach.

2.2. VIPRE-01

VIPRE-01 is a thermal-hydraulic safety related code used widely throughout the global nuclear industry by both nuclear utilities and nuclear fuel vendors. It complies with the requirements of 10CFR50 Appendix B and is approved by the NRC for use in licensing calculations. A subchannel analysis approach is used by the code in which a series of parallel flow areas between adjacent rods are defined, and are divided into smaller sections by axial segmentation called control volumes (sometimes referred to as 'cells' or 'nodes') for use in the conservation equations (mass, momentum, and energy). The homogeneous equilibrium model (HEM) is invoked for the numerical solution to the flow field of each control volume. Individual cells are able to communicate axially with cells directly above and below, and laterally through cross-flow. Analysis by VIPRE is limited to situations that occur entirely within the core and relies on systems codes, which are capable of simulating events outside of the core (e.g. secondary system), to supply boundary conditions.

2.2.1. Code Selection

The Electric Power Research Institute (EPRI) VIPRE-01 thermal-hydraulic code was chosen for the research efforts contained within this thesis in order to maintain continuity between this work and the work performed by Bingham [4]. This allows for direct comparison between the advanced fuel assembly designs proposed by Bingham and the design under investigation in this work in terms of many key thermal-hydraulic parameters, such as maximum temperatures and minimum departure from nucleate boiling ratio (MDNBR), while minimizing the effect of modeling methodology. A thorough review of various codes (including VIPRE-01, COBRA-TF, and COBRA-IV PC) was performed by Bingham. Each code was assessed based on their capabilities and applicability to proposed fuel configurations. Among the selection criteria, it was important to select a code that satisfied the following attributes [4]:

- Contains robust thermal-hydraulic models
- Ability to simulate complex fuel pin geometries (multi-region and annular)
- Allows the user to define material properties and heat conduction models for evaluating advanced fuel types such as AMOX and inert matrix fuels (IMF)
- Ability to calculate selected primary thermal-hydraulic parameters of interest (peak cladding and fuel temperatures, and MDNBR)
- Well documented, maintained, and wide acceptance in the nuclear industry
- Available for academic research

The VIPRE-01 thermal-hydraulic code was selected for use by Bingham based on its thorough documentation, ongoing updates, approval by the NRC as an acceptable reference in licensing applications (complies with 10CFR50 Appendix B), extensive use by the U.S. nuclear industry, application in evaluating MDNBR for the Westinghouse AP1000 reactor design, and use in research for the enhancement of fuel performance and the burning of transuranics (TRUs) in LWRs [4]. Based on a review of the above selection criteria, it was found that the same criteria are applicable to this work, resulting in the continued use of VIPRE-01 for the analysis of the proposed advanced SBU fuel assembly designs under investigation in this thesis. The decision to continue the use of VIPRE-01 for the analysis of the SBU fuel assembly design of principal interest in this thesis is also based on the code's use in similar previous research efforts (Busse [20], Todosow et al. [21] [22], and Wang [23]) in which the VIPRE-01 code was selected to calculate the same key parameters of similar geometrical fuel assembly configurations.

2.2.2. VIPRE Background

VIPRE (Versatile Internals and Component Program for Reactors; EPRI) was sponsored by EPRI and developed for nuclear power industry thermal-hydraulic analysis applications based on the strengths of the COBRA code series (COBRA-IIIC [24], COBRA-IV-I [25] [26], COBRA-WC [27], COBRA-IIIC/MIT [17], MEKIN (coupled neutronics-thermal-hydraulics) [28], and FIBWR (BWR modeling features) [29]). The individual codes of the COBRA code series were not designed to accommodate the needs of the nuclear industry and were not adequately validated and documented for use in licensing calculations. VIPRE-01 MOD2.3 (hereafter referred to as VIPRE) is the union of features found in the individual codes within the code series along with updated capabilities and features to address the specific needs of nuclear utilities, now all contained within a single code package. Examples of features found in VIPRE that have their origins in the COBRA code series is depicted in Figure 2.

A main focus of the VIPRE-01 developmental work consisted of tailoring the code to the nuclear utilities' analytical requirements by including upgraded the code capabilities, upgraded models, thorough documentation and validation, enhanced numerical solution schemes, and improved flexibility of its use [12]. While VIPRE has adopted many features that exist in individual COBRA codes, there are many important features that are unique to VIPRE. Features developed specifically for VIPRE include an automatic time step control, iterative setpoint analysis model, format-free input, and several additional physical models. Additionally, a few of the more important enhancements are [12]: an expanded choice of Critical Heat Flux (CHF) correlations; specific input options tailored for one-pass hot channel analysis; capability to iterate upon operating conditions to a given MDNBR for setpoint analysis; ability to run multiple sequential cases for varying operating conditions automatically; option to use internal water properties functions instead of property tables; and a generalized rod conduction model for nuclear fuel rods (a dynamic gap conductance model is available with this type of rod), electric heater rods, hollow tubes and walls.

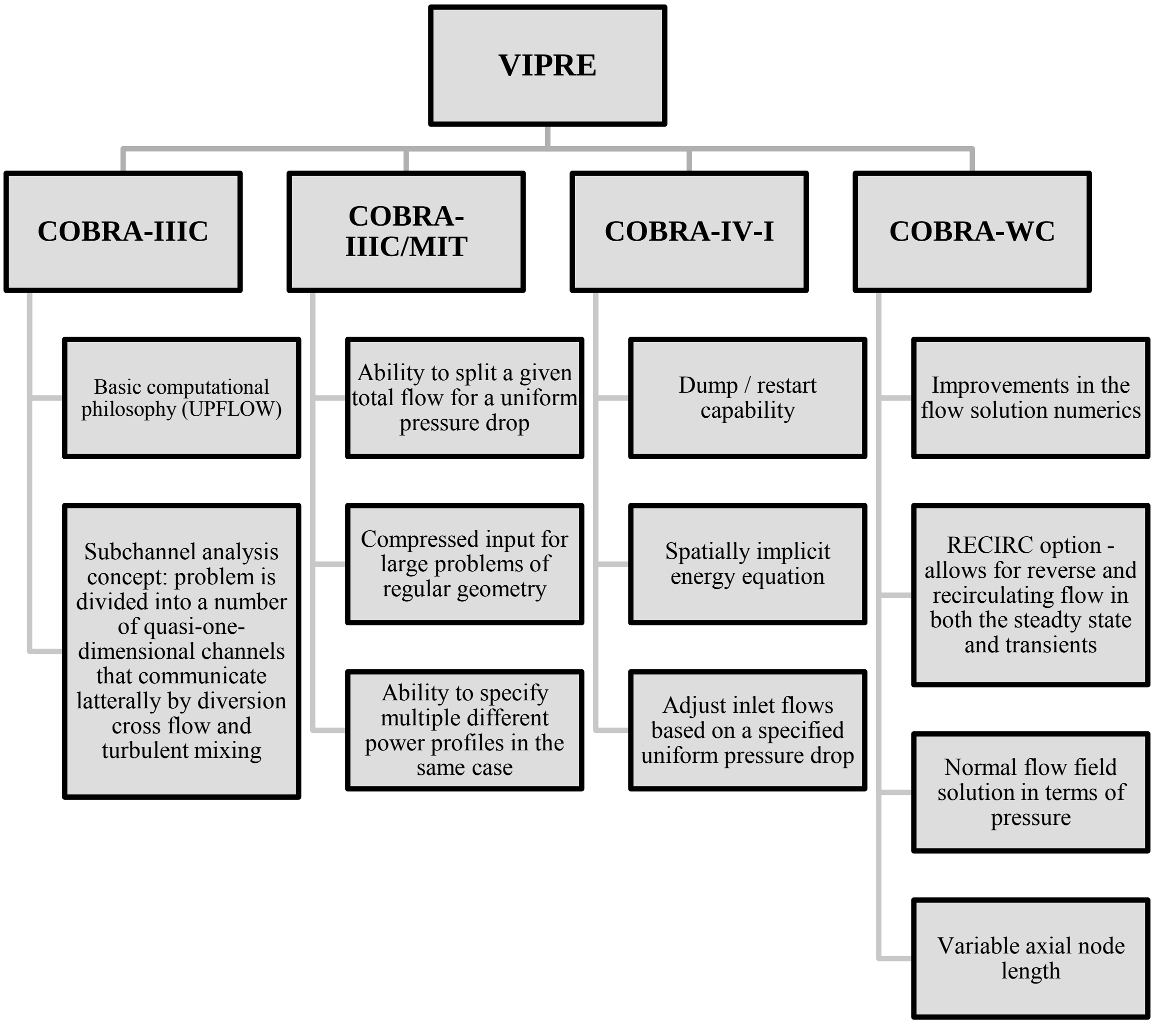


Figure 2. VIPRE components adopted from the COBRA code series [12]

VIPRE simulates the three-dimensional pressure, velocity, and thermal energy fields, and fuel rod temperatures for both single-phase and two-phase flow in conventional LWR systems [18]. It is designed to help in the evaluation of nuclear reactor core safety limits, including MDNBR for PWRs, critical power ratio (CPR) for BWRs, cladding and fuel temperatures, and coolant characteristics in normal operating steady-state and transients and assumed moderately severe accident conditions [12]. Transients that VIPRE can model include flow coastdown to a zero flow condition, loss of load, reactivity changes (ex. control rod drop or ejection), moderate depressurization from small breaks in the primary system, and major secondary system breaks [18]. Results from VIPRE simulations are reported for each cell and axial location, which include pressure drop, fuel rod and cladding radial temperature profiles, fluid properties, heat transfer coefficient, heat flux, critical heat flux, and departure from nucleate boiling ratio (DNBR). Bundle-averaged, or core-averaged, values are also reported, along with the location of the MDNBR for each axial level (identified by the code in terms of the respective rod and channel identification numbers).

VIPRE, using the subchannel approach, applies conventional control volume-base modeling to discrete, user-defined volumes which represent individual flow areas between adjacent rods within fuel assemblies [4]. The control volume in relation to the reactor core is shown in Figure 3. For each control volume, the finite-difference conservation equations for mass, axial and lateral momentum, and energy, for an interconnected array of channels, are solved for by the code assuming incompressible thermally expandable homogeneous flow. The code uses the simplified conservation equations to solve for fluid enthalpy, axial flow rate, lateral flow per unit length, and momentum pressure drop. These equations are also solved for with no time step or channel size restrictions for stability [13].

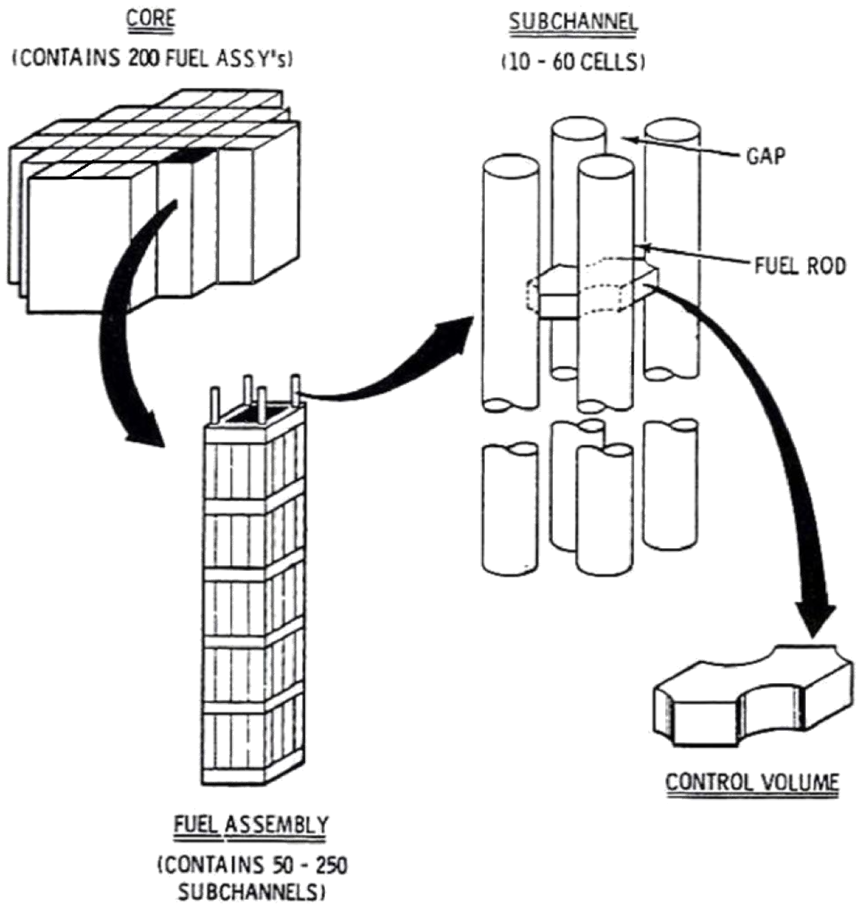


Figure 3. Relation of subchannel control volume to reactor core (from [12])

Transportation of mass, energy, and momentum from one channel to a neighboring channel is done so by diversion crossflow and turbulent mixing. The assumption is made that once the crossflow enters the receiving channel that it loses its sense of direction. This results in an absence of momentum coupling from one crossflow to another. Thus, directionality or boundary conditions of each lateral connection need not to be defined. Although the equations are formulated for incompressible homogeneous flow, nonmechanistic models are included for subcooled boiling and co-current vapor/liquid slip in two-phase flow. However, due to the formulations of the conservation equations and empirical models (i.e. correlations) within VIPRE there are certain limitations to the code.

Stand-alone VIPRE simulations are limited to events occurring entirely within reactor cores. In order to simulate events involving systems outside of the core, a systems code, such as RETRAN, must first be used to simulate the effects and pass boundary conditions (core inlet fluid conditions) to VIPRE. VIPRE should not be used when situations entail large relative phase velocities, pressure wave tracking (blowdown), countercurrent flow, low-flow boil-off, annular flow, phase separation in which a sharp liquid/vapor interface is involved, pressure drop on the order of system pressure, or conditions in which the flow regime changes rapidly [18]. These restrictions are inherent to a homogeneous flow approximation. Also, although the uncoupling of momentum between crossflows in neighboring gaps and neglecting of interfluid viscous shear effects is valid for the general case of large lateral flow resistance compared to the axial flow resistance (i.e. rod or tube bundles), the formulation becomes invalid in a free-field situation in which the wall friction is not dominant.

There are five basic types of information needed for any VIPRE simulation, which are grouped into two main groups: the definition of the model, and the model simulation run control. Each type describes a component of the numerical approximation of the physical entity to be simulated. These types of information are [18]:

- Model Definition: define the numerical approximation of physical entity to be simulated.
    1. Geometry – define the dimensions and interconnections of flow areas and heat transfer surfaces, such as fuel rods.
    2. Operating Conditions – specify inlet and exit boundary conditions, power, and transient forcing functions that are to be applied to the boundary conditions.
    3. Hydraulic Information – define local loss coefficients, lateral flow resistances, and axial friction factors.
- Model Simulation Run Control: set parameters that instruct VIPRE what to do with the constructed model.
    4. Correlation/Model Selection – correlation selection for two-phase flow, heat transfer, CHF, and other thermal-hydraulic parameters.
    5. Run Control Information – specify numerical solution method, solution parameters, output options, and transient time step size.

2.2.3. Fluid Flow-Field Model

Fluid flow in nuclear reactor cores is constrained by the surfaces of closely spaced fuel rods oriented vertically along the primary axial flow direction. On a fuel assembly scale, the closely spaced fuel rods partition the fluid flow area into many smaller channels, or 'subchannels', that communicate laterally with adjacent subchannels by crossflow through narrow gaps between adjacent fuel rods.

As shown in Figure 2, the basic computational philosophy found in VIPRE comes from COBRA-IIIC. Individual control volumes ('cells'), located within a given subchannel (see Figure 3), are coupled to adjacent rods through heat transfer models. Communication between control volumes (i.e. where there is fluid flow) occurs axially with the other cells directly above and below it, and laterally with other adjacent cells by diversion crossflow and turbulent mixing. In this way, VIPRE can be considered a three-dimensional code, capable of modeling lateral changes in velocity and temperature profiles in a channel as a result of pressure gradients, turbulent mixing, and two-phase flow effects [4].

The homogeneous equilibrium model (HEM) within the fluid flow-field model used by VIPRE, approximates fluid conditions through the assumption that the liquid and vapor phases are both in thermal and mechanical equilibrium. Many assumptions were applied to the conservation equations (mass, energy, momentum) during the formulation of the simplified fluid flow-field model in consideration of the intended applications of VIPRE. The main assumptions in the formulation of the simplified fluid flow-field model are [12]:

- Velocity of the fluid flow is low enough such that kinetic and potential energy are small compared to the internal thermal energy
- In the energy equation, work done by body forces and shear stresses are small compared to surface heat transfer and convective energy transport

- Conduction heat transfer through the fluid surface (e.g. between fluid elements) is small compared to convective energy transport and heat transfer from solid surfaces (i.e. rods)
- When both liquid and vapor phases are present, they are in thermodynamic equilibrium
- In the momentum equation, gravity is the only significant body force
- Between fluid elements, viscous shear stresses are small compared to the drag force on solid surfaces
- The fluid is incompressible but thermally expandable, meaning that the density and transport properties vary only with the local temperature (enthalpy).

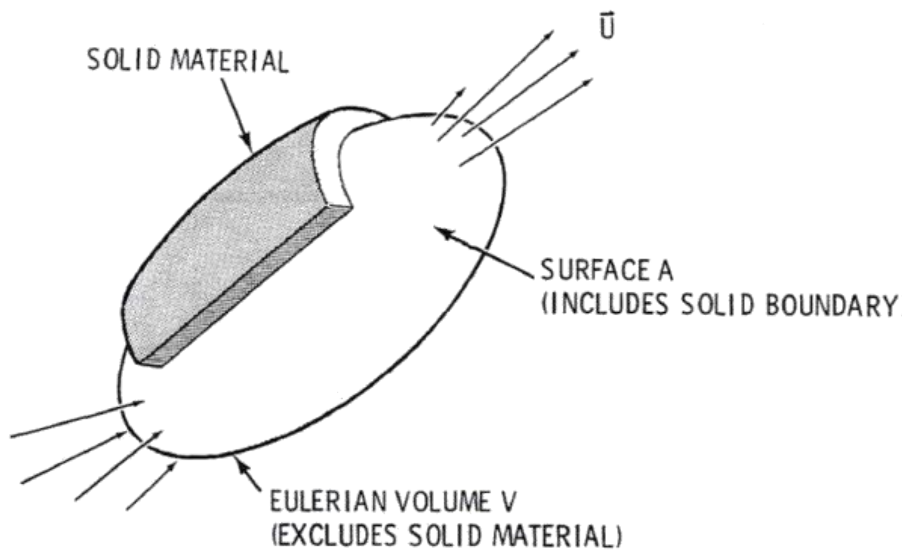


Figure 4. Arbitrary eulerian control volume (from [12])

The final forms of the conservation equations after applying the above assumptions for an arbitrary eulerian control volume, as shown in Figure 4, are [12]:

Mass:

$$\frac{\partial}{\partial t}\int_{\underline{V}} \rho \, d\underline{V} + \int_{\underline{F}} \rho\left(\vec{U}\cdot\vec{n}\right) d\underline{F} = 0 \qquad (1)$$

Energy:

$$\frac{\partial}{\partial t}\int_{\underline{V}} \rho h \, d\underline{V} + \int_{\underline{F}} \rho h\left(\vec{U}\cdot\vec{n}\right) d\underline{F} = -\int_{\underline{W}} \rho h(\vec{q}\cdot\vec{n})\, d\underline{W} + \int_{\underline{V}} \rho r \, d\underline{V} \qquad (2)$$

Momentum:

$$\begin{aligned}\frac{\partial}{\partial t}\int_{\underline{V}} \rho\vec{U} \, d\underline{V} &+ \int_{\underline{F}} \rho\vec{U}\left(\vec{U}\cdot\vec{n}\right) d\underline{F} \\ &= \int_{\underline{V}} \rho\vec{g}\, d\underline{V} - \int_{\underline{F}} P\vec{n}\, d\underline{F} - \int_{\underline{W}} P\vec{n}\, d\underline{W} \\ &+ \int_{\underline{W}} (\vec{\pi}\cdot\vec{n})\, d\underline{W}\end{aligned} \qquad (3)$$

where $\underline{V}$ – represents the eulerian control volume (fluid)

$\underline{F}$ – represents the fluid component of the fluid/wall interface

$\underline{W}$ – represents the solid wall component of the fluid/wall interface

ρ = fluid density

h = fluid enthalpy

$\vec{U}$ = fluid velocity vector

$\vec{n}$ = unit outward normal vector

$\vec{q}$ = heat flux vector

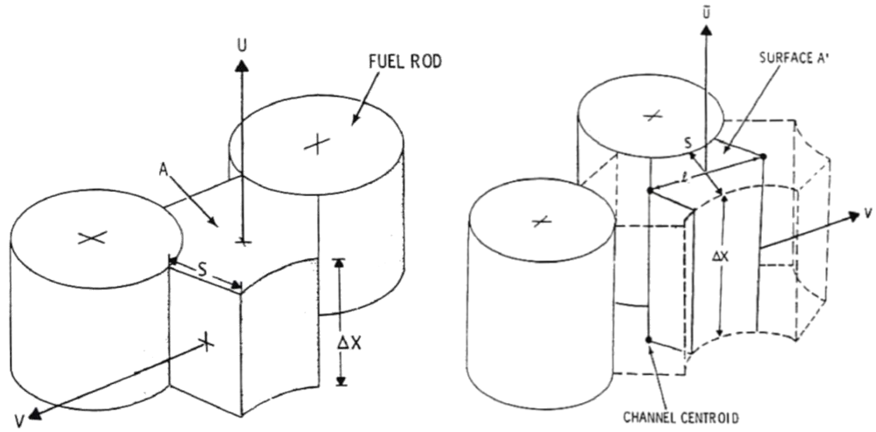
$\dot{r}$ = rate of internal heat generation per unit mass

$\vec{g}$ = gravity vector

P = hydrostatic pressure component of the stress tensor

$\vec{\pi}$ = shear tensor component of the stress tensor

The above conservation equations (Eqs. (1), (2), and (3)) are applied to rod-bundle geometry typically found in a PWR or BWR core to generate respective subchannel control volume forms. The control volumes are shown in Figure 5. When necessary, empirical correlations are used to close the set of control volume conservation equations. However, in order to calculate the fluid and transport properties of each cell, VIPRE applies finite-difference methods to solve the simplified subchannel conservation equations. The finite-difference methods that VIPRE uses require that each channel be divided axially into a number of discrete computational cells, or 'nodes'. The first and last axial nodes, at the inlet and outlet respectively, are used only to supply boundary conditions to the problem and do not otherwise participate in the solution [12]. Axial spacing between nodes of the intermediate levels is defined by the node length, ΔX, which can vary from level to level. Lateral communication between corresponding adjacent nodes can occur through gaps, with widths of S (see Figure 5). In the gap space between adjacent rods, lateral flow areas exist on planes connecting the centerlines of adjacent rods with areas of SΔX. The primary field variables in the solution are axial mass flow rate, lateral mass flow rate per unit length (crossflow), mixture density and flowing enthalpy, and pressure [12].



(a) (b)

Figure 5. Integral conservation equation control volumes: (a) general; (b) lateral momentum (from [12])

VIPRE has two solution methods to the finite-difference conservation equations: subroutines UPFLOW and RECIRC. The normal solution subroutine, UPFLOW, is similar to the one used in COBRA-IIIC, while the subroutine RECIRC owes its heritage to COBRA-WC. The RECIRC scheme allows for reverse and recirculating flows, and can usually simulate upflow in cases where the standard solution (subroutine UPFLOW) fails. This in turn increases the overall stability of the code. Both schemes give essentially the same results. However, RECIRC is usually much slower than the UPFLOW scheme. Thus, UPFLOW should be used primarily over RECIRC when possible [12].

A flow chart of the UPFLOW numerical solution scheme that VIPRE uses is shown in Figure 6. The final overall solution is calculated iteratively by repeatedly sweeping from the inlet to exit, determining new enthalpies, flows, crossflows, and

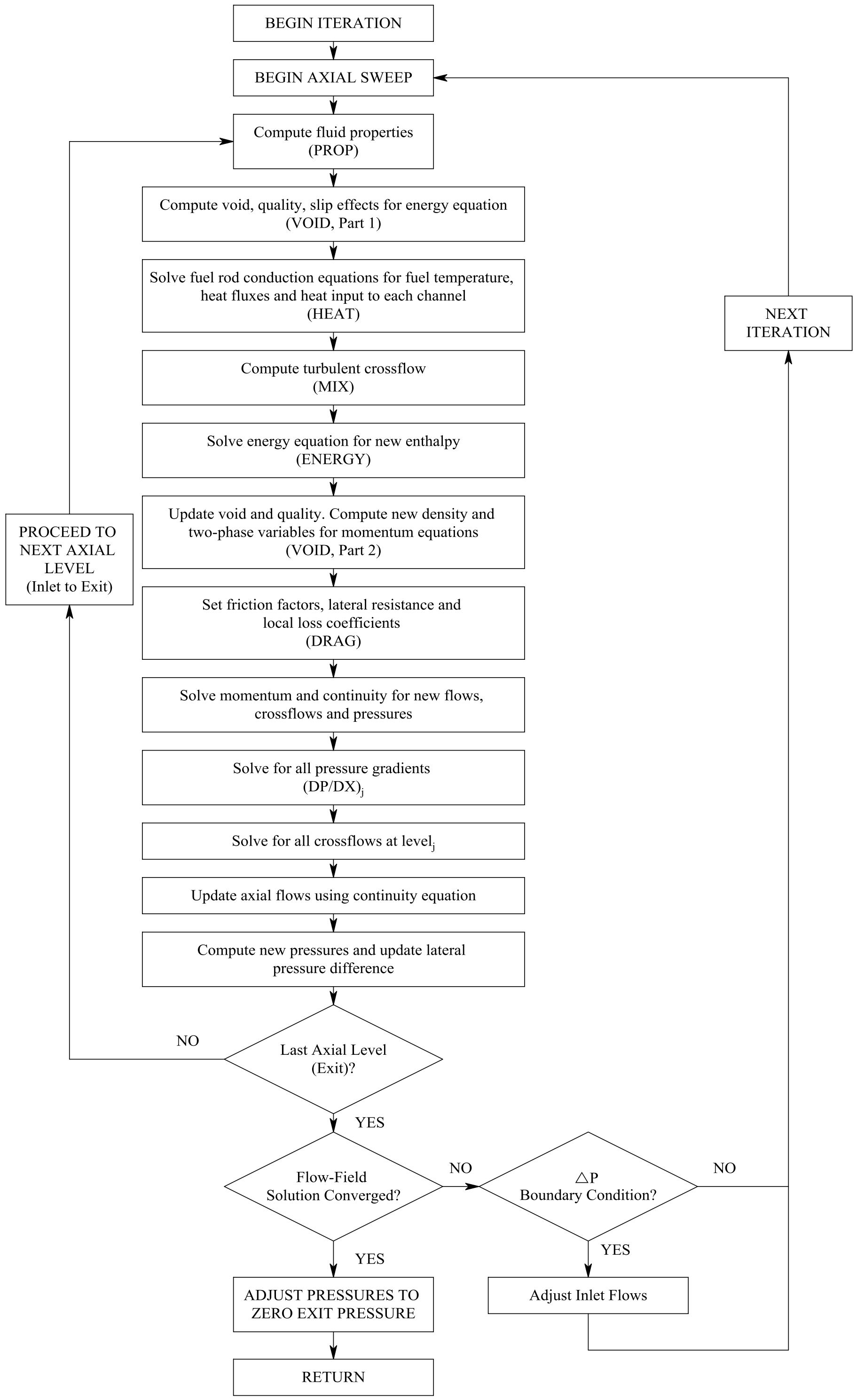


Figure 6. VIPRE “UPFLOW” numerical solution flow chart [12]

pressures for each axial level in turn. Additionally, channel enthalpies and pressures may be iteratively solved for. In such a case, an inner iteration is one complete pass over all channels. The final overall solution is determined to be converged by the code once the maximum fractional changes in crossflow and axial flow between outer iterations are simultaneously below the user-defined input convergence criteria [12].

2.2.4. Heat Transfer Model

Similar to the formulation of the flow-field equations, VIPRE's heat transfer model is based on a control volume approach for the solution to the heat conduction equation. It calculates the rod internal temperature distribution and the heat source term for the fluid energy equation. For the fuel rod type, a dynamic gap conductance model is included in which gap conductance may be specified as either a constant value or with axial and time-dependent variations using input forcing functions. The fluid heat transfer model is used to calculate the heat transfer coefficient of the interface between the heated surface and fluid. The model includes the full boiling curve, from single-phase convection through nucleate boiling to the critical heat flux point, and transition boiling to the stable film boiling regime [12]. Heat conduction is solved for using an implicit finite-difference representation of the conduction equation. VIPRE only considers radial conduction in solid materials such as rods, walls, and tubes, since both circumferential and axial conduction are relatively unimportant in cases applicable to VIPRE. By considering only radial conduction, VIPRE is able to keep the number of conduction nodes down to a manageable size. However, this requires a relatively uniform heat transfer coefficient and fluid temperature distribution around the fuel rod.

The conduction model in VIPRE was developed for nuclear fuel rods, heater rods, tubes, and walls. The heater rod type is included for users needing to simulate heat transfer experiments (e.g. electrical heater rods), while the nuclear fuel rod model allows users to simulate most conductor geometries found in typical reactor fuel bundles. The conductor geometry for a nuclear fuel rod is shown in Figure 7. The nuclear rod type contains a central fuel region followed by a surrounding gap, and finally an outer clad region. There is also an option to model rods with a central void, indicated as “CORE” in Figure 7. However, only cylindrical fuel rods with fluid thermal connection on the exterior of the fuel rod are considered by this model. Material properties needed by the heat conduction model may be obtained by user-input or through built-in functions for uranium dioxide and zircaloy.

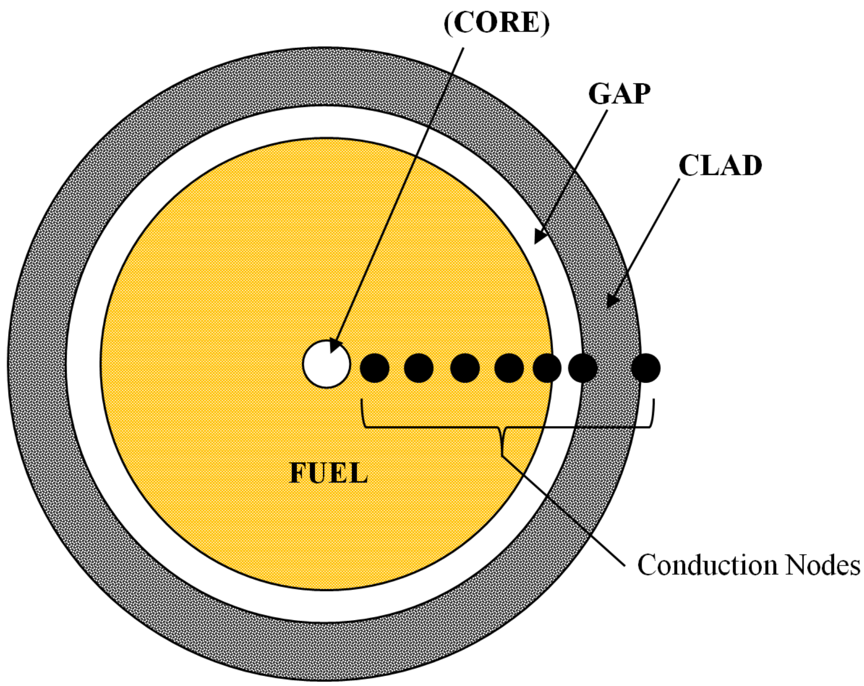


Figure 7. Nuclear rod type conductor geometry

The finite-difference nodes of the heat conduction equation are modeled as control volumes, or 'nodes' (see Figure 7), linked by thermal resistances which form a network of linear equations. The linear equations formed by the set of nodes are solved by Gaussian elimination and simple back-substitution. From a simple heat balance, the heat conduction equation for a control volume (node) can be derived. For node i of Figure 8, the conduction equation is

$$\left(\rho V C_p\right)_i \frac{\partial T_i}{\partial t} = Q_{i-1,i} + Q_{i+1,i} + Q_i''' V_i \tag{4}$$

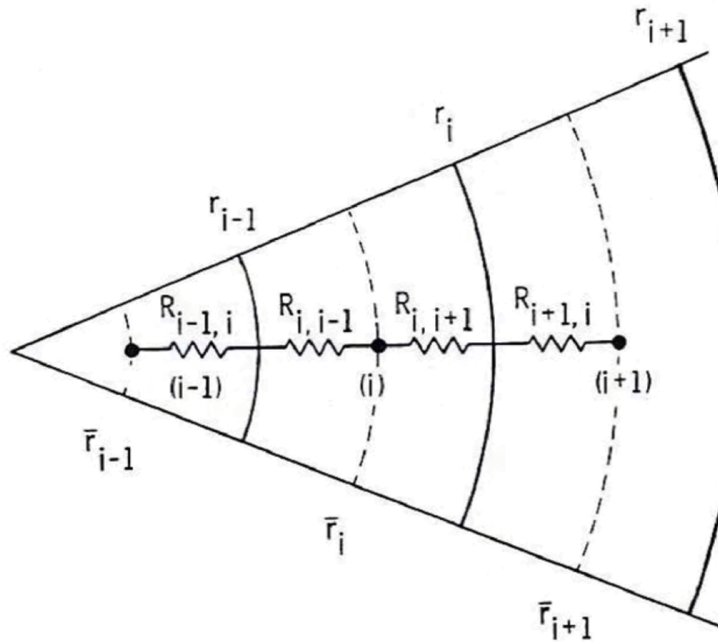


Figure 8. Heat balance node network (from [12])

VIPRE automatically positions radial conduction nodes within conductor geometry. Each region that contains a material is automatically divided into smaller regions of equal radial thickness and a conduction node is place at the volume-average radius of each smaller region, or 'subregion'. However, in regions where one face of a node (subregion) is also a boundary surface, the conduction node is placed at the surface of the region, instead of the center of the node [12]. Boundary nodes occur at the inside and outside surface of both a tube and a wall, and the outside surface of a solid cylindrical rod. They also occur in the case of a nuclear fuel rod at the exterior of the fuel pellet, cladding interior and cladding exterior surface. This nodding within a nuclear fuel rod can be seen in Figure 7. In Figure 8, R is the thermal resistance to heat flow between a set of nodes. The thermal resistance for each node is calculated as a function of thermal conductivity, k, and geometry [12]. The thermal resistance $R_{i-1,i}$ is the resistance to the flow of heat from node $i-1$ to the boundary between nodes $i-1$ and i. The thermal resistance $R_{i,i-1}$ is the resistance to the flow of heat from node i to the boundary between nodes i and $i-1$.

Once the radial locations of the conduction nodes are determined automatically by the code, they are fixed throughout the calculation. Thus, relocation due to thermal expansion is not accounted for [12]. In order to prevent any apparent mass loss from the conductor due to density changes with temperature, the term $(\rho V)_i$ in Eq. (4) is evaluated at the cold state density and dimension to define node i's mass, M_i. Thus, for convenience, Eq. (4) can be re-written as

$$\left(MC_p\right)_i \frac{\partial T_i}{\partial t} = Q_{i-1,i} + Q_{i+1,i} + Q_i^{\prime\prime\prime} V_i \tag{5}$$

The heat transfer through node i is dependent upon the conductance, K, of the material and the temperature gradient applied across the node, which can be expressed as

$$Q_{j,i} = K_{j,i}\left(T_j - T_i\right) \text{ for } j = \begin{cases} i-1 \\ i+1 \end{cases} \tag{6}$$

and

$$K_{i,j} = K_{j,i} \text{ for } j = \begin{cases} i-1 \\ i+1 \end{cases} \tag{7}$$

The conductance can be simply computed as the inverse of the thermal resistance, R, between a set of nodes such that

$$K_{i,i-1} = \frac{1}{R_{i,i-1} + R_{i-1,i}} \tag{8}$$

For the specific case of a node on the external surface of a cylindrical fuel rod ($i = N$), $Q_{i,i+1} = HA(T_b - T_N)$ and Eq. (5) becomes

$$\frac{(MC_p)_N}{\Delta t}(T_N - T_N^n) = K_{N,N-1}(T_{N-1} - T_N) + Q_N'''V_N + (HA_S)(T_b - T_N) \tag{9}$$

where A_s is the surface area, H is the surface heat transfer coefficient, and T_b is the bulk fluid temperature. The surface heat transfer coefficient for a rod n which faces four channels is by definition

$$H_n = \frac{q_n''}{T_n - T_b} \tag{10}$$

The surface heat flux from rod n, q_n'', is defined as

$$q_n'' = \frac{T_n \sum_{i=1}^{4} \phi_{ni} H_{ni} (T_n - T_{bi})}{\sum_{i=1}^{4} \phi_{ni}} \tag{11}$$

where i = subchannel connecting to rod n (6 maximum)

ϕ_{ni} = fraction of rod n's heated perimeter connected to channel i

H_{ni} = heat transfer coefficient based on rod n's temperature and fluid conditions of channel i

T_n = surface temperature of rod n

T_{bi} = fluid temperature of channel i

Separating the temperature terms,

$$q_n'' = \frac{T_n \sum_{i=1}^{4} \phi_{ni} H_{ni} - \sum_{i=1}^{4} \phi_{ni} H_{ni} T_{bi}}{\sum_{i=1}^{4} \phi_{ni}} \tag{12}$$

The average heat transfer coefficient, H_n, is calculated from the heat transfer coefficient in each subchannel as

$$H_n = \frac{T_n \sum_{i=1}^{4} \phi_{ni} H_{ni}}{\sum_{i=1}^{4} \phi_{ni}} \tag{13}$$

and the average bulk fluid temperature, T_b, is

$$T_b = \frac{T_n \sum_{i=1}^{4} \phi_{ni} H_{ni} T_{bi}}{\sum_{i=1}^{4} \phi_{ni}} \tag{14}$$

Equations (13) and (14) are used for the calculations of the circumferentially averaged heat transfer coefficient and fluid temperature for the conduction equation, Eq. (9) [12]. In steady-state simulations, the conduction equation is used to solve for the rod temperatures, and the applied rod power is the fluid heat source term. However, for transients, an iterative procedure is used. This is due to the heat released to the fluid subchannel is coupled to the rod temperature response. In these cases, the boiling heat transfer package is used to calculate the heat transfer coefficients from the fluid conditions and rod temperatures acquired during the previous iteration. After the heat transfer coefficient is solved for, the solution of the conduction equations is used to acquire new iterate rod temperatures. If boiling occurs, the heat transfer coefficient becomes a function of the surface temperature of the rod, which is dealt with by an internal iterative loop between the heat transfer coefficient and the temperature of the rod. Once consistency is reached with the values of both variables, the heat release to the fluid is solved for and another iteration of the fluid solution begins. After convergence is obtained with the fluid solution, more iterations on the conduction solution may be needed, since the paths through which a final solution is obtained are temperature-dependent. These iterations dampen the temperature error (maximum change of node temperature between iterations) to the values specified for convergence [12].

2.3. Neutronic / Thermal-Hydraulic Interface

The adopted neutronic/thermal-hydraulic integration framework consists of a sophisticated spreadsheet (Microsoft Excel) and scripting (PERL [30]) based network [4], however, with significant modifications in both key integration framework components. Modifications to the ‘Excel-based’ VIPRE input deck component were made to accommodate the unique characteristics of the fuel assembly design under investigation in the current research efforts. The script-based run control logic which handles the exchange of information between the neutronics code DRAGON and the thermal-hydraulics code VIPRE, as well as the integration of neutronic power profiles into VIPRE input files were updated to include features required for advanced transuranic materials.

The PERL scripting language was chosen based on its wide use throughout the scientific community, and its strengths in the ability to process text efficiently. This ability allows a PERL script to analyze and manipulate text files easily [4]. The ‘PERL-based’ thermal-hydraulic analysis framework consists of many low-level and high-level scripts which automate the entire analysis process. As a part of this framework, both

VIPRE and DRAGON are treated as "subroutines", supplying information to other processes (scripts) and calculating thermal-hydraulic results (VIPRE). The entire input/output management of files and data is undertaken by the PERL-based framework. This process gathers DRAGON output, integrates the output into the final VIPE file, runs the specified case in VIPRE, and handles the management of results and post-simulation calculations. The only aspect of the thermal-hydraulic analyses which the script-based interface does not handle is the creation of what are called 'skeleton input files' for VIPRE. These files are created by the second component of the analysis framework, the Excel-based interface. Their name is derived from the fact that they consists of only the most basic information, resembling the skeleton of a fully-developed VIPRE input file. These files lack proper VIPRE input formatting, DRAGON-supplied pin radial power peaking factors, material property information, and other key information needed to run a VIPRE simulation. Once the thermal-hydraulic analysis has started, the missing information is supplied to the input deck and properly formatted by the script-based interface. Depending on the type of analysis being performed, additional cases may be added to an input deck based on the specified skeleton input file in order to simulate changes in the power distribution over the lifetime of the core, such as in the case of a steady-state scoping analysis. A complete VIPRE steady-state scoping analysis of a single assembly design may consist of 30 to 50 cases, depending on the lifetime of the assembly and the refinement of the neutronic burnup computational mesh [4].

A basic, but important component of the script-based interface is the handling of DRAGON output for use in VIPRE input, which is needed due to the difference in nodalization schemes between the two codes (depicted in Figure 9). The developed interface translates data (i.e. power profiles) from DRAGON into the proper form for VIPRE.

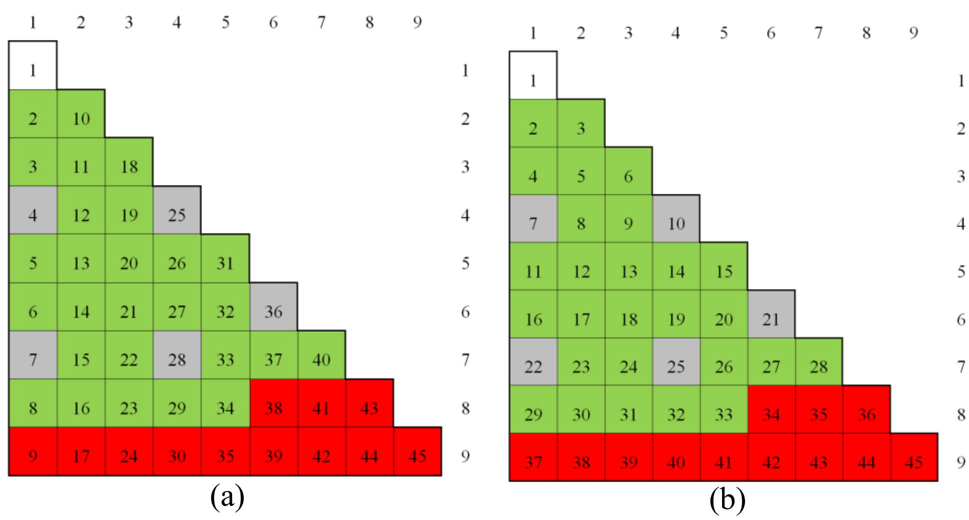


Figure 9. Difference between neutronic and thermal-hydraulic nodalization schemes: (a) Neutronic (DRAGON), (b) Thermal-Hydraulic (VIPRE)

Sophisticated Microsoft Excel spreadsheets are used within the Excel-based interface to aid the thermal-hydraulic analyst in the process of creating accurate representations of desired cases within VIPRE for different analysis types. The need for such a tool is driven by the relatively high likelihood of user-input error in VIPRE input decks. This valuable tool allows for the propagation of simple changes in fuel assembly geometry through tens-to-hundreds of channels. By performing these changes automatically, the likelihood of user-input error is dramatically reduced compared to manually updating values of all dependent-parameters. With the Excel-based method, the analyst is able to input other model parameters such as single and two-phase flow correlations, heat transfer correlations, critical heat flux correlations, inlet temperature and mass flow rate of the coolant, average linear heat rate, grid-spacer location, and system pressure, along with many output options [4]. Many important modifications and features have been added to the Excel-based interface to include the capability to model the SBU-type assembly geometry. Numerous modifications were made to the interface since many of the underlying assumptions in the previous modeling techniques are no longer valid, such as with lumped rod and channel parameter calculations. A more general set of governing equations were utilized in the input deck formulation of the SBU geometry, which reduce to the original set when standard PWR assembly geometry is modeled.

In order to maintain the same total power in VIPRE simulations as the reference core, an iterative core power scheme was added to the Perl script-interface in which the calculated total power output by the code is compared to the user-supplied average linear heat rate. The addition of this scheme to the script-based framework also acts as a modeling check by allowing the analyst to determine if their own calculated average rod linear heat rate results in the equivalent power output of the reference core. If there is a difference between the respective user-calculated and code-calculated power terms, this may imply that either an assumption or modeling error has been made.

3. THERMAL-HYDRAULIC METHODOLOGY

The research efforts of this thesis extend the work of the latest state-of-the-art thermal hydraulic analysis performed by Bingham [4], which studied homogeneous fuel assembly designs, specifically AMOX designs, and created a thermal-hydraulic evaluation methodology for new AFA designs. The particular methodology draws from an extensive list of current thermal-hydraulic methodologies and practices for use in evaluating the thermal performance of fuel assembly designs with similar qualities to those studied in this thesis. The list of reviewed literature includes federal regulatory guides for plant safety and licensing evaluations, previous studies of advanced TRU-burning fuel assembly designs, and work which focused on core and assembly analysis through the use of subchannel codes. For a complete list of reviewed resources, please refer to [4] for further information.

The resulting analysis methodology devised by Bingham [4] allows for the analysis of advanced assembly designs' thermal performance over their entire expected operational burnup lifetime by including time-varying neutronic power profiles due to burnup effects, thermophysical properties specific to an individual fuel type, and accounting for a nuclear power plant's standard operating procedure (SOP) of core reshuffling. Both steady-state and select transient analyses are included in the devised methodology to evaluate the thermal margin of a design during a number of postulated adverse operating conditions; the most limiting of which, is a complete loss-of-flow-accident due to a simultaneous shutdown, or trip, of all reactor coolant pumps (RCP).

The current research efforts extend existing capabilities by introducing the ability to evaluate unique heterogeneous fuel assembly concepts into the thermal-hydraulic analysis framework. In order to demonstrate the added capabilities, the DUPLEX IMF-UOX design, which is a heterogeneous fuel assembly that includes both IMF and UOX fuel within the same assembly, is used.

3.1. Federal Requirements for the Licensing of Nuclear Plants

In the U.S., the federal government has jurisdiction over the licensing and evaluation of all civilian nuclear power plants. The U.S. Nuclear Regulatory Commission (NRC) is the government institution which oversees all civilian nuclear activities and ensures the safety and welfare of the public is protected without undue risk. The NRC was established by the Energy Reorganization Act of 1974, which disbanded the Atomic Energy Commission (AEC) and transferred to the NRC all the licensing and regulatory functions formerly assigned to the AEC by the Atomic Energy Act of 1954 [10 CFR § 1.1 (2012)]. The requirements binding on all persons and organizations who receive a license from the NRC to use nuclear materials or operate nuclear facilities is documented by Title 10 of the Code of Federal Regulations (10 CFR) [31].

In order for a nuclear plant utility to obtain and maintain a license to operate from the NRC, the plant must be shown to satisfy an extensive list of safety criteria set-forth by the NRC as defined by 10CFR. Every nuclear utility company wishing to license a nuclear facility in the U.S. must submit a Safety Analysis Report (SAR) to the

NRC as part of the licensing process, which must address and justify all evaluation criteria covered under the NRC's review process. The NRC's evaluation criteria and guidelines are described by NUREG-0800 [11]. Chapter 15 of NUREG-0800 states that for any new core design, it must be shown to satisfy safety criteria under various postulated events. Such events include various transient conditions, referred to as Anticipated Operational Occurrences (AOO), and postulated accidents. These AOO's are placed in one of the following categories:

1. Increase in heat removal by the secondary system
2. Decrease in heat removal by the secondary system
3. Decrease in Reactor Coolant System (RCS) flow rate
4. Reactivity and power distribution anomalies
5. Increase in reactor coolant inventory
6. Decrease in reactor coolant inventory
7. Radioactive release from a subsystem or component

Additionally, the above categories are divided into four categories by the American Nuclear Society (ANS) according to their anticipated frequency of occurrence and potential radiological consequences to the public and are recognized by the NRC [32]:

- Condition I: Normal operation and operational transients
- Condition II: Faults of moderate frequency
- Condition III: Infrequent faults

- Condition IV: Limiting faults

In order to satisfy the above requirements, many engineering disciplines are needed to thoroughly investigate all required scenarios. For nuclear systems analysis, neutronic and thermal-hydraulic disciplines are used together to form a complete understanding of a design's characteristics. The key thermal-hydraulic parameters which are to be used in discussing the results from accident and transient results are [11]: average and maximum heat flux, RCS pressure, minimum DNBR, core coolant flow rates , fuel and cladding maximum temperatures, and coolant conditions (inlet and average core temperatures, average and hot channel exit temperatures, and steam volume fractions). For each of these parameters, results are discussed in terms of the limiting safety margins defined as the differences between analysis results and respective imposed design limits.

3.2. Review of Latest Thermal-Hydraulic Framework

Much of the fundamental work in regards to VIPRE structure and modeling has been adopted from earlier efforts [4] and is re-iterated here for clarity. Previous efforts by Bingham [4] considered the effect of burnup on AMOX fuel assembly performance and thermal safety margin over the design's 62 GWd/tHM expected operational assembly lifetime. This was accomplished by including burnup-dependent fuel rod power profiles and fuel specific isotopic vectors from neutronics calculation into thermal-hydraulic analyses, and by implementing these neutronics properties into thermal property calculations, which were utilized by the thermal-hydraulic code

VIPRE-01 [12]. The VIPRE code was developed to help utilities perform nuclear plant reload safety and licensing analyses and evaluate thermal margins [18].

The EPRI thermal hydraulic code VIPRE-01 was chosen based on its adoption by nuclear utilities, thorough documentation, ongoing maintenance, and application in evaluating the minimum departure from nucleate boiling ratio (MDNBR) for Westinghouse's AP1000 plant design [4]. VIPRE is a subchannel thermal hydraulic analysis code used throughout the commercial nuclear industry to analyze the thermal margin for existing and new FA designs, and licensing calculations [13]. The developed framework by Bingham [4] is the first to consider the effects of burnup on AMOX fuel assembly performance and thermal safety margin at numerous burnup steps over its expected operational lifetime. This work is extended in the current research efforts by including the DUPLEX fuel design [8] and carrying out similar analyses.

A detailed description of the assumptions, evaluation of transient conditions, neutronic power profile integration, effects of assembly shuffling, and integration of burnup-dependent UO_2 and MOX fuel thermophysical properties can be found in Bingham [4]. A summary of important features, assumptions, and limitations is as follows:

- Steady-state scoping simulations are performed at 118% nominal core power in order to invoke a pseudo-transient state representative of ANS Condition I and II transient events. Since a steady-state pseudo-transient simulation is used to simulate a transient condition, core power is increased an additional 6% above the 112% maximum core limit to induce limiting conditions

- Transient simulations are used to validate steady-state scoping analysis results, and to determine the thermal performance of a design under ANS Condition II and III transient events by simulating partial and complete loss-of-flow-accidents, respectively
- Condition II and III loss-of-flow-accident transients are modeled with less conservatism than the steady-state analysis. Thus, transient analyses are performed at only 12% overpower to allow for consistent overpower margin for any specific case of prescribed axial heat flux and coolant channel conditions [33]
- F_Q (hot pin / core average) = F_Q for CPNPP
- Central void formation within the fuel pellet is not modeled. In typical UO_2-loaded PWRs, the formation of a central void within a fuel pellet, which occurs after the first rise to power within a few days of full power operation, decreases the centerline temperature of the fuel pellet. Since this is not modeled, VIPRE results tend to be conservative
- The conductance between the outer pellet surface and the inner clad surface is assumed to be constant. In actual fuel rods, the gap conductance increases after the first rise of power due to thermal expansion of the fuel pellets. Additional conservatism is added to VIPRE results from this assumption
- The magnitude of the turbulent mixing in the core model is not fully understood

- Effects of fission gas buildup in the fuel pins are not modeled
- Transient boundary conditions are supplied to VIPRE from MELCOR for a generic PWR.

The primary figures of merit for this thesis are the MDNBR, peak cladding temperatures (PCT), and peak fuel temperatures (PFT) in order to determine the thermal safety margins of the DUPLEX design. Existing thermal-hydraulic/neutronic text-based coupling methods are used and modified to allow the inclusion of heterogeneous fuel assemblies into the steady-state and transient analyses. Also, due to the unique material aspects and lack of experimental data for the particular IMF fuel under consideration, theoretical models and combinatory methods of composite material thermophysical properties are explored, evaluated, selected, and utilized in this thesis. *The current work is the first of its kind by performing full core burnup-dependent analyses of heterogeneous Seed-Blanket Unit (SBU) type fuel assemblies with MgO-based IMF fuel designs over the entire expected operational burnup lifetime using the 'subchannel' approach.*

3.3. Previous Work in Advanced TRU-Burning Fuels

The thermophysical properties of UO_2 and MOX fuels have been well studied and have years of successful operation in nuclear reactor cores internationally. However, the thermophysical properties of new advanced fuels (fuels other than UO_2 and MOX) are far less known and further materials R&D is needed to ensure the accurate knowledge of the behavior and safety of these new advanced fuels, under a variety of reactor conditions. Material thermophysical research in the area of AMOX fuels has been under investigation for some time and data is available for only a few types of designs. The amount of available data for minor actinide dioxide based IMF fuels is even scarcer due to difficulties related to their fabrication and handling [34]. Thus, there exists a large uncertainty in minor actinide oxide fuel thermal conductivities.

The IMF fuel designated as the blanket component of the SBU-type DUPLEX FA was proposed under the Advanced Fuels Cycle Initiative (AFCI) LWR transmutation program in which Dr. Medvedev from Idaho National Laboratory (INL) was in charge of fabrication. The fuel designated as "LWR-2-E", $(Pu,Np,Am)O_2$-MgO-ZrO_2, was considered to be an IMF replacement to AMOX fuels [35]. A shortcoming of ZrO_2-based IMFs is the relatively low thermal conductivity of ZrO_2. In order to address this issue, Medvedev et al. [7] [36] [37] investigated the feasibility of a dual-phase MgO-ZrO_2 IMF. The addition of MgO to the ZrO_2 inert matrix in significant quantity has been found to increase the matrix material's thermal conductivity to greater than that of standard UOX or MOX fuel compositions [7] [10] . See Figure 10 for a comparison between the thermal conductivity of MgO and select refractory materials at 500^{o}C. Thus, by increasing the thermal conductivity of the fuel material, this fuel design was expected to produce favorable thermal margin results. However, the AFCI program was canceled before the LWR-2 series fuel tests were completed. Thus, alternative methods must be investigated for the determination of adequate values for the thermal properties, and limits, of $(Pu,Np,Am)O_2$-MgO-ZrO_2 fuel.

Similar fuel designs have been investigated by [38] under the Integrated Project EURO-TRANS (EUROpean research programme for the TRANSmutation of high level nuclear waste in ADS), part of the EURATOM Framework Programme 6 (FP6). The domain AFTRA (Advanced fuels for TRAnsmutation system) identified two composite fuel systems: a CERamic matrix-CERamic host phase (CERCER) where oxide fuel particles are dispersed in a magnesia matrix, and a CERamic matrix-METal host phase (CERMET) with a molybdenum matrix instead of the MgO matrix to host a ceramic fissile phase [38]. The LWR-2-E fuel was similar in chemical composition to the proposed CERCER fuel by AFTRA. However, the AFTRA CERCER fuel for the European Facility for Industrial Transmutation (EFIT) did not contain ZrO_2 in the host inert matrix.

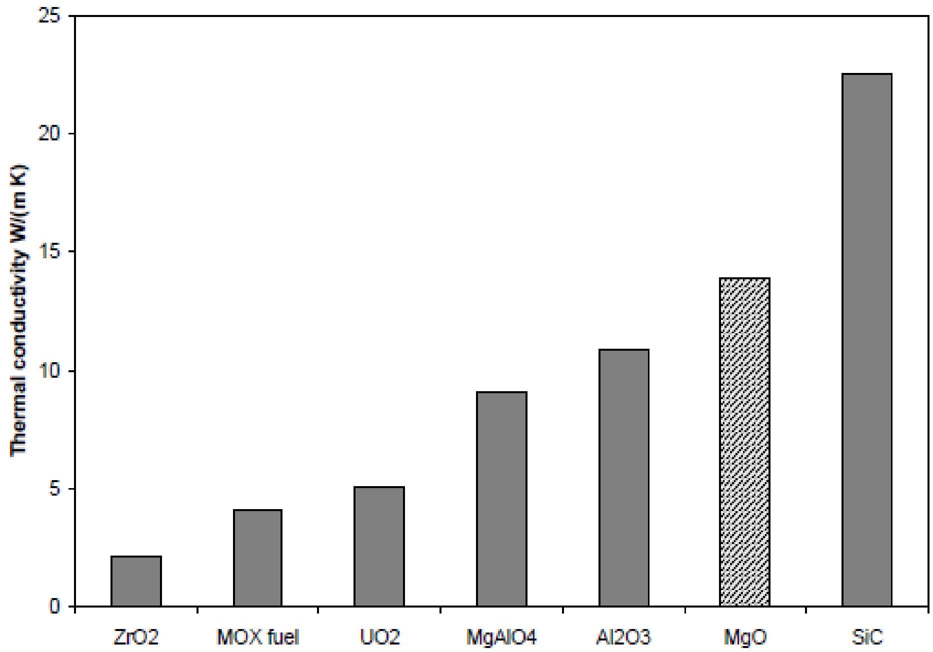


Figure 10. Thermal conductivity of MgO compared to selected refractory materials at 500°C (from [7])

In CERMET fuel elements, in which the heat generating material consists of multiple individual ceramic particles heterogeneously dispersed within a metallic matrix, the heat conduction process is more complex than in that of an alloy system. In all nuclear fuel designs, the thermal conductivity is affected by many factors. The major factors include porosity, temperature, burnup, oxygen-to-metal atom ratio, doping material content, and pellet cracking [33]. However, even more factors are considered in the case of composites. These factors include size, shape, and orientation of the particles as well as the relative amounts and properties of the materials used in the composite [9].

Similar dependencies also apply to CERCER fuels. Burnup phenomena which affect the thermal conductivity include dissolution and precipitation of solid fission products, fission gas bubbles and pores, stoichiometric deviation, and radiation damage induced circumferential cracks [39]. However, many of these phenomena require careful evaluation from experimentation which is not yet available for the DUPLEX IMF fuel.

3.4. Previous Work in SBU Thermal Hydraulic Analysis

The VIPRE code, and its predecessor COBRA-EN [40], for the thermal hydraulic evaluation of SBU-type fuel assemblies has been performed in the past: Busse [20], and Todosow et al. [22]. However, these analyses use the VIPRE code to a limited extent and do not model transient behavior of the reactor system within VIPRE itself, rather they use codes such as RELAP-3D [15] to perform such additional calculations. The thermal-hydraulic analysis framework developed by Bingham [4], simplifies matters by implementing a stream-lined approach to evaluating various fuel assembly designs which results in faster feedback to designers, while maintaining suitable accuracy as compared to more tailored transient codes, such as RELAP-3D [15]. This work aims to gather the knowledge gained from previous SBU analysis and implement into the latest thermal-hydraulic analysis methodology/framework.

Thermal hydraulic analyses of fuel assemblies typically fall into either the fuel assembly scale, or the whole-core scale. Both scales are usually modeled with $1/8^{th}$ symmetry to lessen the computational burden while maintaining satisfactory level of detail.

Hot assembly modeling is a useful tool in the preliminary analysis of various fuel assembly designs and is often used in scoping studies to down-select competing designs. By modeling the most limiting "hot" assembly, designs which do not pass can be discarded or modified before attempting more time intensive whole-core simulations. This type of modeling is usually the first step in thermal-hydraulic analysis of new fuel assembly designs.

Whole-core modeling is usually performed after hot assembly modeling is performed. A detailed description of the latest state-of-the-art whole-core thermal-hydraulic modeling techniques and analyses can be found in Bingham [4]. However, the fuel assemblies investigated by Bingham are homogeneous (only one fuel type). Another study, by Todosow et al. [22], includes the whole-core analysis of SBU-type fuel assemblies, but does not use the latest modeling techniques developed by Bingham [4]. In order to extend the work by Bingham to SBU-type fuel assemblies, a detailed review of the SBU modeling work performed by Todosow et al. [22] was completed, which is used in this thesis to model SBU assemblies using the latest thermal-hydraulic analysis methodology.

3.4.1. 1/8th Hot Assembly Modeling

An extensive study on the optimization of thorium-utilizing heterogeneous core design concepts for use in current PWRs has been performed by Todosow & Kazimi [22]. Analyses utilized a standard Westinghouse reactor with 193 fuel assemblies of the 17x17 variety as the model core, similar to that used by Bingham [4]. Two design concepts were considered: the Whole Assembly Seed and Blanket (WASB) concept and the SBU concept. The WASB concept core utilizes PWR fuel assemblies consisting of either seed units or blanket units arranged in the core in a modified checker-board pattern (Figure 11). On the other hand, the second design, the SBU concept, also known as the Radkowsky Thorium Fuel (RTF) concept, utilizes a dual-zone fuel assembly design with inner and periphery regions composed of different fuels. This type of a design is a one-for-one replacement to standard PWR assemblies (Figure 11). The specific SBU design considered by Todosow et al. utilizes UO_2 seed fuel and UO_2-ThO_2 blanket fuel.

Thermal-hydraulic analyses of the WASB and SBU concepts were performed with the VIPRE and COBRA-EN sub-channel thermal-hydraulics codes, respectively [22]. COBRA-EN was used to calculate the flow distribution, pressure drop, and DNBRs throughout the SBU assembly under various power conditions. Due the similarities in COBRA-EN and VIPRE-01 codes, results of optimization studies and modeling techniques from Todosow & Kazimi [22] are applicable to the work performed in this thesis.

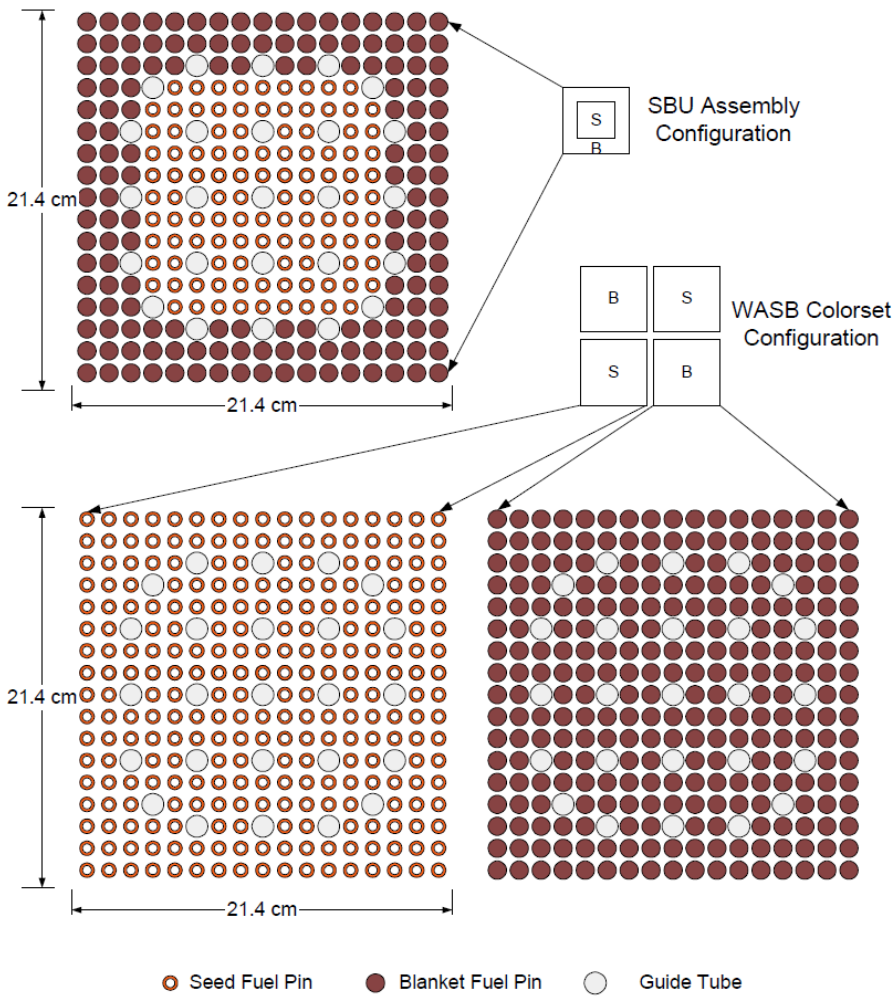


Figure 11. SBU and WASB Fuel Assembly Design (from [22])

Hot assembly modeling for the SBU design determined that the assumed value of 1.5 for the hot assembly peaking factor would result in MDNBR values less than the limit of 1.3 for both nominal and 112% overpower conditions. In order to meet limits, an assembly peaking factor for the hot assembly of ~1.2 is required. Also, in an effort to divert more flow to the regions of low DNBR (shown to occur in the seed rod region), several calculations were performed with higher spacer grid loss coefficients in the blanket rod regions than the seed rod regions to determine the effect on MDNBR. For comparison reasons, the base case was chosen to use a uniform loss coefficient of 0.86 for both seed and blanket regions. Increasing the grid loss coefficients in blanket region over a range of 0.86 to 1.5 showed only marginal improvement in the resulting MDNBR values (from 1.280 to 1.335). As a result of these findings, the conservative uniform spacer grid loss coefficient of 0.86 will be used in DUPLEX calculations. It should be noted, however, that it should be possible to tailor the grid-loss coefficients in each region (i.e. resistance of the grid-spacers) so as to achieve acceptable thermal margin. One acceptable combination is to reduce the grid loss coefficients of the inner "seed" region to K_{seed}~0.6 while increasing the coefficients of the outer "blanket" region to $K_{blanket}$~2.0 [21]. The resulting hot assembly peaking factor would be reduced from 1.5 to 1.4, and even at 118% power, the optimized SBU assembly design will have an MDNBR > 1.3, while the baseline case remains below [22].

COBRA-EN has many built-in DNBR correlations, the most recent of which is the EPRI correlation. Comparisons by Todosow & Kazimi [22] showed very similar results for the W-3 and EPRI correlations. The W-3 correlation calculated an MDNBR of 1.280 at an axial location of 1.638 m, and the EPRI correlation calculated an MDNBR of 1.241 at an axial location of 2.095 m. Both correlations predicted the same rod and channel locations of the MDNBR. Due to the similarity of results, it was decided to use the W-3 correlation for the evaluation of DNBRs in the rest of their analyses.

3.4.2. 1/8th SBU Core Modeling

The 1/8th hot assembly model discussed in the previous section can be extended to a 1/8th core-wide model in a similar manner. Core-wide modeling is usually performed after a particular design has been shown to satisfy selected metrics of the 1/8th hot assembly model simulations, usually in terms of safety margin or performance characteristics. Since a 1/8th core model is more detailed in terms of what is being modeled, the computational time involved is greater than that of the hot assembly model. In order to decrease the computational burden of the increased modeling detail, the technique of lumping assemblies can be utilized to decrease the overall detail of the core model, while maintaining sufficient accuracy. Lumping of assemblies further away from the hot assembly is possible in a sub-channel analysis, since the effect of other assemblies on the thermal-hydraulic response of the hot assembly is reduced as the distance between them is increased [22]. Thus, as the distance from the hot assembly is increased, the number of assemblies lumped together increases. The basic lumping methodology of both the channels and the rods used in the work performed in Todosow et al. [22] is the same as that found in Bingham [4], and is also suggested for use by the VIPRE-01 manual [13].

The fractions of power generated in the seed and blanket regions were taken to be the same values as those used in the hot assembly modeling (seed: 0.602; blanket: 0.398). The resulting peak local power factor for the first cycle was shown to be 3.65. Results of the 1/8th core simulations showed similar MDNBR values to that of the 1/8th

assembly case. The MDNBR at nominal conditions for the 1/8th core case is 1.588, and for the 1/8th hot assembly case is 1.585. Additional cases were performed for each model in which more conservative assumptions were used. In order to simulate a transient in a steady-state simulation, the inlet temperature was raised by 2ºC, the core flow rate was reduced by 5%, and the power was increased to 118%. The resulting pseudo-transient simulation for the 1/8th core case yielded a MDNBR value of 1.241, which is below the suggested limit of 1.3 for most LWR's.

3.5. Technical Approach for Thermal-Hydraulic Analysis of DUPLEX Fuel Assembly Designs

The thermal-hydraulics code VIPRE-01 is used to evaluate steady-state and transient analyses. Steady-state analysis boundary conditions are supplied from the reference plant's Final Safety Analysis Report (FSAR) and neutronic calculations. The reference plant for the current research efforts is the Comanche Peak Nuclear Power Plant (CPNPP) Nuclear Unit 1, due to the availability of data. Operating parameters and characteristics of the reference plant are shown in Table 1. The design characteristics of the reference UO_2 design are given in Table 2. Transient analyses include loss-of-flow accidents (LOFAs) ranging from a partial LOFA (PLOFA), in which only one reactor coolant pump is tripped off-line, to a complete LOFA (CLOFA), in which all four reactor coolant pumps are tripped off-line. The LWR severe accident code MELCOR [14] is also used to model the primary side of the reference nuclear power plant (NPP) throughout the proposed transient progressions to supply boundary condition data, such

Table 1
Reference Westinghouse PWR plant operating parameters and characteristics (from [41])

Property	Value
Nominal reactor core power (MW)	3458 (thermal)
Primary system pressure (MPa)	15.41
Estimated core pressure drop (MPa)	0.12
Core coolant inlet temperature (K)	566.1
Average coolant core temperature rise (K)	32.9
Total core mass flow rate (Mg/s)	18.91
Effective core mass flow rate (Mg/s)	17.93
Active core height (m)	3.66
Heat flux hot channel factor (F_Q)	2.42
Nuclear enthalpy rise hot channel factor ($F_{\Delta H}^N$)	1.55
Nuclear conservatism factor (F_U^N)	1.05
Fuel assemblies in core	193
Fuel rods per assembly	264
Instrument tubes per assembly	1
Control rods per assembly	24
Grid-spacers per assembly	8

Table 2
Fuel design parameters of the reference Westinghouse PWR plant, Comanche Peak NPP [41]

Parameter	Value
Fuel type	UO_2
^{235}U enrichment (wt. %)	4.90
Fuel pellet outer diameter (mm)	8.2
Gap thickness (mm)	0.05
Cladding thickness (mm)	0.57
Fuel rod outer diameter (mm)	9.50
Number of fuel rods	264
Cladding material	Zircaloy-4
Control rod and instrumentation tube diameter (mm)	12.24
Assembly geometry	17 × 17
Lattice pin-to-pin pitch (cm)	1.26
Fuel assembly pitch (cm)	21.50

as system pressure and flow rate, to VIPRE. Details of the MELCOR analysis can be found in [4]. The detailed core and assembly results from the VIPRE transient simulations are then compared to simulation results of a standard UO_2 loaded reference core in terms of the aforementioned thermal figures of merit, and to design limits specific to each fuel design provided in the available literature and from guidance in Federal Regulatory Guide NUREG-0800 [11].

4. THERMAL CONDUCTIVITY OF ADVANCED FUEL MATERIALS

As an extension to the work performed by [4], the fuel thermal conductivity is the primary thermophysical property of interest for the current research effort. In regards to nuclear fuel safety and design, the thermal conductivity is one of the most important material properties since it is a measure of how well a particular material is able to dissipate thermal energy. A material's ability to dissipate thermal energy affects fuel performance parameters such as maximum fuel temperature, cladding temperature, pore migration, and fission gas release. However, the thermal conductivity of materials is not well understood, and has been the focus of numerous studies. The environment that nuclear fuel is exposed to further complicates the ability to accurately determine all of the contributing factors to a fuel's thermal conductivity. Models representing nuclear fuel thermal conductivity are highly dependent upon actual experimental and operational data for specific, already developed, fuel types. Also, the extrapolation of such models to new advanced fuel materials has been difficult without the backing of experimental data. While many theoretical methods have been made for predicting the thermal conductivity of materials, none have been found to produce reliable results without the presence of experimental data for tuning and model selection.

Fuel thermal conductivity has been found to be dependent on numerous parameters and is related to both the chemical and physical structure of the material in a complex manner, leading to difficulty in quantifying such a property analytically.

Therefore, the accurate determination of a fuel material's thermal conductivity is desirable. In order to produce a thermal conductivity model, with its many dependencies, for IMF fuel in VIPRE, an extensive survey of similar fuel material components, methods, and models was made, including standard and advanced fuel types. A more detailed analysis of standard UO_2 and AMOX properties previously implemented in the VIPRE framework can be found in Bingham [4].

4.1. Theory and Background

Thermal energy, or heat, can be transmitted through solids via electrical carriers (electrons or holes), lattice vibration waves (phonons), electromagnetic waves, spin waves, or other excitations [42]. The thermal conductivity is the summation of these lattice vibrations, electron hole pairs, and radiant heat transfer [43]. The dominant heat transport method, if not the only one, for insulators is through lattice vibrations, while in metals and alloys the free electrons transport most of the thermal energy, and often overshadow the lattice vibration contribution. The thermal conductivity of materials can vary greatly in both magnitude and temperature dependence from one material to another. This variability is caused by differences in grain sizes for polycrystalline materials, lattice defects (imperfections), carrier concentrations, dislocations, anharmonicity of the lattice forces, carrier and lattice wave interactions, magnetic ion and lattice wave interactions, etc [42]. Ceramic materials, such as those found in nuclear fuel, i.e. UO_2, exhibit insulator like properties at lower temperatures and metal like properties at much higher temperatures, if at all.

Lattice thermal conduction dominates the heat transport of thermal energy in non-metals for a large temperature range. Thermal vibrations within a rigid crystal lattice arise from a superposition of progressive displacement waves (lattice waves), which are the normal modes of the crystal and carriers of thermal energy as well [44]. In solids, atoms vibrate about their equilibrium positions (crystal lattice). The vibration of each atom is strongly coupled with neighboring atoms. The quantized modes of these crystal lattice vibrations are defined as "phonons". In the presence of a temperature gradient, thermal energy is carried by wave packets consisting of various phonons [42].

Experimentally, thermal conductivity is usually determined from thermal diffusivity, heat capacity, and density according to the following equation:

$$k(T) = \alpha(T)\rho(T)C_p(T) \tag{15}$$

where $\alpha(T)$ is the thermal diffusivity, $\rho(T)$ is the density, and $C_p(T)$ is the heat capacity.

The thermal conductivity of non-metallic materials can be expressed by a classical phonon transport model of dielectric solids above their Debye temperature:

$$k = \frac{1}{A + BT}\ [W/m \cdot K] \tag{16}$$

where the constant A in Eq. (16) above, is the *lattice defect thermal resistivity* due to the interaction of phonons with the lattice defect, and the BT term corresponds to the *intrinsic lattice thermal resistivity* due to phonon-phonon interactions based on the Umklapp process [45]. A caveat to using theoretical models such as Eq. (16) however, is that most of them can only be compared to experimental results in lower temperature ranges [42].

4.2. Thermal Conductivity Modeling

In order to determine the operating fuel temperature of fuel elements within a nuclear reactor, the thermal conductivity of the material must be known. However, when the fuel material is of the CERCER type, the determination of the thermal conductivity without extensive experimentation is difficult, due to the complex nature of the heat conduction process in such a material [9]. Thus, in the case of (Pu,Np,Am)O_2-MgO-ZrO_2 the problem of determining thermal properties is two-fold: (1) determining the method in which to combine thermal properties of component materials to yield an accurate representation of the final composite's thermal properties, and (2) the inclusion of transuranic oxides requires theoretical modeling of the component materials' properties or assumptions to be made on their properties since experimental data is scarce.

If a composite material is formed from the inclusion of a small number of spherical particles dispersed within another material, it is possible to derive a mathematical relationship between the two constituent materials' volume fractions and thermal conductivities such that the effective thermal conductivity of the composite may be determined. A variety of investigators have attempted to mathematically solve the problem of predicting properties of heterogeneous materials. Much of this work has been summarized by Miller [9], Staicu et al. [46], and Wang et al. [47] [48]. From these works, several analytical and theoretical methods that can be used to predict the thermal conductivity of composite systems have been examined for their applicable ranges, and were found to be fairly restrictive in their applicability.

There are two main approaches for modeling the thermal conductivity of materials. The first approach is to theoretically model the lattice thermal conductivity of composite materials based on the Debye-Einstein theory of ionic dielectrics and on the Klemens-Callaway approach to the heat conduction problem [42] [44] [49]. This method requires the mass numbers, the lattice parameters, the elastic moduli, the Grüneisen parameters, the electronic excitations spectra, the concentrations and dimensions of the static defects [34]. Determining these parameters for most actinide dioxide materials can be difficult, if not impossible without experimentation. The second approach is to use a combinatorial method, such as one of the five fundamental effective thermal conductivity structural models (*Series*, *Parallel*, two forms of the *Maxwell-Eucken*, *Effective Medium Theory*) [46] [47], to combine component material properties in order to predict the properties of the composite material. The *Series* and *Parallel* models, referred to as the Wiener bounds, define the lower and upper bounds for the effective thermal conductivity of any heterogeneous material for which the components' volume fractions, v, and thermal conductivities, k, are known accurately, as long as conduction is the only mechanism for heat transfer involved [47]. The two forms of the *Maxwell-Eucken* model, referred to as the Hashin-Shtrikman (HS) bounds, give the upper and lower bounds of the effective thermal conductivity for two-phase isotropic materials [48]. Due to the current high degree of uncertainty in CERCER fuel properties, simpler methods are more convenient. Thus, the method of effective thermal conductivity structural models is primarily used in modeling of CERCER fuel for this thesis, but theoretical microscopic approaches such as in [34] have still been reviewed and are discussed for future use as research and data becomes available in the open literature.

4.3. Estimating Thermal Conductivity of CERCER Fuel Materials for Nuclear Reactor Applications

The thermal conductivity of representative ZrO_2 [43], MgO [44], and 50/50 (wt. %) MgO-ZrO_2 [7] samples are depicted in Figure 12. It is easy to recognize that a simple average over the constituent parts does not accurately reproduce the result depicted for the binary MgO-ZrO_2 composition. Thus, the need for models which can accurately reproduce thermal conductivity behavior of multi-component systems arises such that the unknown behavior of similar systems can be accurately predicted. As mentioned in the previous section, there are many different methods available for effective thermal conductivity calculations. However, there is no universally agreed upon method or scheme which has been found to accurately represent complex phenomena in all cases. The following sections discuss various methods suggested in the available literature, so that the formulation of an appropriate approach to modeling LWR-2-E fuel thermophysical properties can be made.

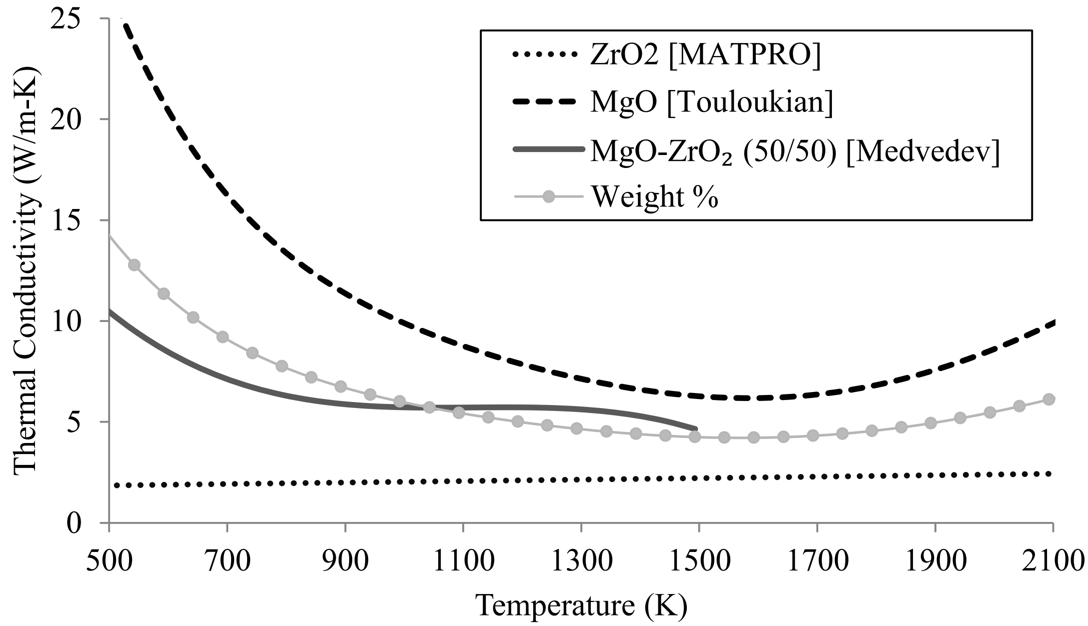


Figure 12 Thermal conductivity of MgO, ZrO_2, MgO-ZrO_2 50/50 wt.% mixture, and calculated mixture based on wt.%

4.3.1. The 5 Basic Structural Models for Effective Thermal Conductivity

The five fundamental effective thermal conductivity structural models for two phase materials as described by [47] and [48] are the *Parallel*, *Maxwell-Eucken* (two forms), *Effective Medium Theory* (*EMT*), and *Series*. The Parallel and Series methods assume in their derivations that the physical structures are composed of layers of the components oriented in either parallel or perpendicular to the direction of heat flow, as indicated by their names. The Wiener bounds are valid for any microstructure and are based on the simplest statistical information that can be found for a material: the volume fraction.

The *Maxwell-Eucken* (*ME*) model is a rather useful tool in effective thermal conductivity modeling. The *ME* model assumes a dispersion of small spheres within a matrix of a different component (continuous phase), with the spheres being far enough apart such that the local distortions to the temperature distributions around each of the spheres do not interfere with their neighbors' temperature distributions. In the case of a two-component material, there are two forms (corresponding to upper and lower bounds) of the *ME* model which depend on which component makes up the continuous phase [47]. These bounds are known as the Hashin-Shtrikman bounds and are valid for any macroscopically homogeneous and isotropic medium. The Hashin-Shtrikman bounds can be extremely useful in cases that involve two-components of similar thermal conductivities. If the differences between the upper and lower bounds are small, an equivalent thermal conductivity can be easily derived. If the continuous phase has a much larger thermal conductivity than the dispersed phase, the upper bound provides a good estimate of the effective thermal conductivity and vice-versa [46].

The *Effective Medium Theory* (sometimes referred to as the Bruggeman mixture model [9]) assumes a completely random distribution of the components in which neither phase is completely surrounded by the other phases. The *EMT* model has been widely used throughout the industry for CERMET fuels and has shown to produce favorable results in most cases, such as W-UO_2 and Mo-UO_2 [9]. The equations for the five fundamental effective thermal conductivity structural models are given by Eqs.

(17)-(21), summarized in Table 3. In the case of multi-component materials (> 2 components), Wang et al. states that they may be dealt with through the successive application of the basic two-component models. Using the same data for MgO and ZrO_2 from Figure 12, the *Parallel*, *ME1*, *EMT*, *ME2*, and *Series* models as defined in Table 3, are used to re-create the thermal conductivity curve for the MgO-ZrO_2 50/50 wt.% depicted in Figure 13.

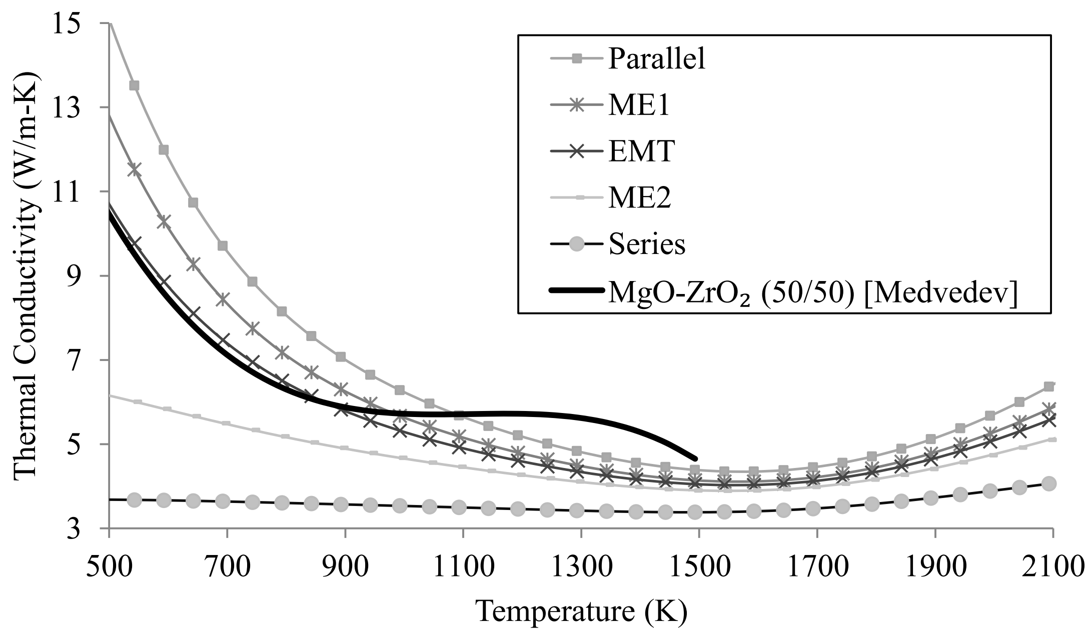
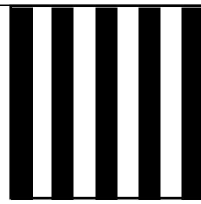
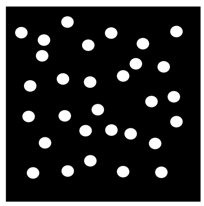
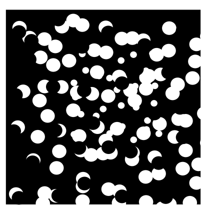
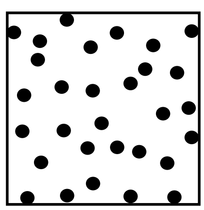
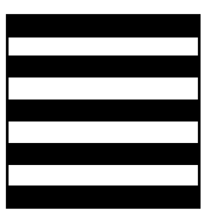


Figure 13 Effective thermal conductivity structural models for MgO-ZrO_2 50/50 wt.% mixture

Table 3
Fundamental k_{eff} structural models for two-component materials (from [47])

Model	Structure schematic (vertical heat flow)	k_{eff} equation	Eq. number
Parallel (maximum value)		$k_{eff} = v_m k_m + v_f k_f$	(17)
Maxwell-Eucken 1 (*ME1*) k_m = continuous phase k_f = dispersed phase		$k_{eff} = \dfrac{k_m v_m + k_f v_f \frac{3k_m}{2k_m + k_f}}{v_m + v_f \frac{3k_m}{2k_m + k_f}}$	(18)
Effective Medium Theory (*EMT*)		$\dfrac{k_m - k_{eff}}{k_m + 2k_{eff}} = \dfrac{v_p}{1 - v_p} \dfrac{k_{eff} - k_p}{2k_{eff} + k_p}$	(19)
Maxwell-Eucken 2 (*ME2*) k_f = continuous phase k_m = dispersed phase		$k_{eff} = \dfrac{k_f v_f + k_m v_m \frac{3k_f}{2k_f + k_m}}{v_f + v_m \frac{3k_f}{2k_f + k_m}}$	(20)
Series (minimum value)		$k_{eff} = \dfrac{1}{\frac{v_m}{k_m} + \frac{v_f}{k_f}}$	(21)

4.3.2. Estimating CERMET Fuel Material Thermal Conductivity

In determining the thermal conductivity of CERMET fuels, an extensive literature survey and review was documented by Miller [9]. The same methods used in deriving mathematical relationships for effective CERMET fuel properties can be applied to CERCER fuels. As a result of the literature review, three basic models were shown to be satisfactory for estimating the thermal conductivity of CERMET fuel material:

1) The dilute dispersion model
2) The Bruggeman variable dispersion model
3) The Bruggeman mixture model (EMT Eq. (19))

The above models are idealized in assuming spherical shape and isotropic behavior of the particles. Anisotropic effects are not taken into account. While most things in nature are non-ideal, these models have been shown to provide satisfactory results. Anisotropic effects are addressed in other models, but the use of such models would be unwise since the actual characteristics and final manufacturing techniques of the LWR-2-E fuel material are unknown.

The Rayleigh-Maxwell dilute dispersion model, shown in Eq. (22) below, has been successfully applied to many diverse materials [50]. However, because of the assumptions made in its derivation, it is only applicable for dilute concentrations (less than 10 to 15 volume percent) of dispersed particles within the mixture.

$$k_{eff} = k_m \left[\frac{2k_m + k_f - 2v_f(k_m - k_f)}{2k_m + k_f + v_f(k_m + k_f)} \right] \tag{22}$$

A more general equation for a variable dispersion of particles has been derived by Bruggeman [50] and should be applicable for any concentration [9]. By first differentiating the Rayleigh-Maxwell equation (Eq. (22)) and then integrating between appropriate limits, the variable dispersion model, Eq. (23), is given as:

$$k_{eff} = k_f + (1 - v_f)(k_m - k_f)\left(\frac{k_{eff}}{k_m}\right)^{\frac{1}{3}} \tag{23}$$

This model is actually limited to a particle concentration of 74.05% volume, however, since this corresponds to the maximum packing density for spheres stacked in a rhombohedral array. For greater concentrations, or for lesser concentrations, in which the particles are not uniformly distributed throughout the matrix material, Miller [9] states that another model such as the mixture model (EMT model, Eq. (19)) derived by Bruggeman is a more suitable model.

All three models show relatively good agreement when modeling low particle concentrations. For a case in which $k_m/k_f = 50$, the deviations between the three models is less than 10% for particle concentrations up to 30% volume. At greater particle concentrations, the deviations between the models increase significantly. However, Miller notes that the difference between Eqs. (22) and (23) (the dilute and variable dispersion models) at 50% volume concentrations is only about 10%. Although this concentration is above the maximum concentration recommended for the dilute dispersion model, the relatively low difference in results may allow for the use of either model without significant error. Using the same data for MgO and ZrO_2 from Figure 12, the EMT, Rayleigh-Maxwell dilute dispersion, and Bruggeman variable dispersion models are used to re-create the thermal conductivity curve for the MgO-ZrO_2 50/50 wt.% depicted in Figure 14.

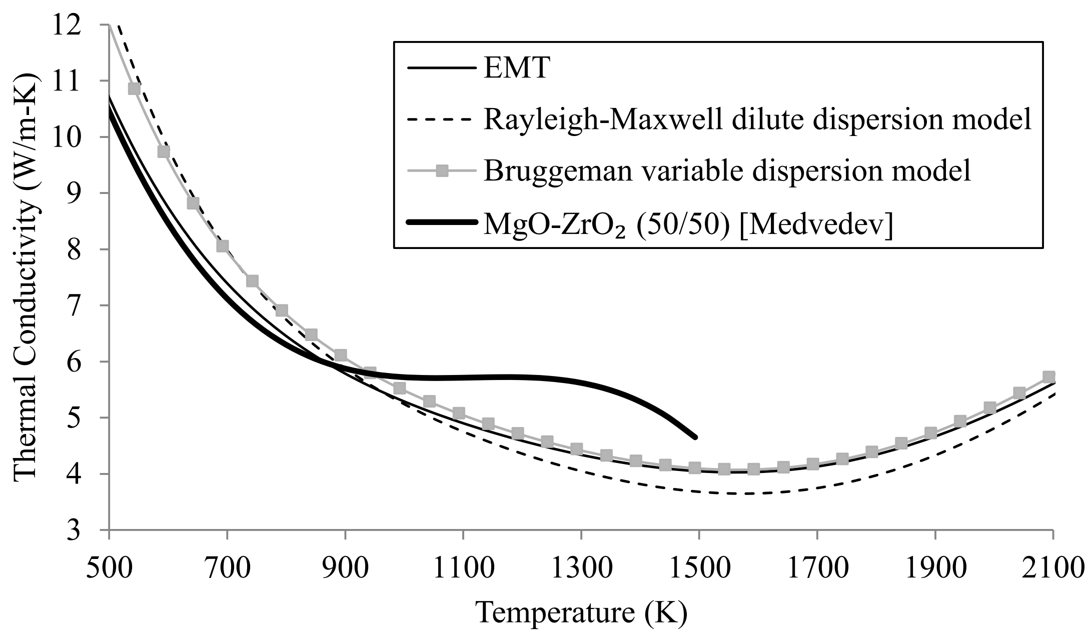


Figure 14. Comparison of the suggested effective thermal conductibity models by Miller

4.3.3. CERMET Fuel Behavior and Properties

Haas et al. [51] modeled CERMET fuel using an analytical thermal conductivity model taking into account the high volume fraction of the dispersed phase and the large difference in the thermal conductivity of the dispersed and matrix phases. The fuel was made up of a Mo-matrix with $Am_{0.224}Pu_{0.756}O_{2-x}$ inclusions. The microstructure of CERMET fuel was shown to have a random, Boolean distribution of spherical inclusions, with some interpenetration. The value of the upper bound of the thermal conductivity allows the prediction of CERMET fuel conductivity when the inclusions are de-bonded from the matrix: the inclusions can be modeled by a two-phase (porous matrix) Boolean distribution of spheres. For these composites in which $k_m > k_f$, the equivalent thermal conductivity upper bound (Beran bound), k_{max}, is given by [46], [51]:

$$k_{max} = k_m \frac{1 + \left((d-1)(v_f + \xi) - 1\right)\beta_{fm} + (d-1)\left(\left((d-1)v_f - v_m\right)\xi - v_f\right)\beta_{fm}^2}{1 - \left(1 + v_f - (d-1)\xi\right)\beta_{fm} + \left(v_f - (d-1)\xi\right)\beta_{fm}^2} \quad (24)$$

where k_m is the thermal conductivity of the matrix, k_f is the thermal conductivity of the fuel inclusions, $\beta_{ij} = \frac{k_i - k_j}{k_i + (d-1)k_j}$, d is the number of dimensions involved in the heat transfer $(d = 3)$, and $\xi = 0.5615\, v_f$ [46]. Results of two CERMET samples were compared to the model given by Eq. (24) [51]. The model assumed inclusion volume fractions of 13.5% and 38.9%, and a density of 95% TD. The thermal conductivity of the Mo-matrix was taken from applicable data. However, the thermal conductivity of the inclusions, $Am_{0.224}Pu_{0.756}O_{2-x}$ was taken to be equal to that of PuO_2. The developed model was shown to be in good agreement in comparison to measured data over the entire temperature range for the 13.5% inclusion volume fraction. The 38.9% volume fraction inclusion was observed to exhibit about 10% greater thermal conductivity in the lower temperature range. This is expected since the model was developed as an upper bound to the equivalent thermal conductivity and not a conservative estimate. However, this model can be applied to CERCER fuel analysis as it was with CERMET fuel, due to the similarities in both fuel types.

Using the same data for MgO and ZrO_2 from Figure 12, the Beran Bound suggested for use by Haas et al. [51], Eq. (24), and the Bruggeman variable dispersion models suggested by Miller [9], Eq. (23). are used to re-create the thermal conductivity curve for the MgO-ZrO_2 50/50 wt.% depicted in Figure 15. Interestingly, both models yield similar results for this specific case.

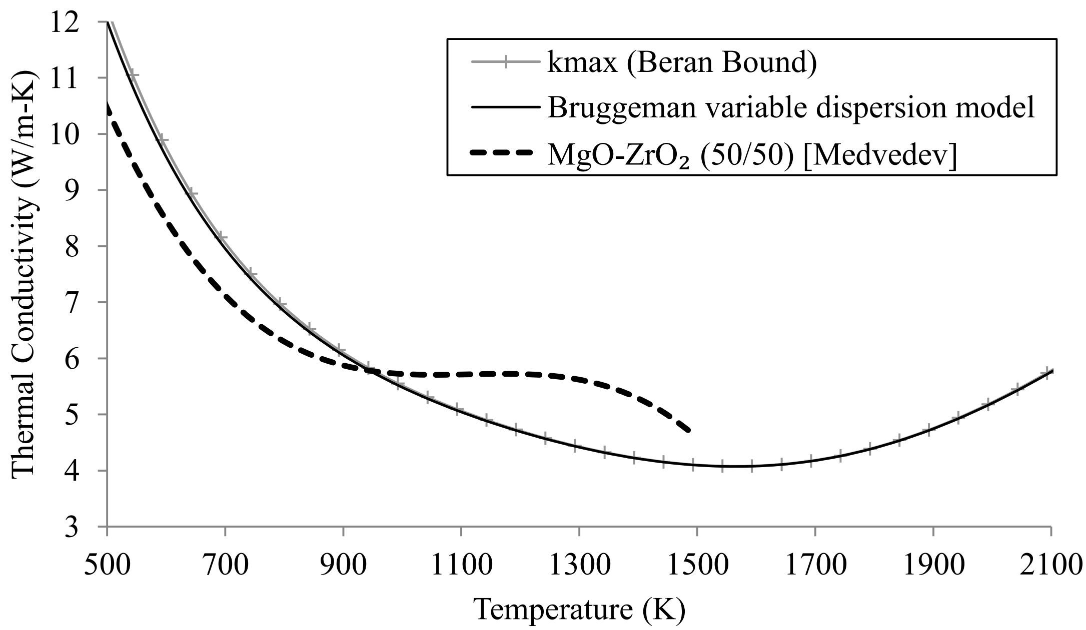


Figure 15. Comparison of the thermal conductivity models given by Eqs. (23) and (24)

4.4. Available Thermal Conductivity Correlations and Data

Although exact thermophysical property data is not available for the specified DUPLEX fuel, the proposed effective thermal conductivity equations given by Wang et al. [48] allow for the estimation of a multi-component fuel, as long as the data for each component is available. Thus, in theory, a rough estimation can be made as to the thermal conductivity of $(Pu,Np,Am)O_2$-MgO-ZrO_2 if the corresponding values of PuO_2, NpO_2, AmO_2, MgO, and ZrO_2 are known. This multi-component approach enables complex material property estimations to be broken down into manageable components for which data is available. Although, this technique alone does not account for material-specific properties of a composite such as burnup dependencies or matrix-fuel material interactions, trends can be adapted from the available literature of similar materials to generate more accurate bounds on theoretical estimations.

This type of approach has been performed in previous work for which the fuel thermal properties of $(Pu,Np,Am,Cm)O_2$-MgO were estimated as part of the EFIT project by a combination of the *Maxwell-Eucken* correlation for the fissile phase and the Bruggeman correlation for the CERCER equivalent fuel [2]. Data from fabricated pins was compared to theoretical estimates and both were in relatively good agreement until about 1500 K in which the data began to diverge from estimates. The characteristics of MgO were expected to yield a “recovery” effect in the thermal conductivity of the composite fuel above 1500 K. However, the MgO recovery effect was not observed in the experiment. Researchers decided to adopt a modified method to generate future estimates of similar fuel. The evaluation of EFIT fuel thermal conductivities was performed discarding the results of the Bruggemann correlation above 1500 K and the resulting fuel temperatures were expected to be underestimated [2]. Due to the similarity of the EFIT fuel and LWR-2-E fuel, a parallel approach for use with LWR-2-E calculations is ideal. However, actual experimental data is not publicly available, but will most likely be in the near future. A significant effort has been made to recreate similar trends in the theoretical modeling of LWR-2-E fuel using the basic combinatory methods summarized earlier.

4.4.1. Analytical Approach to Modeling Minor Actinide Dioxide Fuel Thermal Conductivity

Successful modeling of actinide dioxide thermal conductivity has been developed by Sobolev [34]. Comparisons between the model and the limited amount of available data for actinide dioxides (AmO_2, NpO_2, and CmO_2) were shown to be in relatively good agreement for an extended temperature range. The analytical model for actinide dioxide thermal conductivity is given by [34]:

$$k(T) \approx \frac{k_B N}{9 \cdot V}\left[u_{AL}\left(\frac{T}{\theta_{AL}}\right)^3 \int_0^{\frac{\theta_{AL}}{T}} \left[\frac{l_{AL}(x) x^4 e^x}{(e^x - 1)^2}\right] dx + 2u_{AT}\left(\frac{T}{\theta_{AT}}\right)^3 \int_0^{\frac{\theta_{AT}}{T}} \left[\frac{l_{AT}(x) x^4 e^x}{(e^x - 1)^2}\right] dx\right] \tag{25}$$

The longitudinal sound velocity, u_L, and transverse sound velocity, u_T, are:

$$u_L = \sqrt{\frac{3B_{T0}(1-\mu)}{\rho(1+\mu)}} \tag{26}$$

and

$$u_T = \sqrt{\frac{3B_{T0}(1-2\mu)}{2\rho(1+\mu)}} \tag{27}$$

The Poisson ratio is assumed to be 0.333 for minor actinides. For the acoustic phonon free path lengths, l_A, a linear superposition of the phonon scattering terms was assumed to form a general equation for transverse and longitudinal components:

$$\frac{1}{l(\omega)} = \frac{1}{l_{gb}(\omega)} + \frac{1}{l_{pd}(\omega)} + \frac{1}{l_{ph}(\omega)} \tag{28}$$

The phonon free path lengths of the grain boundary, l_{gb}, and point defect, l_{pd}, terms are given by :

$$l_{gb}(\omega) = a_0 \text{ (effective crystallite size)} \tag{29}$$

$$l_{pd}(\omega) = a_{pd}\left(\frac{\omega_{max}}{\omega}\right) \tag{30}$$

The characteristic frequencies of the <u>L</u>ongitudinal and <u>T</u>ransverse <u>A</u>coustic waves are:

$$\omega_{AL} = \frac{\pi\sqrt{2}\cdot u_L}{a} \tag{31}$$

and

$$\omega_{AT} = \frac{\pi\sqrt{2} \cdot u_T}{a} \tag{32}$$

The phonon-phonon interaction scattering term of the acoustic phonon free path lengths is given by Eq. (33) and is solved through the use of Eq. (34):

$$l_{ph}(\omega) = a_{ph}\left(e^{\frac{\bar{\theta}}{b_U T}} - 1\right)\frac{\omega_{max}^2}{\omega^2} \tag{33}$$

$$\frac{a_{ph}}{b_U} = 8.62 \times 10^{-26}\left(\frac{K_B}{\hbar^2}\right)\left(\frac{a^3\bar{M}\bar{\theta}}{\gamma_G^2}\right) \tag{34}$$

For minor actinide dioxides AmO_2, NpO_2, and CmO_2 the constant b_U is set equal to 4 in order to account for the fraction of phonons that can participate in the Umklapp processes. All of the parameters required for Eqs. (25) through (34) are given in the reviewed work by Sobolev except for one, a_{pd}, which was estimated from experimental thermal conductivity data of minor actinides at their lowest temperature. The experimental data could not be located in the available literature and thus prevented the use of this model for the calculation of minor actinide temperature-dependent thermal conductivity within the updated VIPRE thermal-hydraulic analysis framework.

4.4.2. *Thermal Conductivity of (U,Pu,Np,Am)O_2*

The thermal conductivity of (U,Pu,Np,Am)O_2 has been expressed by a classical phonon transport model by Morimoto et al. [45]. In the study, stoichiometric MOX fuels containing 6% and 12% of Np-oxide were prepared, and their thermal conductivities were studied at temperatures from 900 to 1770 K. Thermal conductivities of the samples were derived from the thermal diffusivity measured by the laser flash method. Data from earlier experiments of (U,Pu,Am)O_2 [52] was used to analyze thermal conductivities below 1400 K. The resulting expression derived for the thermal conductivity of fully-dense (U,Pu,Np,Am)O_2 is

$$\frac{1}{k(T)[W/mK]} = 3.583 \times 10^{-1}(z_{\mathrm{Am}}) + 6.317 \times 10^{-2}(z_{\mathrm{Np}}) + 1.595 \times 10^{-2} + 2.493 \times 10^{-4}\, T \tag{35}$$

The resulting thermal conductivity produced by this model is shown in Figure 16 for maximum Am- and Np-content, in which it is compared to thermal conductivity data for MgO-ZrO_2, as well as to currently implement FRAPCON MOX models within the VIPRE thermal-hydraulic analysis framework (a detailed description of the specific MOX models can be found in Appendix A). Although the temperature regime in which Eq. (35) was developed is limited to temperatures above 1700 K, the assumption is made that the application of Eq. (35) up to temperatures equivalent to the damage limit of the fuel (~ 2100 K) is satisfactory for the purposes of the current research effort.

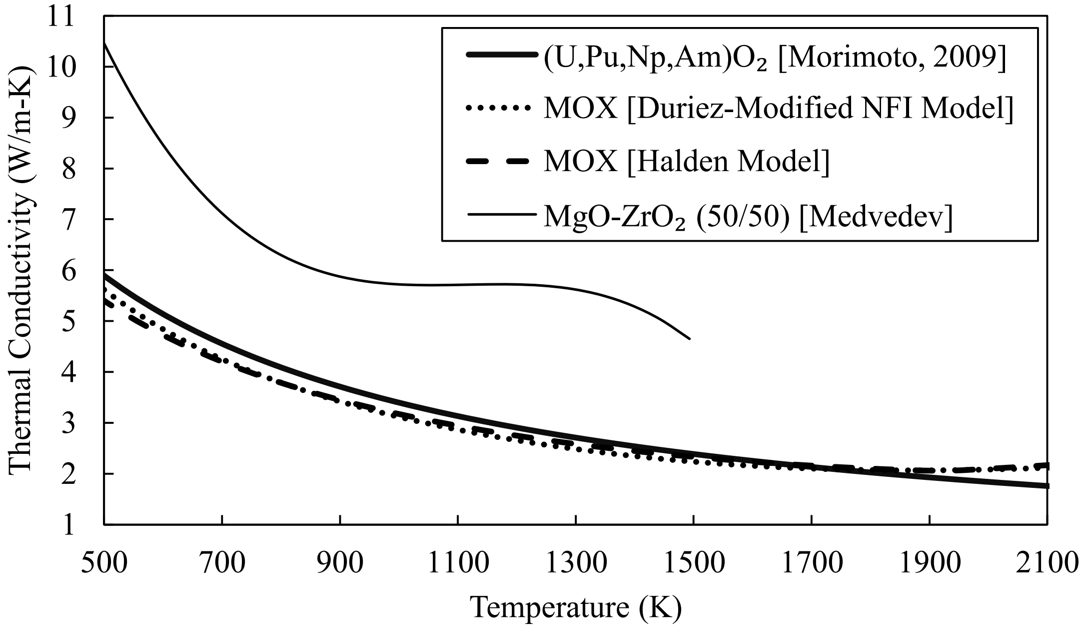


Figure 16 Comparison of $(U,Pu,Np,Am)O_2$ [45] thermal conductivity curve to MOX models [53] and MgO-ZrO_2 data [7]

In its current state, the thermal conductivity relationship for $(U,Pu,Np,Am)O_2$ given above is not suitable for use in effective thermal conductivity calculations of LWR-2-E fuel. The uranium thermal conductivity component must be subtracted such that a conservative approximation can be made for $(Pu,Np,Am)O_2$. Based on an analysis between porosity-corrected UO_2, MOX, and limited PuO_2 data [54], a conservative correction factor of 0.81 is assumed, which is directly applied to the result of Eq. (35).

4.4.3. Characterization of MgO-ZrO_2

MgO-ZrO_2 ceramics have been studied as a candidate host matrix material for the deposition of plutonium and minor actinides in light water reactors. The development, characterization, and evaluation as a potential matrix component, in an IMF, of dual-phase magnesia zirconia ceramics is reported by Medvedev [7]. The thermal conductivity of all investigated mixtures was found to be superior to that of UO_2, so much so as to allow for the possibility of many favorable options. One of which is for the inclusion of more minor actinides into potential nuclear fuels than AMOX designs.

After an extensive literature search and review, the work performed by Medvedev [7] on MgO-ZrO_2 fabrication and characterization is the only one of its kind in the open literature. The two phases of the developed magnesia-zirconia ceramics consisted of: cubic zirconia-based solid solutions and cubic magnesia. The main variational parameter in the study was the effect of zirconia content on the overall characteristics of the resulting ceramic. These characteristics were limited to the hydrothermal stability and thermal conductivity of the fuel such that the feasibility of the dual phase ceramic may be assessed.

A detailed literature review on the thermal properties of MgO by Medvedev [7] revealed that MgO had many of the desirable qualities for use as a potential inert matrix component which include: higher thermal conductivity than currently used UO_2, lower thermal neutron absorption cross-section than U-238, inertness towards the fissile phase, resistance to irradiation effects, high melting point, simple phase relations with the fissile phase, ease of manufacture and lower cost, and solubility in strong acids allowing for reprocessing [7]. However, the main disadvantages to using MgO are its ability to undergo hydration in hydrothermal conditions and large thermal expansion. Experiments with MgO have shown that it reacts with water (hydration), resulting in catastrophic and complete conversion to hydroxide (leading to severe pellet degradation), which has historically caused its discouragement from use in LWRs. Thus, in order to increase magnesia's resistance to hydration and prevent dissolution of an inert matrix, dual phase magnesia-zirconia was developed. The addition of zirconia in large enough quantities was found to stabilize MgO, such that an increase in zirconia content exponentially decreased the hydration-induced mass loss of MgO, thus preventing pellet cracking.

The following three binary compositions were fabricated for evaluation of possible compositional dependency effects [7]:

Table 4
Manufactured binary MgO-ZrO_2 compositions

Sample name	MgO (wt.%)	ZrO_2 (wt.%)	% TD
40/60	40	60	99.6
50/50	50	50	99.8
60/40	60	40	99.5

In addition to the binary compositions listed in Table 4, ternary compositions were studied which included 7 wt. % Erbia in order to simulate the presence of burnable poisons typically found in LWR fuel for neutronic reactivity control. No detrimental effects due to Erbia were observed. However, Erbia was found to have completely dissolved in the zirconia-based solid solution, displacing some of the magnesia. This resulted in a negative effect on the hydration resistance compared to un-doped binary compositions.

Borated water was also studied for its effects on magnesia hydro-stability. Borated water is typically added to PWRs as a neutronic reactivity control to allow for increased duration of operational cycles at plants. However, borated water is not used in BWRs due to the detrimental effects boron would have on reactor components during the boiling process. Although this type of study is only applicable for situations involving the failure of cladding (which would then allow for contact between magnesia and borated water), it is important to understand all possible effects during both normal and abnormal events which could possibly impede safety.

It was found that the presence of boron in the water had a significant positive effect on the hydration resistance of the magnesia. X-ray diffraction (XRD) analysis of samples exposed to borated water did not show the presence of magnesia hydroxide, typically observed in samples exposed to de-ionized water. Instead, magnesium borate hydroxide $Mg(OH)BO_2$ was found. By suppressing the formation of magnesia hydroxide, the normalized mass loss rate (NMRL) is 45 times less than of the same sample in de-ionized water. However, as stated previously, the positive effect of borated water can only be accounted for in PWR systems.

Thermal conductivity for each sample was determined from measured thermal diffusivity, measured density and estimated heat capacity using Eq. (15). Third order polynomial fits of the calculated data were performed by a least squares linear regression analysis, resulting in the following form:

$$k(T) = aT^3 + bT^2 + cT + d \quad [w/m°C] \tag{36}$$

where $k(T)$ is the temperature dependent expression for the thermal conductivity of dual phase MgO-ZrO_2, and the constants a, b, c, and d are fitting parameters of a least-squares regression. For the 50 wt.% MgO and 50 wt.% ZrO_2 (referred to as 50/50) samples, values of the constants are:

$$a = -2.1058 \times 10^{-8}$$

$$b = 5.3122 \times 10^{-5}$$

$$c = -4.4452 \times 10^{-2}$$

$$d = 18.05258$$

The third order polynomial fit to the 50/50 composite calculated data is depicted in Figure 17, along with representative data of zirconia [43] and magnesia [44] for comparison. MgO-ZrO_2 thermal conductivity decreases with increasing temperature until about 900 K in which it begins to increase. A possible explanation for this feature may be obtained from similar work by Ronchi et al. [55]. Ronchi et al. showed the thermal conductivity of heterogeneous zirconia-actinide materials was enhanced at higher temperature through an increased interface conductance between the constituents. This enhanced interface conduction is attributed to the positive differential thermal expansion between zirconia and the actinide oxides. This explanation might apply to MgO-ZrO_2 systems as well, since the thermal expansion of magnesia is far greater than zirconia.

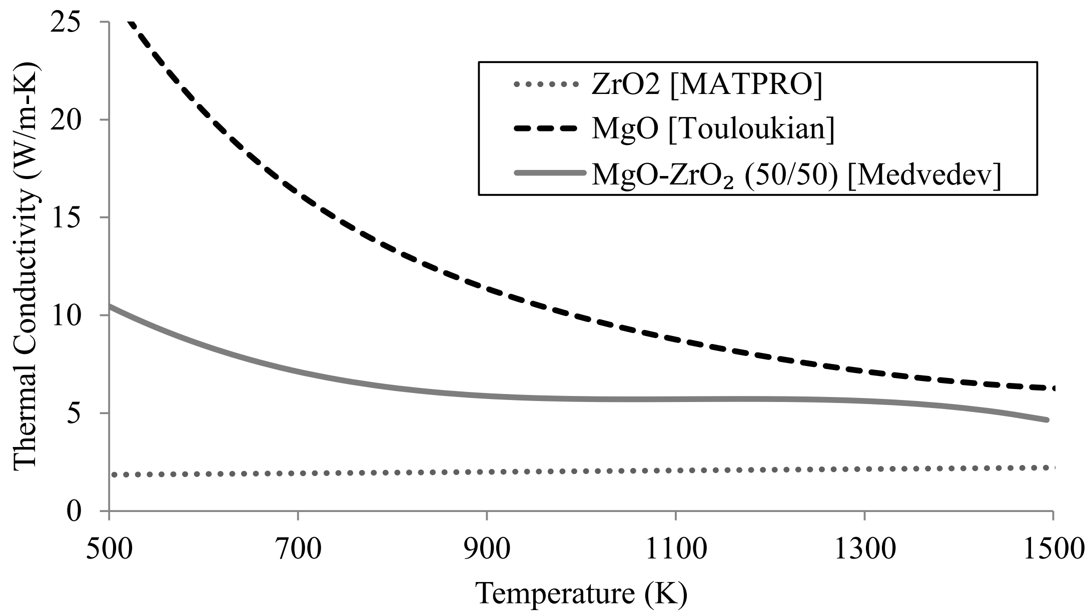


Figure 17. Thermal conductivity of MgO, ZrO_2, and MgO-ZrO_2 50/50 wt.% mixture

4.5. Thermal Conductivity Modeling Methodology

Fuel thermal conductivity is one of the most important material properties in fuel assembly design and safety analysis, yet the current analytical models for predicting this property without supplementary experimental data are still inadequate for nuclear fuel licensing purposes. The thermal conductivity of any material indicates the ability of the material to conduct heat. A fuel material's ability to conduct heat directly affects fuel assembly design parameters such as maximum centerline temperature, which drives other phenomena in the fuel: poor migration, fission gas release, structural stability, fuel restructuring, etc. [4]. The difficulty in determining thermal conductivity analytically lies in the fact that it is dependent upon many features, most of which are difficult to quantify themselves, these include fuel density, porosity, structure, phase transformations, various burn-up related properties, and is related to the chemical makeup and physical structure in a complex manner. Therefore, it is desirable from a design standpoint to accurately represent the fuel thermal conductivity with its many dependencies [4]. However, this is not always possible when supplementary experimental data from as-fabricated fuel is unavailable and models must be relied upon.

As one of the main objectives of this thesis is to determine a best-estimate representation of an exotic nuclear fuel's thermal conductivity for use in calculations using a modified VIPRE-01 analysis framework, an extensive literature survey has been performed of various conventional and advanced fuel materials.

Assuming the availability of data, the ideal analysis scheme through which to determine an equivalent effective thermal conductivity relation for the $(Pu,Np,Am)O_2$-MgO-ZrO_2 composite fuel is shown in Figure 18. However, due to the scarcity of data pertaining to the LWR-2-E design, the scheme shown in Figure 19 was utilized to approximate the

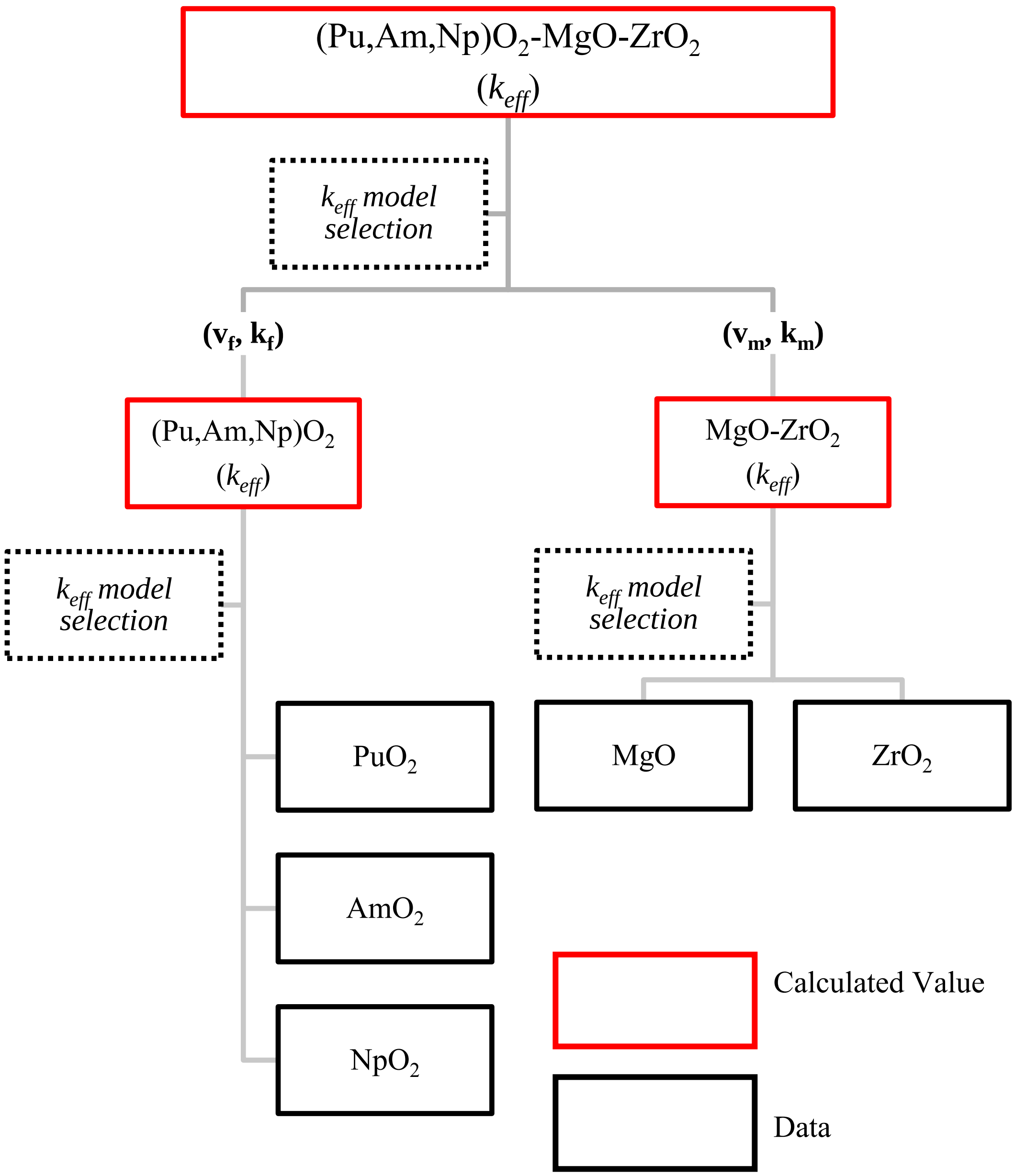


Figure 18. Ideal solution scheme for the effective thermal conductivity of LWR-2-E Fuel

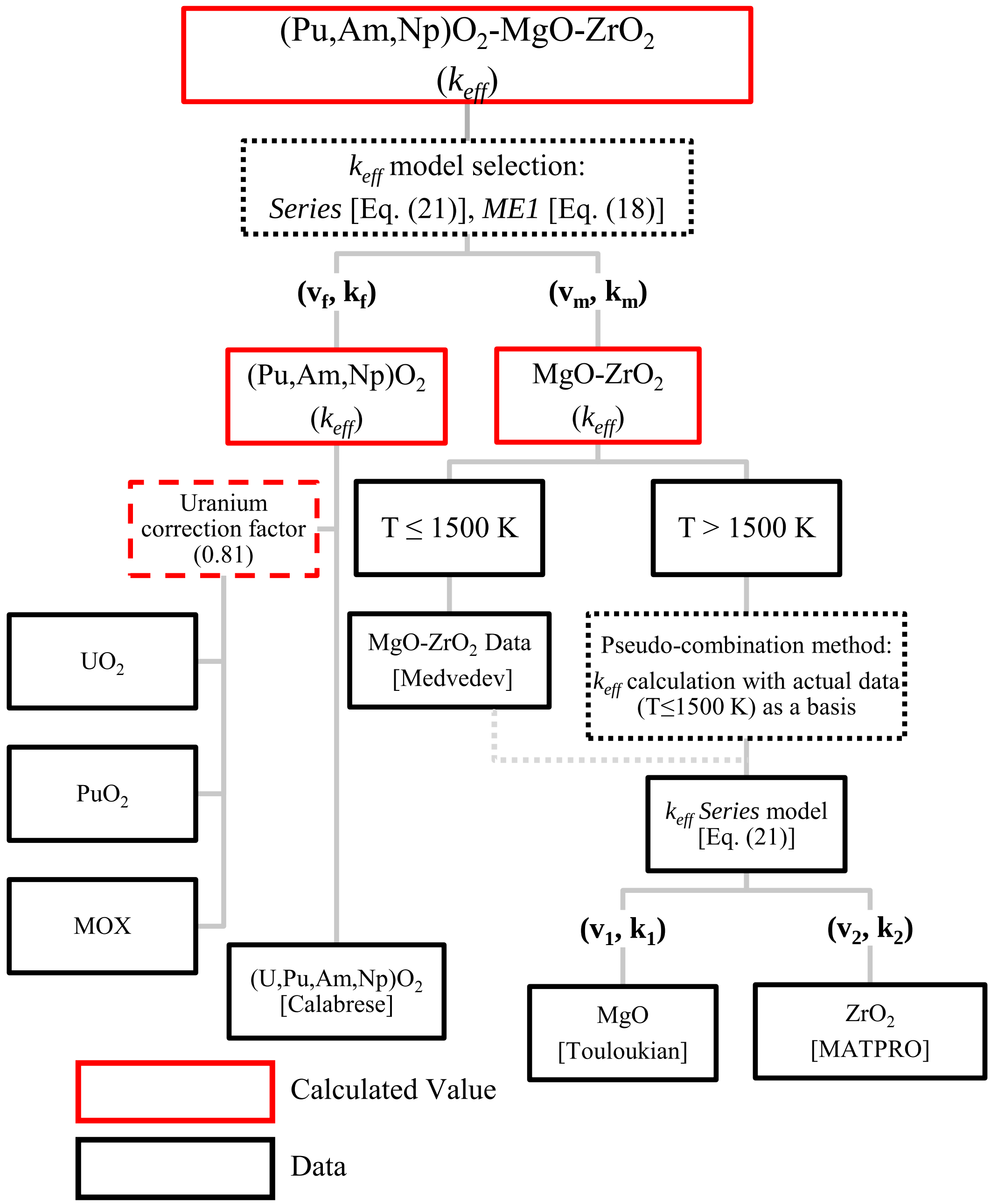


Figure 19. Thermal conductivity modeling scheme developed for LWR-2-E Fuel

overall LWR-2-E k_{eff}. As prescribed by the LWR-2-E thermal conductivity modeling scheme in Figure 19, the available data for MgO-ZrO_2 must be extended to a wider temperature range.

The extension of MgO-ZrO_2 data is performed by first applying the *Series* effective thermal conductivity model, Eq. (21), to available MgO and ZrO_2 data. The *Series* model was chosen based on a review of how (Pu,Np,Am,Cm)O_2-MgO model predictions for the EFIT project [2] was estimated and how it compared to experimental data. As stated previously, a “recovery” effect from the large MgO thermal conductivity was expected to overcome the relatively low thermal conductivity of the fissile phase at high temperatures. However, this was not observed and the resulting CERCER equivalent model over predicted the thermal conductivity values for high temperatures. As a result for this work, the *Series* model has been chosen in order to give the most conservative estimate of the MgO component in the overall CERCER equivalent fuel.

Next, by using the data for MgO-ZrO_2 up to its applicable temperature range, a superposition of the *Series* model (such that there is continuity between the MgO-ZrO_2 data and *Series* model at the interface defined by the maximum temperature of MgO-ZrO_2 data) yields a conservative model (resulting in higher calculated temperatures for thermal safety evaluation) while some credit is taken to enhance the thermal conductivity values through the use of a MgO-ZrO_2 data-basis. Overall this reduces the large uncertainty in the estimation of MgO-ZrO_2 data for an extended temperature range. The resulting thermal conductivity profile from this process is shown in Figure 20, indicated by “Medvedev + Series”.

A sixth-ordered polynomial fit to the "Medvedev + Series" curve in Figure 20 is used for implementation within VIPRE-interface scripts, which were developed specifically for the analysis of the DUPLEX assembly design. The script-based interface allows for user-defined variables which run the creation of thermal conductivity tables which are included in VIPRE input decks. User-defined variables for the developed LWR-2-E thermal conductivity modeling scheme include the k_{eff} calculation method (*Series*, *ME1*, *ME2*, etc.), MgO-ZrO2 and $(Pu,Np,Am)O_2$ volume fractions, a uranium correction factor to be applied to Eq. (35), and input for calculating the porosity correction factor.

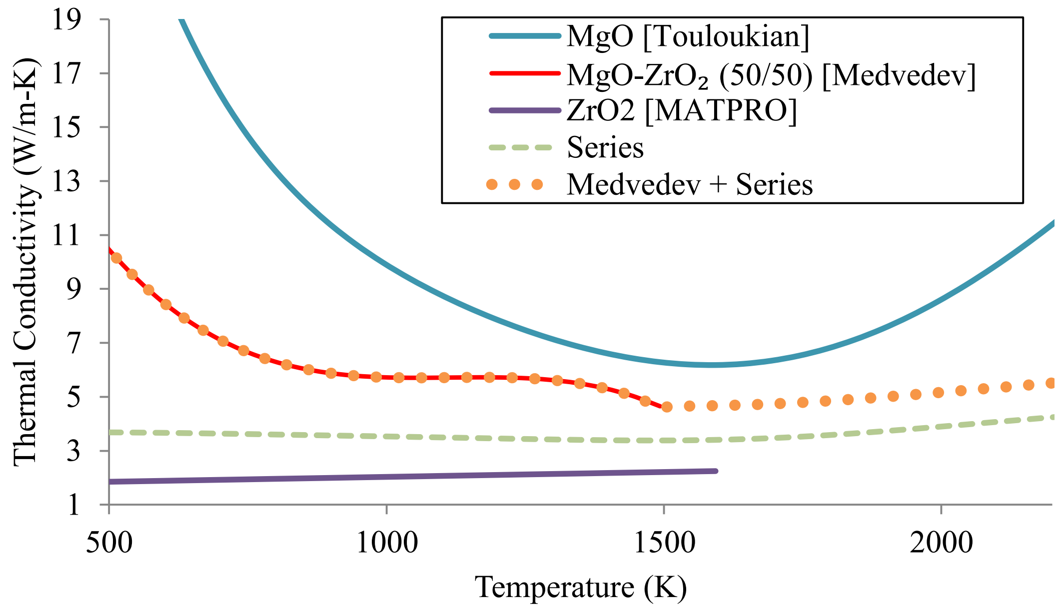


Figure 20. Extension of $MgO-ZrO_2$ data to a wider temperature range through a combined approach involving the superposition of *Series* k_{eff} model estimates

Using the modeling scheme in Figure 19, the developed thermal conductivity models for the overall combined fissile and host phases, along with the MNFI model for UO_2, is shown in Figure 21. The VIPRE thermal-hydraulic analysis framework has been updated to include both developed models. The *Series* method values agree very well with the experimental results given by Calabrese et al. [2]. However, the magnitude of the *Series* method is slightly less than that given by Calabrese et al., due to the inclusion of ZrO_2 in the developed model for the proposed DUPLEX assembly design. Both the *Series* and *ME1* models yield greater thermal conductivity values than that of UO_2, which is expected.

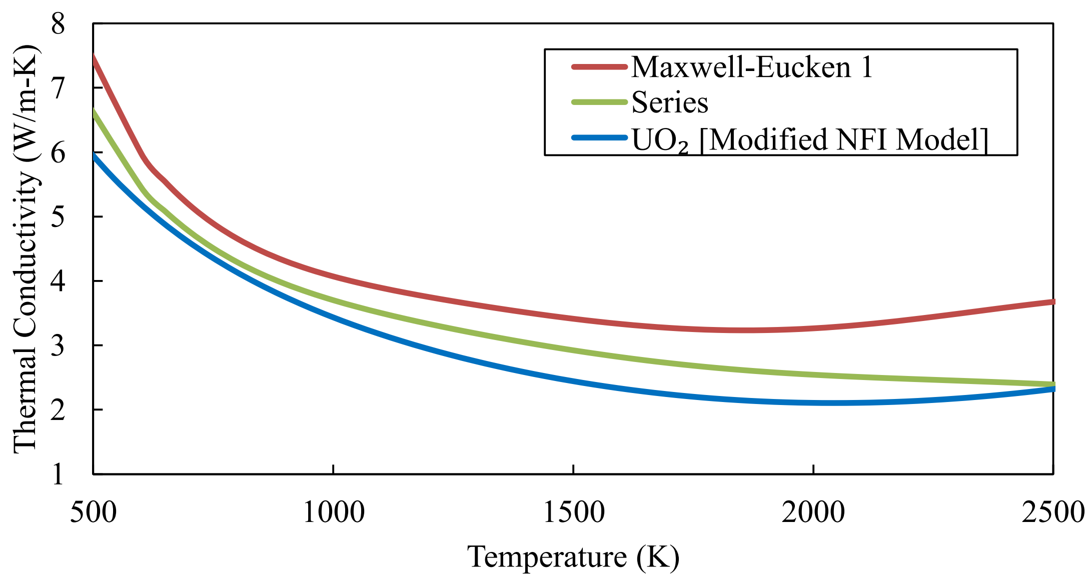


Figure 21. Devloped thermal conductivity models for $(Pu,Np,Am)O_2$-MgO-ZrO_2 using the *Series* and *ME1* k_{eff} approaches to combine the fissile and host phases.

4.6. Additional Considerations

Both the melting temperature and the heat capacity of a composite material can be accurately determined in most situations through the application of Vegard's law. Vegard's law is an approximate empirical rule which states that at constant temperature, a linear relationship exists between the crystal lattice constant of an alloy and the concentrations of the constituent elements [56]. Thus, in terms of heat capacity, knowing the temperature dependent heat capacities of constituent elements and their relative concentrations, a temperature dependent heat capacity can be deduced for the mixture by a simple summation of parts.

4.6.1. Heat Capacity

Specific heat calculations were made via Vegard's law. Vegard's law is an approximate empirical rule which assumes that a linear relationship exist, at constant temperature, between the composite material's specific heat and the *molar* fractions of the respective constituents [56]. For example, consider the TRU component of the CERCER fuel, $(Pu_{(1\text{-}x\text{-}y)},Am_x,Np_y)O_2$. A linear relationship exists between the constituent elements and their associated heat capacities, C_p, such that:

$$C_{p_{(Pu,Am,Np)O_2}} = (1-x-y)C_{p_{PuO_2}} + xC_{p_{AmO_2}} + yC_{p_{NpO_2}} \tag{37}$$

where $C_{p_{(Pu,Am,Np)O_2}}$ is the specific heat of the composite. The relationship used for determining $C_{p_{PuO_2}}$ was the FRAPCON model [53]. The specific heat relationship for $C_{p_{NpO_2}}$ is given by Arkhipov et al. [57]:

$$C_{p_{NpO_2}} = \frac{79.16 + 1.67 \times 10^{-2}(T) - \dfrac{3.67 \times 10^5}{(T)^2}}{269.047 \times 10^{-3}} \tag{38}$$

where T is the temperature in Kelvin, and C_p is the heat capacity in J/kg-K. The heat capacity for the final component, $C_{p_{AmO_2}}$, is substituted for by a $C_{p_{CmO_2}}$ model which has been shown to have similar, but slightly less, heat capacity as $C_{p_{AmO_2}}$ [38]. Thus, the following model by suggested by Konings [58] was used:

$$C_{p_{AmO_2}} = C_{p_{CmO_2}} = \frac{64.871 + 19.152 \times 10^{-3}(T) - \dfrac{7.86 \times 10^5}{(T)^2}}{279.062 \times 10^{-3}} \tag{39}$$

where T is the temperature in Kelvin, and C_p is the heat capacity in J/kg-K. Medvedev [7] suggest the following heat capacity relation of a composite:

$$C_{p_{composite}} = aC_{p_{MgO}} + bC_{p_{ZrO_2}} + cC_{p_{Er_2O_3}} \tag{40}$$

where a, b, and c are the *weight* fractions of the components in the ceramic. The following recommended temperature dependent heat capacities of magnesia and zirconia were used [7]:

For magnesia:

$$C_{p_{MgO}}(T) = 47.25995 + 5.681621 \times 10^{-3}(T) - 8.72665 \times 10^{-7}(T)^2 + 1.043 \times 10^{-10}(T)^3 - 1.053955 \times 10^{6}(T)^{-2} \quad (41)$$

where T is the temperature in Kelvin, and $C_p$is the heat capacity in Joule/K-mole.

For zirconia:

$$C_{p_{ZrO_2}}(T) = 69.20001 + 8.54829 \times 10^{-3}(T) - 8.62921 \times 10^{-7}(T)^2 + 2.46374 \times 10^{-10}(T)^3 - 1.382767 \times 10^{6}(T)^{-2} \quad (42)$$

where T is the temperature in Kelvin, and $C_p$is the heat capacity in Joule/K-mole.

4.6.2. Fuel Porosity

Fuel porosity can have a significant negative influence on fuel thermal conductivity. Porosity, p, is defined from the theoretical density ρ_{th} and the manufactured density ρ of the specimen as follows [52]:

$$p = 1 - \left(\frac{\rho}{\rho_{th}}\right) \quad (43)$$

The porosity influence on CERCER fuel thermal conductivity data was corrected using the modified Maxwell-Eucken relation:

$$F(p) = \frac{1 - p}{1 + \beta p} \quad (44)$$

where β is an experimentally determined constant, and p is the porosity of the fabricated fuel. Based on recommendations from Morimoto et al. [45] for (U,Pu,Np,Am)O_2, $\beta = 0.5$ was chosen as the nominal parameter for CERCER porosity corrections. From the relation given by Eq. (44), the thermal conductivity of 100% TD can be determined from the thermal conductivity of fabricated fuel with porosity, p. This is a powerful tool in comparing multiple data sets of similar fuels, which may be manufactured with various values of % TD.

4.6.3. Fuel Melting

The temperature at which fuel melting occurs is a significant contributor in determining the limiting maximum operational fuel temperature such that fuel failure does not occur. The fuel failure point can be defined as the fuel's solidus temperature [51]. The solidus (appearance of lowest temperature liquid phase) and liquidus (melting of the last solid phase) temperatures of oxide fuels can be calculated by the application of Vegard's law, which relates the oxide components' atomic fractions (f_k) and respective melting points to the final mixture's melting point:

$$T_{sol}^{fuel} = \sum_{k=1}^{K} T_k^{melt} f_k + C_{sol} \tag{45}$$

$$T_{liq}^{fuel} = \sum_{k=1}^{K} T_k^{melt} f_k + C_{liq} \tag{46}$$

where C_{sol} and C_{liq} in Eqs. (45) and (46) above, are solidus and liquid correction factors accounting for deviations from stoichiometry. These simple relationships for determining the melting temperature of an oxide fuel are relatively good for most situations. However, these relationships do not provide accurate predictions in situation where oxides form eutectic systems.

A eutectic system is a mixture of chemical compounds or elements, whose melting temperature is lower than any of the individual constituents. The formation of eutectic systems can be shown through the use of phase-diagrams. A generalized phase-diagram of a two-component chemical mixture forms a eutectic system is depicted in Figure 22. A and B in Figure 22 represent two fictitious materials whose solid phases are indicated by α and β, respectively. The melting temperature can be determined by locating the relative composition of A and B and selecting the minimum temperature for which a point lies within the liquid phase (L). The melting temperature as a function of relative composition is indicated by the red line in the example.

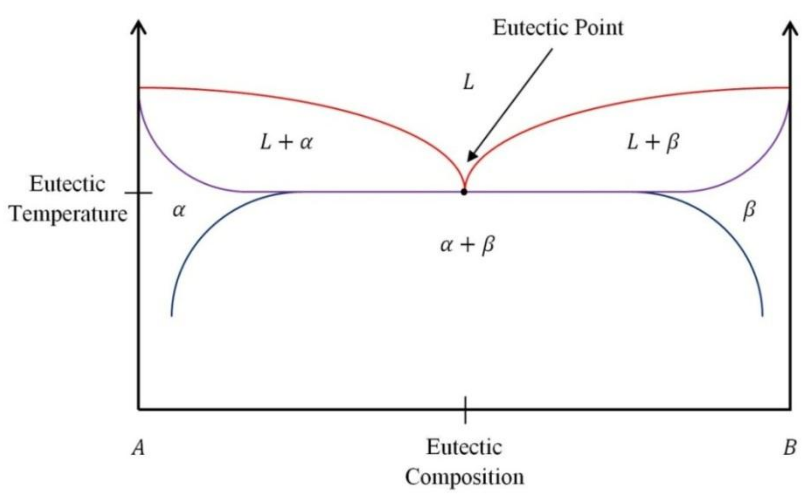


Figure 22. Generalized phase diagram of a two component chemical mixture which forms a eutectic system

Eutectic formation causes a decrease in melting temperature from the predicted Vegard's Law values and thus the maximum allowable operating fuel temperature. This phenomenon has been observed in systems with similar sub-components of the LWR-2-E fuel. For example, the individual melting temperatures of MgO, PuO_2, and AmO_2 are 3250 K, 2843 K, and 2773 K respectively [59]. However, experimentation showed that the liquidus temperatures of Pu-Mg-O, Am-Mg-O, and Pu-Am-MgO systems began at 2503 K [60], 2350 K [61], and 2573 K [59] respectively, in a eutectic reaction. These eutectic liquid temperatures are far lower than the lowest melting temperature of any individual component. This eutectic effect can play a significant role in decreasing the thermal safety margin if the fuel's thermal conductivity is not significantly large enough to maintain a lower maximum fuel temperature than the fuel's melting temperature.

4.6.3.1. MgO-Based IMF Designs

Besides the issue of magnesia hydration (described earlier), another leading safety concern for MgO-based IMF is the possibility of the matrix undergoing 'vaporization', leading to disintegration of the fuel pellet. This vaporization of the fuel matrix occurs around T ~ 2200 K, which happens to be much lower than the melting temperature of the TRU particles dispersed throughout the matrix. Thus, the matrix vaporization temperature is the most limiting safety relevant temperature. Melting and eutectic temperatures of fuels relevant to the MgO-ZrO_2-based CERCER fuel for the purposes of this thesis are summarized in Table 5.

Table 5
Melting and eutectic temperatures relevant to CERCER MgO fuels

Oxide Fuels	Melting or eutectic temperature (lower limits) (K)
MgO	3250[a]
ZrO_2	2988
CmO_2	2838[a]
NpO_2	2820[a]
PuO_2	2663[a], 2843[c]
AmO_2	2783[a], 2448[b], 2773[c]
Pu_2O_3	2358[b]
MgO-PuO_{2-x} system	2341[b], 2503[c]
MgO-AmO_2	2291[b], 2350[c]
MgO-AmO_{2-x} ($1.62 \leq 2\text{-}x \leq 2$)	2319[b]
MgO-AmO_{2-x} ($1.5 \leq 2\text{-}x \leq 1.62$)	1930[b]
Pu-Am-MgO system	2573[c]

[a] Calabrese et al. [38], [b] Maschek et al. [62], [c] Miwa et al. [59]

It should be noted that the melting temperature listed for Pu-Am-MgO systems of 2573 K in Table 5 (determined by Miwa et al. [59]) is a result of tests performed at only three temperature steps: 2173 K, 2373 K, and 2573 K. Miwa et al. [59] reports melting was not observed for the lower two temperatures, but was for 2573 K. However, melting due to the eutectic reaction could have occurred anywhere in the temperature range $2373\ K < T \leq 2573\ K$.

For the Am-Mg-O and Pu-Mg-O systems, Zhang et al. [60] [61] provides the most recent analysis of available experimental data backed by theoretical predictions of the respective phase diagrams. According to Zhang et al. [61] the melting behavior of Am-Mg-O and Pu-Mg-O systems are similar. It was shown that MgO-AmO2-x has a very low melting temperature of 1930 K at partial oxygen pressures below 1 bar. In order to raise the melting temperature to a value of 2200 K, the partial oxygen pressure must be raised to over 4.5 bar. A maximum melting temperature of 2356 K occurs at 10.6 bar. However, the increase in partial oxygen pressure degrades the corrosion resistance of the cladding. For these reasons Zhang et al. [61] suggest that MgO is not a suitable matrix material for the transmutation of americium. Limiting temperatures based on select safety criteria used by MgO-based CERCER fuel in EFIT experiments are shown in Table 6 [62].

Table 6
Categorization of CERCER (with MgO matrix) limiting fuel temperatures (BOL fuel) for EFIT (from [62])

Category	Comments	Limiting temperature (K)
Fuel melting point		2450
Matrix melting point		3100
Pellet stability limit or eutectic "melting"		2130[a]
DBC[*] I	No melting/disintegration	1750
DBC[*] II	No melting/disintegration	1850
DBC[*] III	No melting/disintegration	1950
DBC[*] IV	No 'melting' for CERCER fuels	1950
DEC[**]	Limited up to extended 'melting'	2130

[a] Matrix evaporation limit, [*] DBC – design basis conditions (structured into 4 categories), [**] DEC – design extension conditions (limiting events, complex sequences and severe accidents)

In Table 6, the DEC limiting temperature was chosen for EFIT CERCER calculations [62]. This value is based on the temperature at which eutectic phase transition occurs, resulting in "melting" of the fuel. Based on the similarity between the EFIT CERCER design and the DUPLEX CERCER design, a value of 2130 K was adopted as the limiting temperature for the current IMF design under investigation in this thesis.

4.6.3.2. UO_2

Already implemented within the thermal analysis framework, the burnup-dependent melting temperatures for UO_2 and $(U,Pu)O_2$ are calculated for with the following FRAPCON model [63]:

$$T_{melt} = 3113.15 - 5.41395(PuCon) + 7.468390 \times 10^{-3}(PuCon)^2 - 3.2 \times 10^{-3}Bu \tag{47}$$

where $PuCon$ is the PuO_2 wt.%, and Bu is the burnup in MWd/tHM. In the absence of PuO_2, the $PuCon$ terms of Eq. (47) disappear leaving a relation for UO_2. The limiting temperature for the seed region UO_2 fuel in the DUPLEX design is taken as 200 K less than the melting temperature.

5. FUEL ASSEMBLY MODELING

Input decks for VIPRE analysis have been developed to model the fuel designs under investigation in this thesis. In order to run the code, five basic types of information must be supplied by the input deck, each describing a component of the numerical approximation of the physical entity to be simulated [13]: the problem geometry, the physical properties of the working fluid, the boundary conditions and forcing functions, the constitutive models for the flow and heat transfer solutions, and the numerical solution method to be used. The two main parts of the input deck are the model definition (define the numerical approximation of physical entity to be simulated) and the model run control information (set parameters that instruct VIPRE what to do with the constructed model). Some of the inputs which fall under the category of defining the model are the core boundary conditions, data for geometrical representations of rods and fuel assemblies, rod material data, axial and radial power profiles, and form losses. The model run control information in VIPRE controls how each case being modeled is simulated through input parameters, such as the numerical solution method, convergence criteria, and specifications for both flow-field and heat transfer model correlations. A brief overview of the VIPRE input deck structure, along with a summary of the VIPRE modeling parameters used for DUPLEX cases, is provided in the following sections.

5.1. VIPRE Input

Within VIPRE, input data is arranged to collect all parameters with similar functions into the same '*GROUP*'. The two most important groups for modeling new assembly designs are *GEOM* and *RODS*. Thus, they are a part of the primary groups for which input is always required at a minimum along with *VIPRE* and *OPER* [13]. A description of each possible group defined by VIPRE follows:

**VIPRE*:	Title of simulation and number of cases to run
**GEOM*:	Defines fluid subchannel geometry in terms of flow area, wetted and heated perimeter, and gap connections between subchannels as shown in Figure 23
BWRG:	Defines optional data for BWR bundle inlet and outlet geometry
PROP:	Fluid property options
**RODS*:	Defines the number of rods, types of rods, rod axial and radial power profiles, and material properties for *nuclear* rod types
**OPER*:	Operating conditions, boundary conditions, and transient forcing functions
CORR:	Choose correlations for flow-field and heat-transfer parameters
MIXX:	Defines options for turbulent mixing of momentum and energy between subchannels
DRAG:	Axial and lateral friction factors
GRID:	Models the axial pressure loss associated with grid spacers

AXLV: Model axial variations in channel area, channel wetted perimeter, and gap width

CONT: Controls numerical solution method and convergence criteria

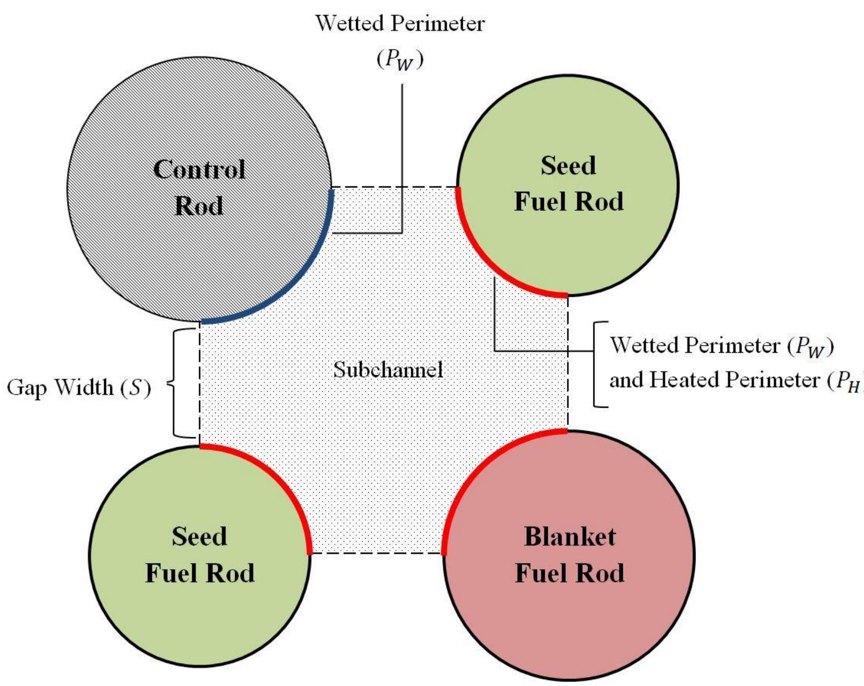


Figure 23. Subchannel, gap and rod definition for the SBU assembly

In the developed input decks for the thermal-hydraulic analysis of SBU-type assemblies, only the *VIPRE*, *GEOM*, *PROP*, *CORR*, *DRAG*, *GRID*, *RODS*, *CONT* and *OPER* groups are used. Reference plant characteristics from Table 1 are used to supply boundary conditions to VIPRE calculations in the group *OPER*. Changes to the basic modeling techniques used in previous analyses [4] were made for SBU-type assemblies through modifications in groups *PROP*, *DRAG*, *GRID*, and *CORR* based on recommendations from previous work involving heterogeneous fuel assembly designs [20], [22]. For the analysis of DUPLEX assemblies, only groups *GEOM* and *RODS* are modified to reflect design changes, and only the *RODS* group is modified from case to case during steady-state scoping analyses in which designs are analyzed over their entire burnup lifetime. The groups besides *GEOM* and *RODS* are used to reflect the basic thermal-hydraulic modeling assumptions developed by Bingham [4], along with SBU-specific modifications suggested by Busse [20] and Todosow et al. [22]. Default values for VIPRE input have been set for parameters which fall outside the scope of [4] and [20], unless otherwise noted here.

5.2. DUPLEX Assemblies

The DUPLEX fuel assembly differs from standard reference plant design by the inclusion of a heterogeneous 17 × 17 rod assembly unit, which consists of two regions: the inner ‘seed’ region and the outer ‘blanket’ region. However, both the control rod and instrumentation tube locations are the same as the reference plant. By maintaining the 17 × 17 assembly layout, along with the control rod and instrumentation tube locations, the DUPLEX design has the ability to be implemented within the reference core without the need for any modification to the reactor’s internals. Usually, new fuel designs incorporate the standard homogeneous assembly loading scheme which requires only minor modification to a few input deck parameters. In the case of DUPLEX assemblies, many modifications are needed to accommodate two fuel regions, each requiring their own individual rod information and data. The seed fuel pins incorporate a standard UO_2 design, while the blanket region consist of $(Pu,Np,Am)O_2$-MgO-ZrO_2 IMF pins with larger pin diameters. The main VIPRE parameters for SBU analysis are summarized in Table 7.

Table 7
Summary of VIPRE-01 model parameters for SBU assembly analysis

Property	Value
Nominal core operating parameters	Table 1
Coolant inlet temperature (K)	Nominal + 2 K
Core power [steady-state scoping, transient]	[118%, 112%]
Mass flow rate	Nominal - 5%
Coolant channels [SS, transient]	[45, 292]
Number of rods [SS, transient]	[54, 325]
Rod pitch (in.)	0.496
Axial nodes	31, equally spaced
Spacer grids	8, equally spaced starting at 6 in. from bottom
Grid spacing (in.)	20
Grid form loss coefficient	0.86 (constant)
Turbulent mixing model	None
Cross-flow resistance factor	$K_{ij} = 0.5$
Two-phase friction multiplier	Columbia/EPRI correlation
Subcooled void correlation	EPRI void model
Bulk void/quality correlation	EPRI model (Zuber-Findlay drift flux equation)
Heat transfer correlations	Dittus-Boelter (DB) for single-phase forced convection, DB plus Thom for both subcooled and saturated nucleate boiling
CHF correlation	W-3L
Inlet flow condition	Equal mass flux per channel

Inputs for groups *PROP*, *DRAG*, *GRID*, and *CORR* are based on recommendations from previous work involving heterogeneous fuel assembly designs [20], [22]. The EPRI water properties function of group *PROP* was selected for the generation of water tables in which the fluid saturated and superheated steam properties are included. In group *DRAG* a constant lateral resistance factor of 0.5 is applied to all gaps. A constant grid spacer form loss coefficient of 0.86 [22] is applied to 8 equally spaced grid spacers by 20 in. starting at 6 in. [4] in group *GRID*. In the group *CORR*, the default EPRI correlations for the evaluation of subcooled void, bulk void/quality, and two-phase friction factor were chosen along with the W-3L CHF correlation for DNB analysis [20].

In the group *RODS, VIPRE's nuclear* rod type is used to model both fuel regions within the DUPLEX assembly design. Utilizing this rod type within VIPRE adds the thermal conductivity model option along with a gap conductance model to the fuel pins for thermal analysis. Thus, the temperature profile of both the seed and blanket rods can be determined and compared to respective temperature limits. However, certain VIPRE output options which were created for user convenience are only capable of reporting the most limiting fuel rod in terms of the highest temperature, regardless of fuel rod type. Without modification, a violation of imposed limits may be "masked" by the output for situations involving significant difference in limiting values. In order to resolve this issue, a scheme was added to the analysis framework so that the most limiting conditions of each fuel region can be compared to their respective limits.

Tables of temperature-dependent thermophysical properties are supplied to the code in group *RODS*. UO_2 temperature-dependent thermophysical tables are generated for each burnup step from the FRAPCON model (see Appendix A) by the script-based interface and integrated into the VIPRE input decks, yielding a burnup-dependent and temperature-dependent analysis for UO_2. IMF fuel thermophysical properties are handled in a similar manner, but are only dependent on temperature and do not change from one burnup case to another. Thermal conductivity models that were developed in Section 4.5 are included in the script-based interface to generate appropriate material property tables.

An overview of the DUPLEX design is given in Section 1.4. In the seed region of the assembly, the UO_2 fuel pin design dimensions are slightly modified from the reference fuel pin design, as given in Table 2. The DUPLEX UO_2 fuel pellet diameter is smaller than the reference design by 0.001 inch, which results in a larger gap thickness by 0.001 in. as well. In the blanket region, the $(Pu,Np,Am)O_2$-MgO-ZrO_2 IMF fuel dimensions and properties are significantly different from the reference design. Within the assembly, there are 180 UO_2 pins in the seed region and 84 IMF pins in the blanket region. While the cladding and gap thickness remain constant, the IMF fuel pellet diameter is ~ 9% greater than the reference design. The design parameters for the IMF fuel can be found in Table 8.

Table 8
Blanket region IMF design parameters for the DUPLEX assembly [8]

Parameter	Value
Fuel type	$(Pu,Np,Am)O_2$-MgO-ZrO_2
Manufactured density (%TD)	90
Fissile content (wt.%)	43.28 Pu
	5.59 Am
	1.75 Np
Fuel pellet outer diameter (mm)	9.0
Gap thickness (mm)	0.05
Cladding thickness (mm)	0.57
Fuel rod outer diameter (mm)	10.32
Number of fuel rods	84
Cladding material	Zircaloy-4
Fuel limiting temperature	2130 K (from Table 6 [62])

Within the thermal-hydraulic analysis framework, the subchannel nodalization for both the core and hot assembly is design-independent along as the 17 × 17 assembly scheme is maintained. The hot assembly and core subchannel nodalizations for steady-state analysis are shown in Figure 24 and Figure 25, respectively. The subchannel identification numbers in each figure correspond to input subchannels in *GROUP* for the

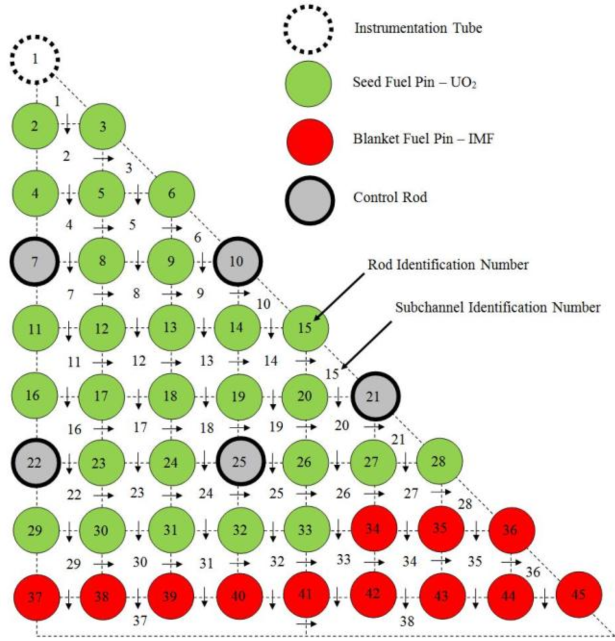


Figure 24. 1/8th Hot Assembly rod and subchannel nodalization for steady-state analysis

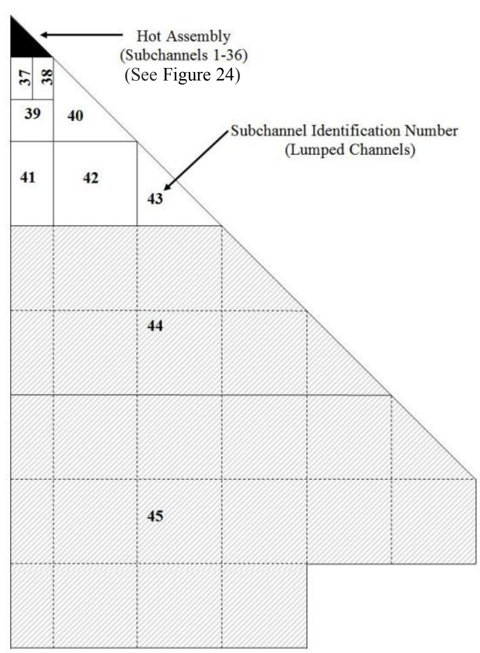


Figure 25. 1/8th Core subchannel nodalization for steady-state analysis (from [4])

steady-state scoping analysis. For transient analyses, the location of the hot assembly in the core is changed and the number of subchannels and fuel rods included increases since the full hot assembly is modeled, as shown in Figure 26 and Figure 27, respectively. The connections between the subchannels and rods for this analysis are

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Figure 26. VIPRE Hot Assembly Subchannel nodalization for transient analysis

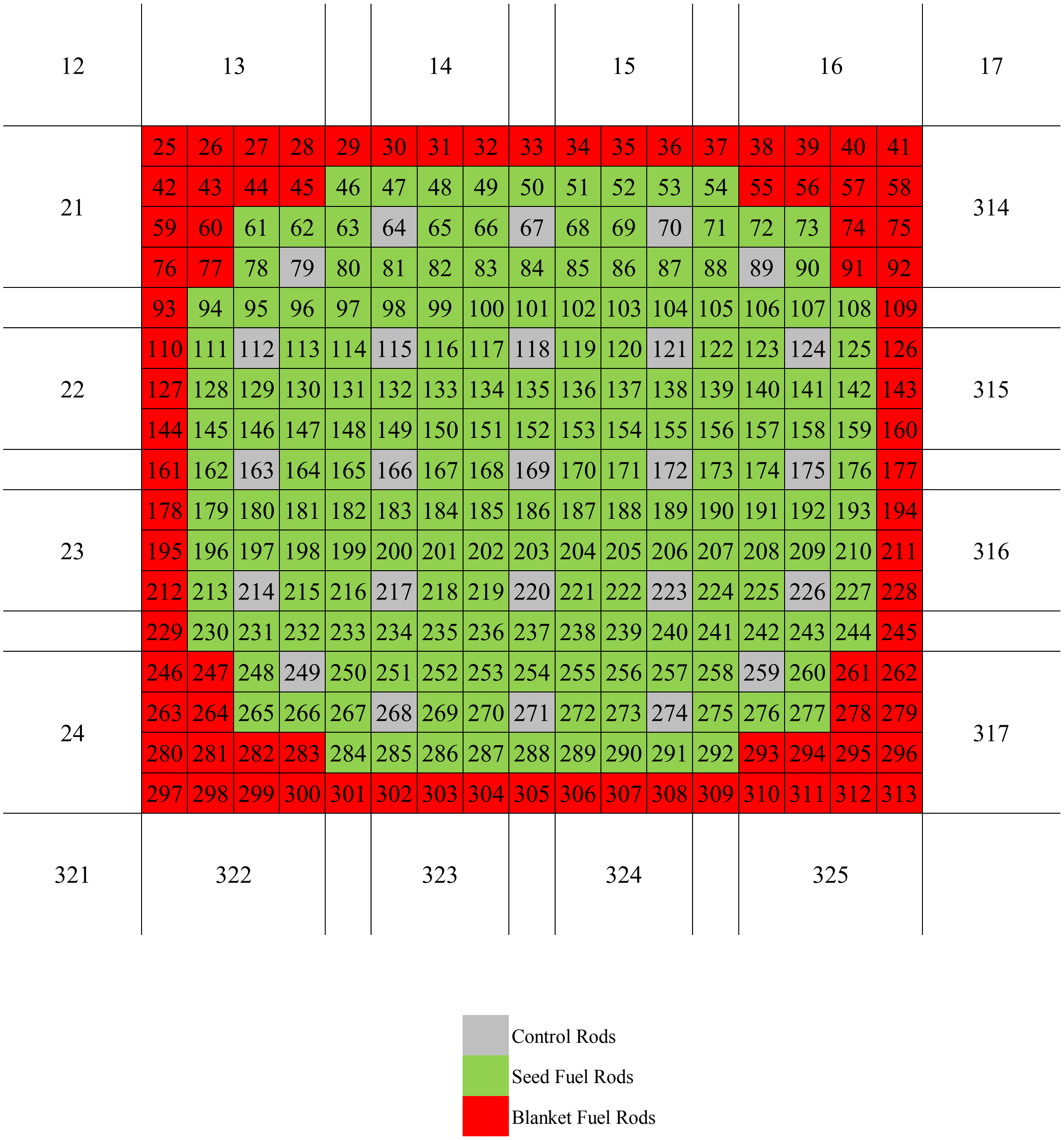


Figure 27. VIPRE Hot Assembly Rod nodalization for transient analysis

selected based on the information given in Figure 28. The subchannel identification scheme for the 1/8th core nodalization used in transient analyses is depicted by Figure 29. The transient subchannel nodalization gives maximum resolution within the hot assembly while also maintaining computational efficiency by using a lumped analysis approach. The lumped analysis approach increases the size of subchannels as their distance from the hot assembly increases.

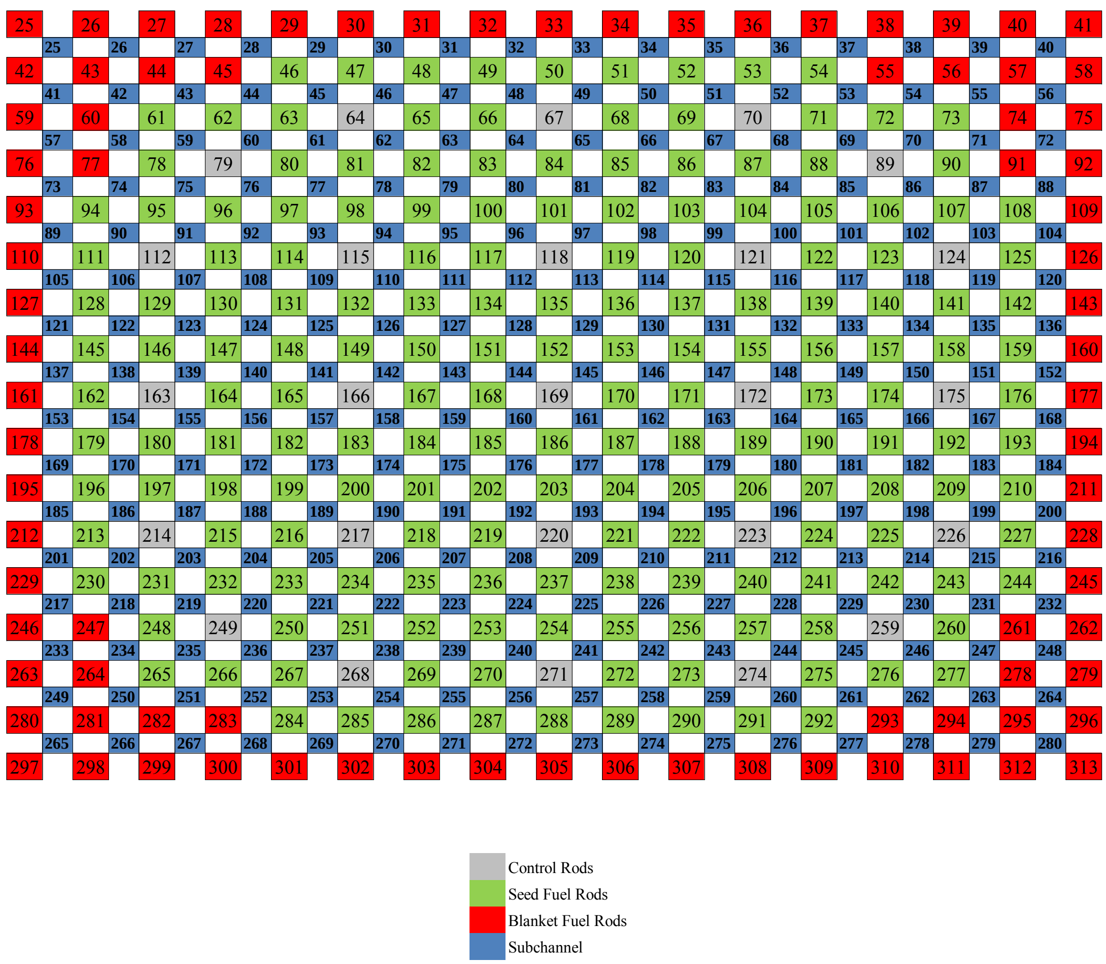


Figure 28. Hot assembly rod and subchannel nodalization for transient analysis

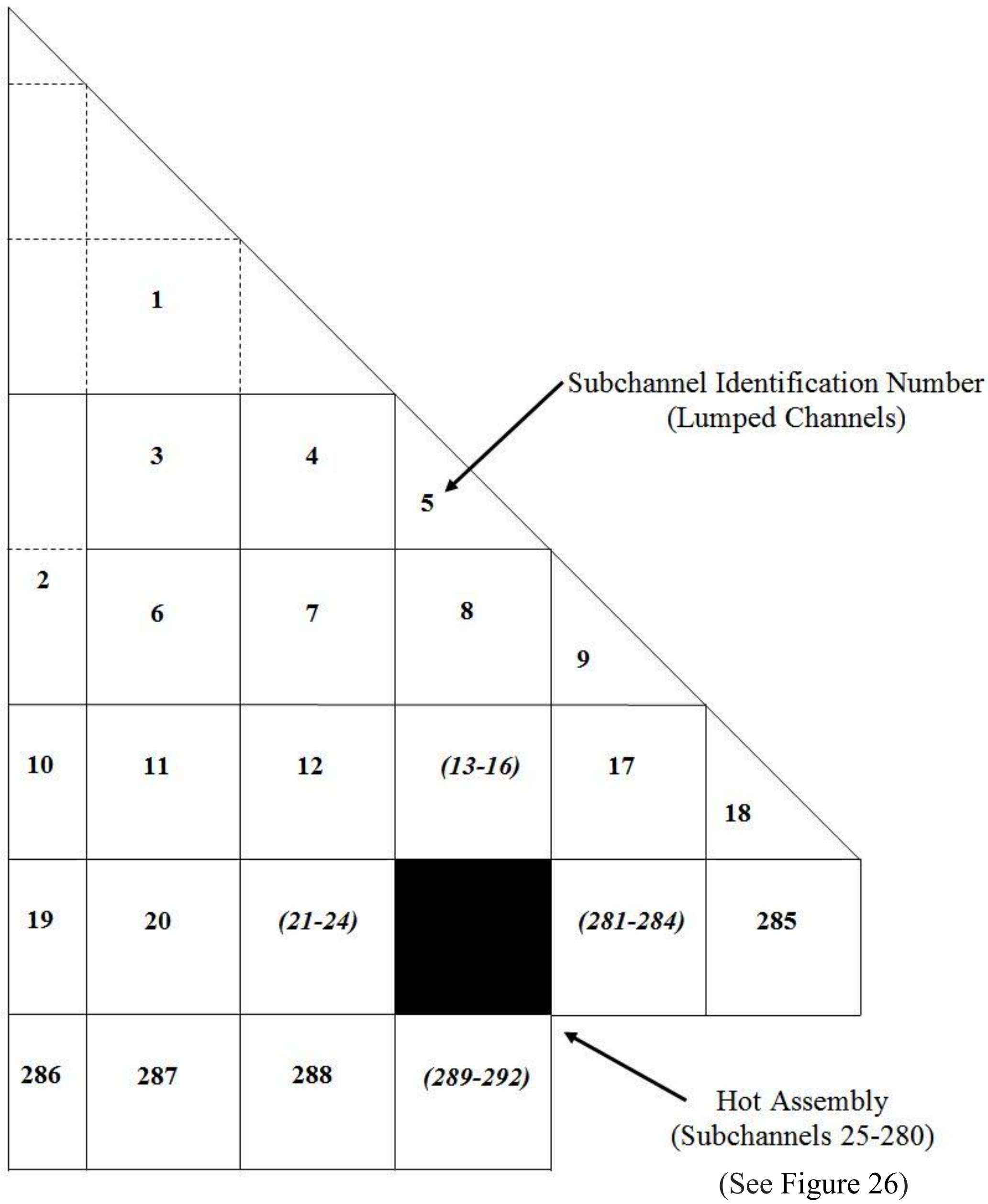


Figure 29. VIPRE 1/8th Core subchannel nodalization for transient analysis (from [4])

6. THERMAL-HYDRAULIC ANALYSIS OF DUPLEX DESIGN

The thermal-hydraulic analysis of the DUPLEX assembly design discussed in Section 5 is performed within this section using VIPRE. The full analysis includes both the steady-state scoping analysis and the transient analyses for partial and complete loss-of-flow-accident events. Boundary conditions for each component of the full analysis include coolant inlet temperature and mass flow rate, pressure, and the average linear heat generation rate (LHGR). The average LHGR for each analysis component is adjusted to correspond to the equivalent thermal energy output of the reference core. The updated methodology and treatment of multi-component fuel thermal conductivity have been added to the script-based interface (a part of the thermal-hydraulic analysis framework), which generates VIPRE input decks and execute VIPRE. The thermal margin of the DUPLEX design is discussed in terms of the primary parameters of interest, which are MDNBR, maximum fuel temperatures (MFT), and peak cladding temperature (PCT).

The MDNBR limit, PCT, and UO_2 maximum fuel temperature limit are carried over from the original framework. Due to the lack of a MDNBR limit for the reference core in the literature, the limit was set to the standard value of 1.3 associated with the W-3L CHF correlation [4]. The peak cladding temperature limit has been maintained at 948 K and the maximum fuel temperature limit for UO_2 is set to 200 K below the UO_2 melting temperature (given by Eq. (47)), which is calculated by the FRAPCON model. The PCT limit is not expected to be reached unless the coolant breaks contact with the surface of the cladding and a CHF condition occurs. The maximum fuel temperature limit for (Pu,Np,Am)O_2-MgO-ZrO_2 is set to 2130 K, which corresponds to the eutectic phase transition temperature for the EFIT CERCER design investigated by Maschek et al. [62].

Due to the large uncertainty in the evaluation of (Pu,Np,Am)O_2-MgO-ZrO_2 thermal conductivity, each analysis type is performed with two different effective thermal conductivity models: *Series* (Eq.(21)) and *ME1* (Eq.(18)). These models are used to estimate resulting thermal conductivity from the inclusion of (Pu,Np,Am)O_2 fissile particles into a MgO-ZrO_2 inert matrix. The *Series* model was chosen to provide the most conservative data-based estimate possible such that the most limiting conditions could be predicted. The *ME1* model was also included to provide a best-estimate, based on the similarity between the fuel specifications and the structure schematic of the *ME1* model in Table 3. Results from the DUPLEX fuel design analyses are compared to the imposed limits and results from the original framework for the UO_2-loaded reference design (from [4]).

6.1. Steady-State Scoping Analysis

The steady-state scoping analysis utilizing the latest thermal-hydraulic methodology has been performed for the DUPLEX fuel assembly design. The steady-state scoping analysis provides a more efficient computational method, by which less computational resources are needed, for the evaluation of the proposed DUPLEX designs. In this type of analysis, the hot assembly is relocated to the center of the reactor, as shown in Figure 30, and core power is raised to 118% of the nominal value in order to account for ANS Condition I and II transient events through the use of a steady-state scoping simulation. The 118% value comes from the 112% maximum overpower limit for U.S. PWRs and an additional 6% power increase to account for transient conditions using steady-state calculations. In addition to the overpower condition, the core mass flow rate is reduced by 5% and the coolant inlet temperature is raised by 2K. The results of the steady-state analysis for both *Series* and *ME1* k_{eff} approaches are given in the following section.

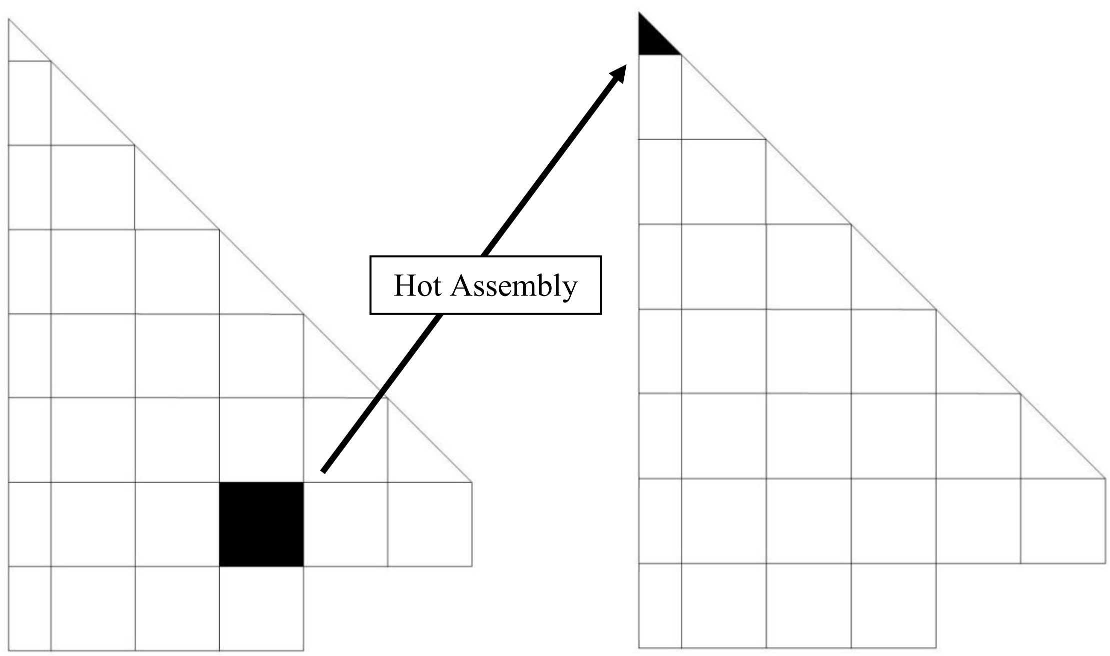


Figure 30. Relocation of hot assembly to the center of the core for steady-state analysis

6.1.1. SS Results Utilizing the Series and ME1 k_{eff} Approaches for DUPLEX IMF

The core-wide MDNBR values for both k_{eff} approaches over the assembly design's entire operational lifetime, in terms of burnup, are shown in Figure 31. The MDNBR limit of 1.3 is also included. The results for both approaches are the same. The three step-increases of the MDNBR in Figure 31 are due the reduction of assembly power as fuel assembly shuffling occurs in which the hot assembly is relocated to lower power regions of the core at 20 and 40 GWd/tHM. The MDNBR safety margin significantly increases as the assembly is reshuffled. The lifetime minimum MDNBR value is 2.024, which occurs at 906 MWd/tHM. This is much greater than the imposed limit of 1.3.

As with the case of the MDNBR, the maximum seed region temperatures are the same for both approaches. The maximum fuel temperatures for the seed region UO_2 fuel over the entire assembly operational lifetime, in terms of burnup, are shown in Figure 32. The UO_2 burnup-dependent melting temperature, given by Eq. (47), is also included, with the imposed limit of 200 K below the melting temperature. At 19,024 MWd/tHM, a lifetime maximum fuel temperature of 2512 K is obtained for rod location #2 (see Figure 24), which is well below the corresponding design limit of 2853 K at that particular burnup. The seed region maximum fuel temperatures decrease significantly at both 20 and 40 GWd/tHM reshuffling steps due to the decreased assembly power of the new assembly locations. However, at both 20 and 40 GWd/tHM, the curves should be vertical since no burnup occurs between reshuffling. This should be corrected in future

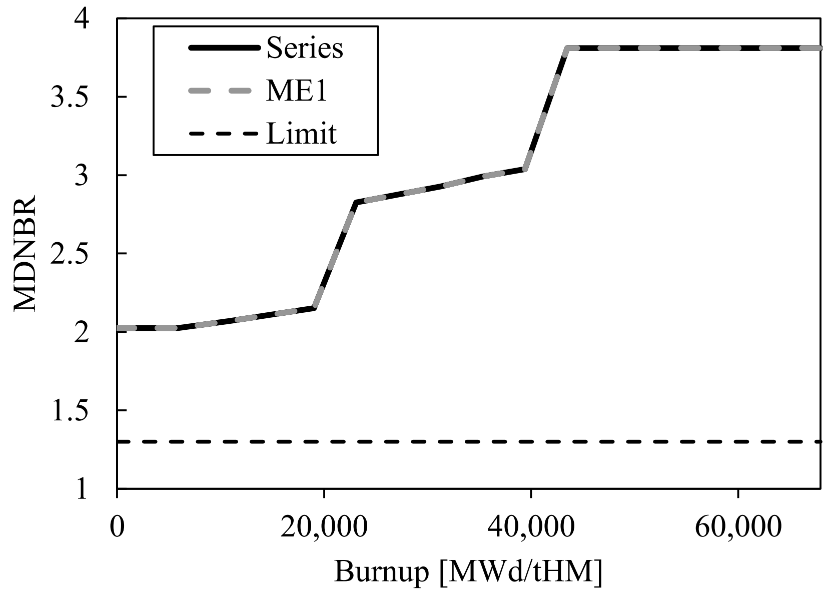


Figure 31. DUPLEX design MDNBR

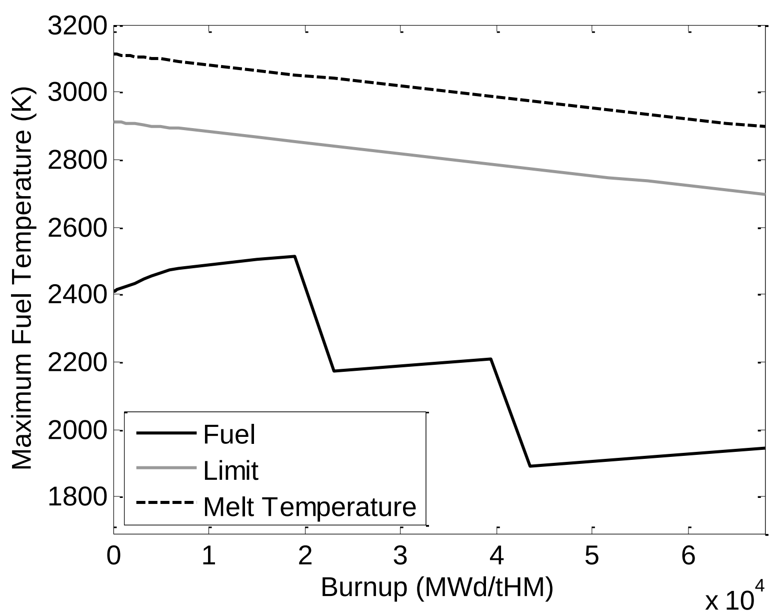


Figure 32. DUPLEX design seed region UO_2 maximum fuel temperatures

analyses by adding explicit neutronic power profiles for both 20 and 40 GWd/tHM burnups. After the thermal-hydraulic framework changes assembly power factors to simulate reshuffling, the next case should be performed at the previous burnup (ex. one case before reshuffling at 20 GWd/tHM and the following case at 20 GWd/tHM with updated assembly power factors).

For the *Series* approach to modeling the IMF k_{eff}, the maximum fuel temperatures for the blanket region (Pu,Np,Am)O_2-MgO-ZrO_2 fuel over the entire assembly operational lifetime in terms of increasing burnup, and the imposed 2130 K design limit are shown in Figure 33. At 19,024 MWd/tHM (the same as for the seed region), a lifetime maximum fuel temperature of 2118 K is obtained for rod location #34 (see Figure 24), which is slightly below the design limit of 2130 K. As with the seed region, the blanket region maximum fuel temperatures decrease significantly at both 20 and 40 GWd/tHM reshuffling steps due to the decreased assembly power of the new assembly locations.

For the *Maxwell-Eucken-1* approach to modeling the IMF k_{eff}, the maximum fuel temperatures for the blanket region (Pu,Np,Am)O_2-MgO-ZrO_2 fuel over the entire assembly operational lifetime in terms of increasing burnup, and the imposed 2130 K design limit are shown in Figure 34. At 19,024 MWd/tHM (the same as for the *Series* k_{eff} case), a lifetime maximum fuel temperature of 1918 K is obtained for the same blanket rod location #34 (see Figure 24), which is well below the design limit of 2130 K.

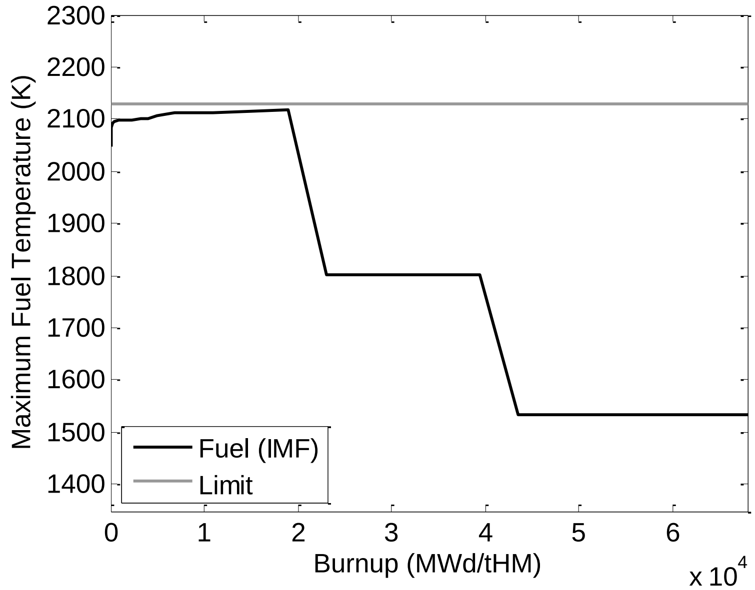


Figure 33. DUPLEX design blanket region (Pu,Np,Am)O_2-MgO-ZrO_2 maximum fuel temperatures utilizing the *Series* approach for k_{eff} of IMF fuel

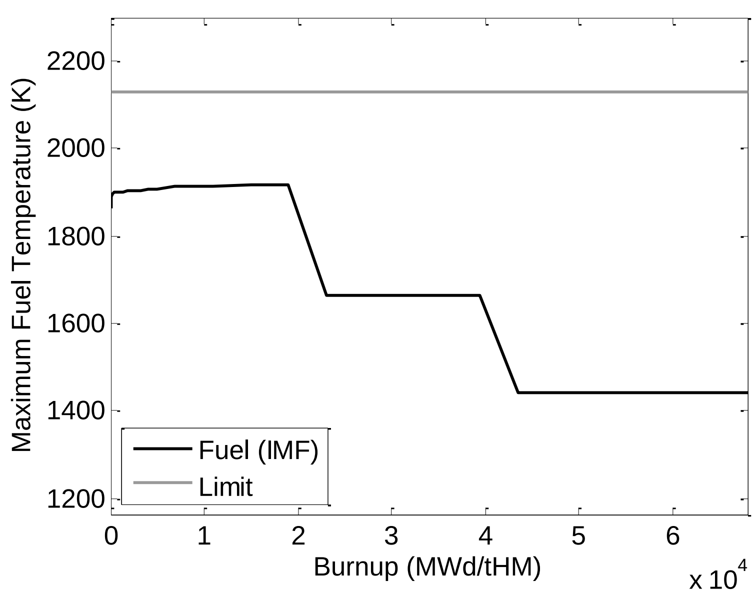


Figure 34. DUPLEX design blanket region (Pu,Np,Am)O_2-MgO-ZrO_2 maximum fuel temperatures utilizing the *ME1* approach for k_{eff} of IMF fuel

The peak cladding temperatures were not affected by the specific k_{eff} approach used for estimating IMF properties. The core-wide peak cladding temperatures over the entire assembly operational lifetime along with the 948 K design limit are shown in Figure 35. A lifetime PCT of 643 K occurs at the assembly design's BOL (0 MWd/tHM) for rod location #22 (see Figure 24), which is well below the design limit. As the DUPLEX fuel assembly is relocated to a lower power core region during reshuffling, the incremental decrease in the PCT values is on the order of only about 8 K, which is significantly less than what is observed in the results for the maximum fuel temperatures of the seed and blanket fuel regions. This occurs since the outer surface of the cladding is more tightly coupled to the surrounding coolant channel temperatures than the fuel pellets are.

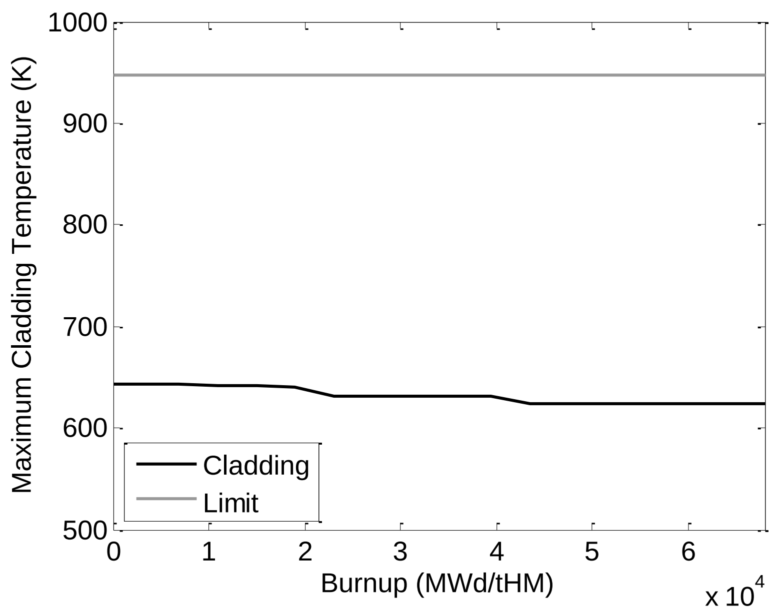


Figure 35. DUPLEX design peak cladding temperatures

6.2. Transient Analysis

Transient analyses are performed for both partial and complete loss-of-flow-accidents (LOFA), in which either one, or all, reactor coolant pumps (RCP) become unavailable. A LOFA describes a series of events that lead to a reduction in the coolant mass flow rate through the reactor core. LOFAs are mainly associated with either a mechanical or electrical failure of a reactor coolant pump, or pumps, or from a fault in the pump power supply [4]. In each case, the key thermal margin parameters listed earlier are evaluated with respect to time for a specific burnup. Analyses are performed at 19,024 MWd/tHM, which corresponds to the most limiting conditions from the steady-state scoping analysis in Section 6.1.1 and the power is reduced from 118% to 112% during both transient analyses. The reactor power is maintained at 112% power throughout each transient until the reactor is finally shut down (9.18 seconds for PLOFA and 9.06 seconds for CLOFA). The PLOFA and CLOFA sequences of events are both included in Table 9. In both transient analyses the coolant mass flow rate is reduced at the initiation of the transient. The magnitude of the reduction is determined by the transient type. While the coolant mass flow rate decreases, the heat transfer effectiveness of the coolant is reduced, causing the coolant temperature to rise. Both the magnitude and time profile of the coolant temperature changes, along with the specific duration of the 112% power condition, result in various effects observed for the MDNBRs, peak cladding temperatures, and maximum fuel temperatures. The results of the transient analysis for both *Series* and *ME1* k_{eff} approaches are given in the following sections.

Table 9
PLOFA and CLOFA sequences of events

Time (s)	PLOFA	CLOFA
< 5	Steady-state operation a 112% power	
5.00	Loss of only one RCP	Loss of all RCPs
8.06	------------------	87% loop low-flow signal
8.18	87% loop low-flow signal	------------------
9.06	------------------	Reactor trip
9.18	Reactor trip	------------------

6.2.1. PLOFA Transient Results Utilizing the Series and ME1 k_{eff} Approaches for DUPLEX IMF

Partial LOFA transient analysis results for the DUPLEX assembly design core-wide MDNBR values and the 1.3 limit are depicted in Figure 36. The magnitude and profile of the MDNBR curve for both k_{eff} approaches are the same. At 112% core power, before the transient is initiated at 5 seconds, the MDNBR is constant at 2.26. Beginning at 5.79 seconds, the reduction in core mass flow rate causes the MDNBR to decrease to a minimum value of 2.16 at 9.57 seconds, which is well above the 1.3 limit.

As with the case of the MDNBR, the maximum seed region temperatures are the same for both approaches. The maximum fuel temperatures with respect to time for the seed region UO_2 fuel for the PLOFA transient analysis are shown in Figure 37, along

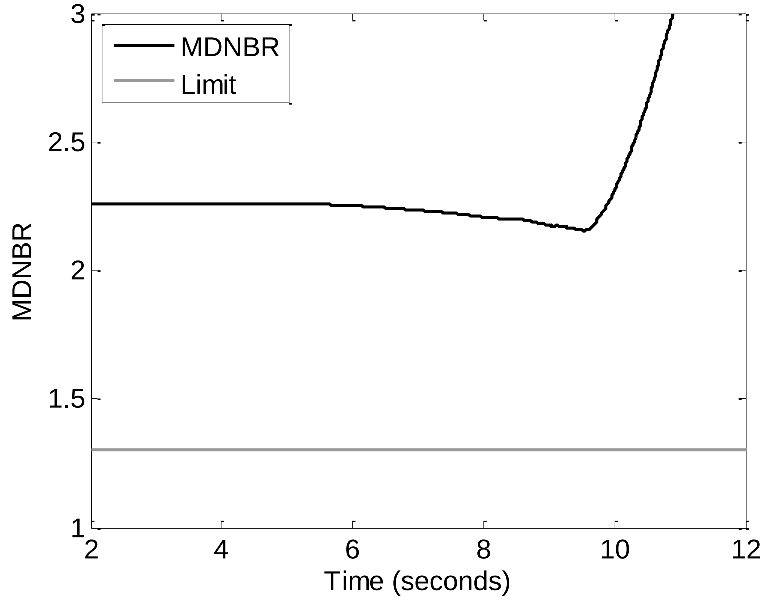


Figure 36. PLOFA DUPLEX design MDNBR

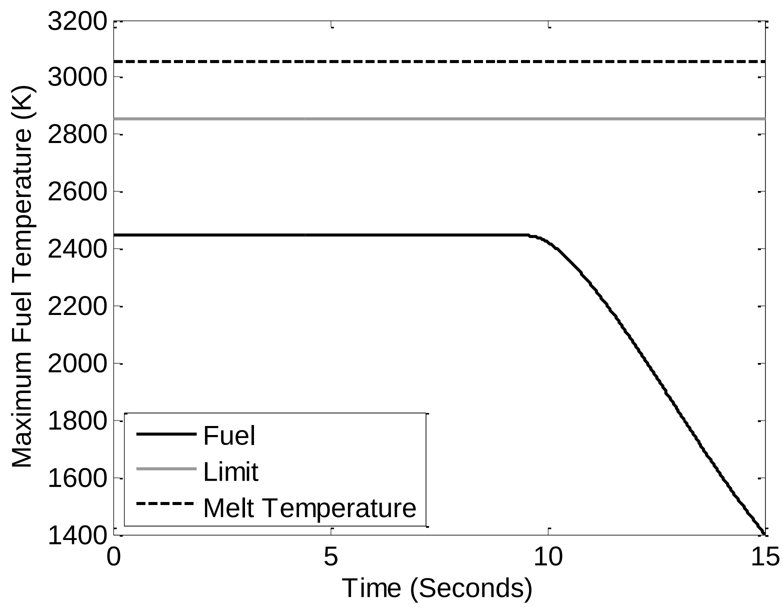


Figure 37. PLOFA DUPLEX design seed region UO_2 maximum temperatures

with the UO_2 melting and limiting temperatures. The fuel temperatures are at their maximum value at 112% core power, before the transient sequence is initiated. During this time a maximum temperature of 2447 K is observed, which is far below the imposed design limit of 2852 K. A change in the maximum fuel temperatures does not occur immediately following the loss of one RCP at 5 seconds. Only after the reactor has shutdown at 9.18 seconds is an effect noticeable. The blanket region maximum fuel temperatures follow in a similar manner to that observed by the seed region. The maximum fuel temperature for the blanket region (Pu,Np,Am)O_2-MgO-ZrO_2 fuel also occurs before the transient is initiated at a value of 2055 K for the *Series* k_{eff} approach which is below the respective steady-state analysis maximum temperature and even further below the limit of 2130 K.

The maximum PCT values obtained by both approaches are also the same. The PCT versus time during a PLOFA transient along with the corresponding limit of 948 K are shown in Figure 38. A maximum PCT of 644 K occurs at 9.55 seconds during the PLOFA transient, which is only 1 K greater than the PCT for the steady-state scoping analysis. The PCT is initially constant at 642 K at 112% power. At 7.29 seconds, the PCT begins to increase until the maximum value is obtained at 9.55 seconds, after which the PCT curve decreases. Not until 9.98 seconds does the PCT drop below the original value obtained before the transient was initiated. The PCT then continues to decrease monotonically. Sufficient thermal safety margin in regards to the peak cladding temperatures is maintained throughout the transient.

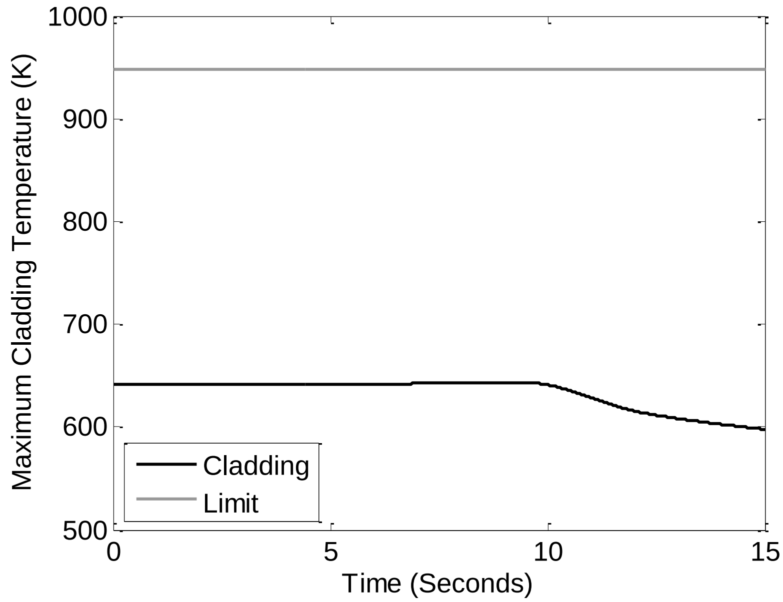


Figure 38. PLOFA DUPLEX design peak cladding temperatures

6.2.2. *CLOFA Transient Results Utilizing the Series and ME1 k_{eff} Approaches for DUPLEX IMF*

As with the PLOFA transient analysis, the *Series* and *ME1* k_{eff} approaches yielded similar results for the MDNBR, PCT, and maximum seed region fuel temperature profiles during the CLOFA transient analysis. For simplicity, only a single representative curve for each key parameter is used to depict results of both approaches.

Complete LOFA transient analysis results for the DUPLEX assembly design core-wide MDNBR values and the 1.3 limit are depicted in Figure 39. The reduction in MDNBR safety margin is much more pronounced than in the case of the PLOFA transient analysis. This is due to a loss of all 4 reactor coolant pumps, reducing the core coolant mass flow rate significantly. While the average fuel pin heat flux remains constant for both analyses, the critical heat flux is reduced even further for the CLOFA analysis, resulting in decreased MDNBR values. At 112% core power, before the transient is initiated at 5 seconds, the MDNBR is constant at 2.26. Beginning at 5.43 seconds, the increased reduction in core mass flow rate causes the MDNBR to decrease to a minimum value of 1.60 at 9.31 seconds, just shortly after the reactor shutdown at 9.06 seconds. Not until 10.04 seconds does the MDNBR return to the original value obtained before the transient was initiated. The MDNBR then continues to monotonically increase. Sufficient thermal safety margin in regards to the MDNBR is maintained throughout the transient.

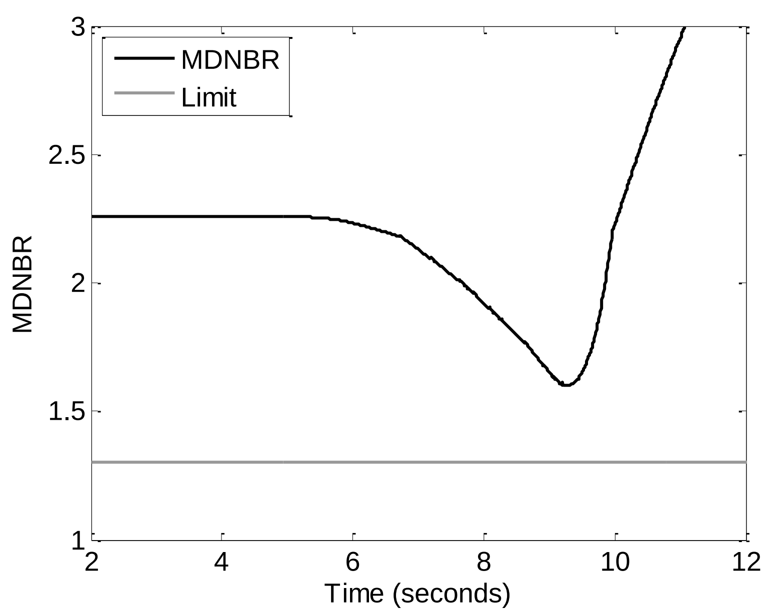


Figure 39. CLOFA DUPLEX design MDNBR

The CLOFA transient analysis maximum fuel temperatures with respect to time for the seed region UO_2 fuel are shown in Figure 40. The UO_2 melting and limiting temperatures are also included. The fuel temperatures are at their maximum value at 112% core power, before the transient sequence is initiated. During this time a maximum temperature of 2447 K (same as for the PLOFA analysis) is observed, which is far below the imposed design limit of 2852 K. A change in the maximum fuel temperatures does not occur immediately following the loss of all 4 RCPs at 5 seconds. The maximum fuel temperature does not begin to decrease until 9.02 seconds. However, only after the reactor has shutdown at 9.18 seconds is an effect noticeable.

CLOFA transient analysis results for the blanket region $(Pu,Np,Am)O_2$-MgO-ZrO_2 fuel maximum temperatures are shown in Figure 41. The blanket region maximum fuel temperatures follow in a similar manner to that observed by the seed region. The maximum fuel temperature for the blanket region $(Pu,Np,Am)O_2$-MgO-ZrO_2 fuel also occurs before the transient is initiated at a value of 2055 K for the $Series\ k_{eff}$ approach which is below the limit of 2130 K.

The PCT versus time during a PLOFA transient along with the corresponding limit of 948 K are shown in Figure 42. A maximum PCT of 647 K both approaches occur at 9.22 seconds during the CLOFA transient, which is 4 K greater than the PCT for the steady-state scoping analysis and only 3 K greater than that for the PLOFA analysis. The PCT is initially constant at 642 K at 112% power. At 6.06 seconds, the PCT begins to increase until the maximum value is obtained at 9.22 seconds, after which the PCT curve decreases. Not until 10.25 seconds does the PCT drop below the original

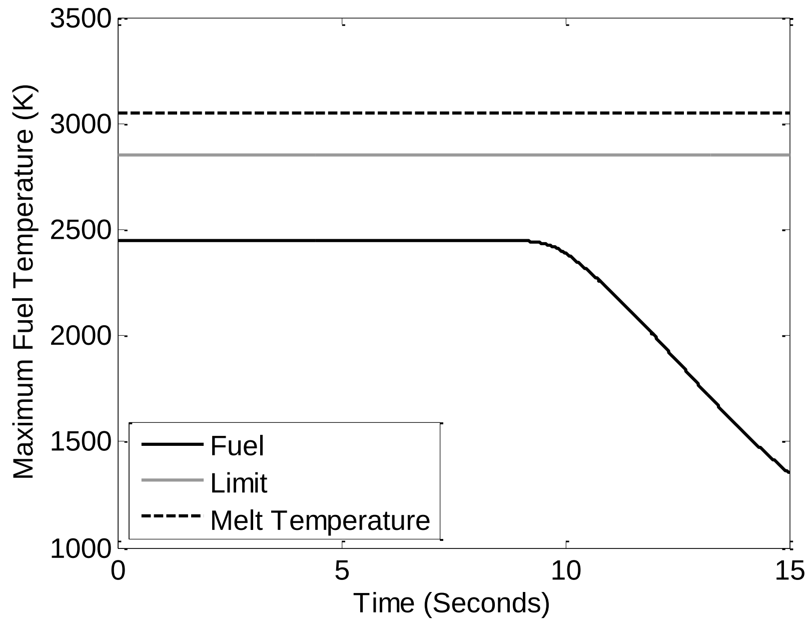


Figure 40. CLOFA DUPLEX design seed region UO_2 maximum temperatures

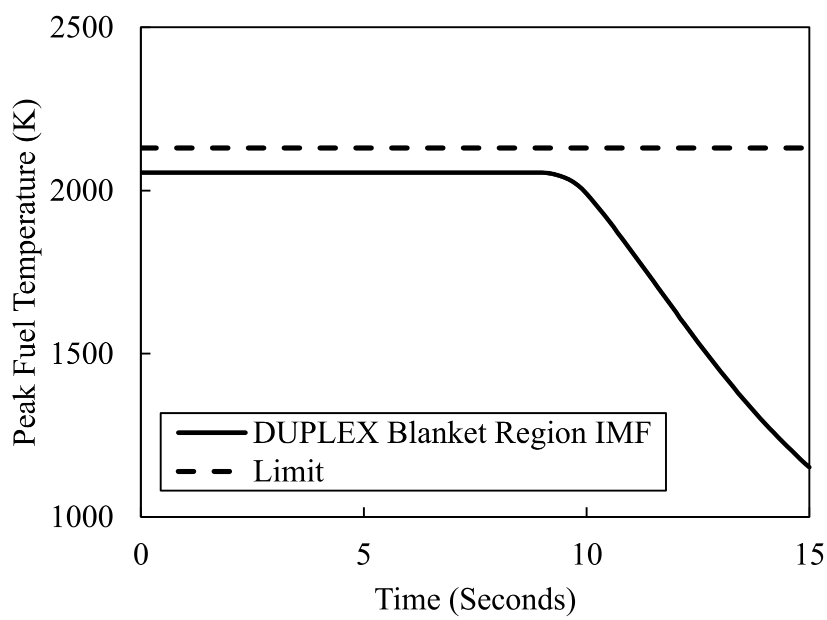


Figure 41. CLOFA DUPLEX design blanket region $(Pu,Np,Am)O_2$-MgO-ZrO_2 maximum fuel temperatures utilizing the *Series* approach for k_{eff} of IMF fuel

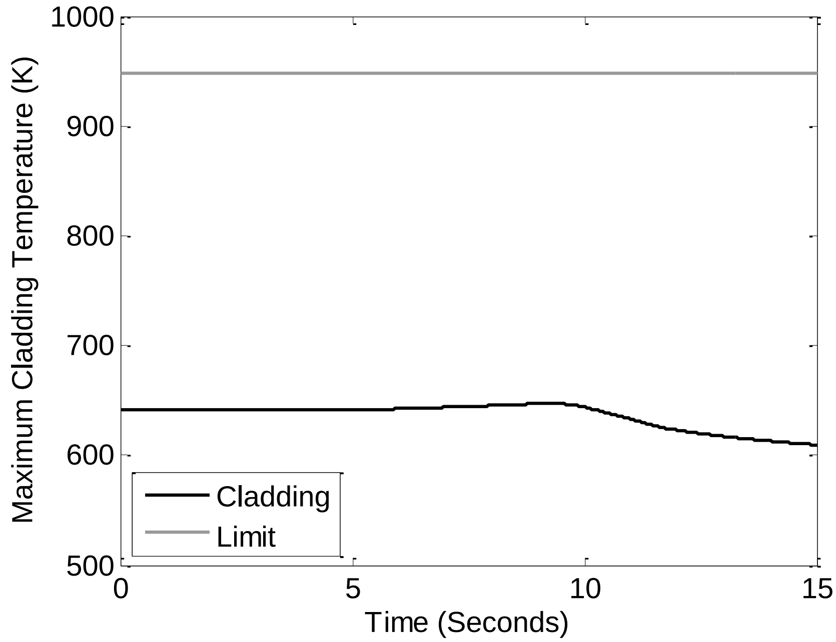


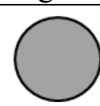
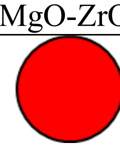
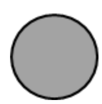
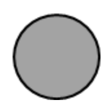
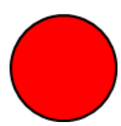
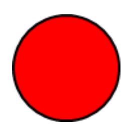
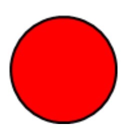
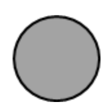
Figure 42. CLOFA DUPLEX design peak cladding temperatures

value obtained before the transient was initiated. The PCT then continues to decrease monotonically. Sufficient thermal safety margin in regards to the peak cladding temperatures is maintained throughout the transient.

6.3. Fuel Rod Diameter Variation Analysis

An additional thermal-hydraulic study was performed in which three variations on the diameters of the DUPLEX fuel rods were made. In each case the *ME1* k_{eff} approach was used for estimating $(Pu,Np,Am)O_2$-MgO-ZrO_2 thermal conductivity values. The list of cases is given in Table 10. The "IMF decreased" case reduces the blanket region fuel rod diameter to the nominal seed region fuel rod diameter, the "UO_2 increased" case enlarges the seed region fuel rod diameter to the nominal blanket region fuel rod diameter, and the "IMF and UO_2 switched" case simply swaps the fuel rod diameters of each region. In each case, only the fuel rod diameters are adjusted and no modifications to fuel materials, or their properties, are made. Based on the results from the full thermal-hydraulic analysis of the nominal DUPLEX design, only steady-state scoping and CLOFA transient analyses were considered, since these analyses were found to yield the most limiting parameters.

Table 10
Zoned fuel diameter variations

Cases	Seed Region UO_2	Blanket Region $(Pu,Np,Am)O_2$-MgO-ZrO_2
Nominal		
IMF decreased		
UO_2 increased		
IMF and UO_2 switched		

Steady-state scoping analysis results for the blanket region $(Pu,Np,Am)O_2$-MgO-ZrO_2 fuel maximum temperatures are shown in Figure 43. The maximum fuel temperature for all three cases occurs at a burnup of 19,024 MWd/tHM, the same as for the nominal case. Lifetime maximum fuel temperature values of 1950 K, 1910 K, and 1943 K are observed for the decreased diameter IMF, increased diameter UO_2, and switched seed and blanket region rod diameter cases, respectively. For the cases in which the IMF rod diameter is decreased to the diameter of the seed region fuel, the IMF maximum temperatures are at their highest. This is expected since the power generated in each fuel rod remains constant, while the volume decreases, resulting in an increase in the volumetric heat generated within the fuel pin. However, in all cases the maximum fuel temperatures are maintained below their imposed design limits.

The CLOFA transient analysis of each case was performed for their respective most limiting burnup values based on the steady-state MDNBR analysis, all of which occur before the first shuffling of the core at 20 GWd/tHM. The minimum MDNBR values from steady-state analysis for each case and their respective burnups are: 2.02 at a burnup of 906 MWd/tHM for the nominal design; 1.88 at a burnup of 18 MWd/tHM for the "IMF Decreased" case; 2.44 at a burnup of 4,982 MWd/tHM for the "UO_2 Increased" case; and 2.21 at a burnup of 19,024 MWd/tHM for the "IMF/UO_2 Switched" case.

CLOFA transient analysis maximum seed region UO_2 fuel temperatures with respect to time are shown in Figure 44. The UO_2 temperature limit is also included for a burnup of 19,024 MWd/tHM. The greatest UO_2 maximum fuel temperature is 2451 K

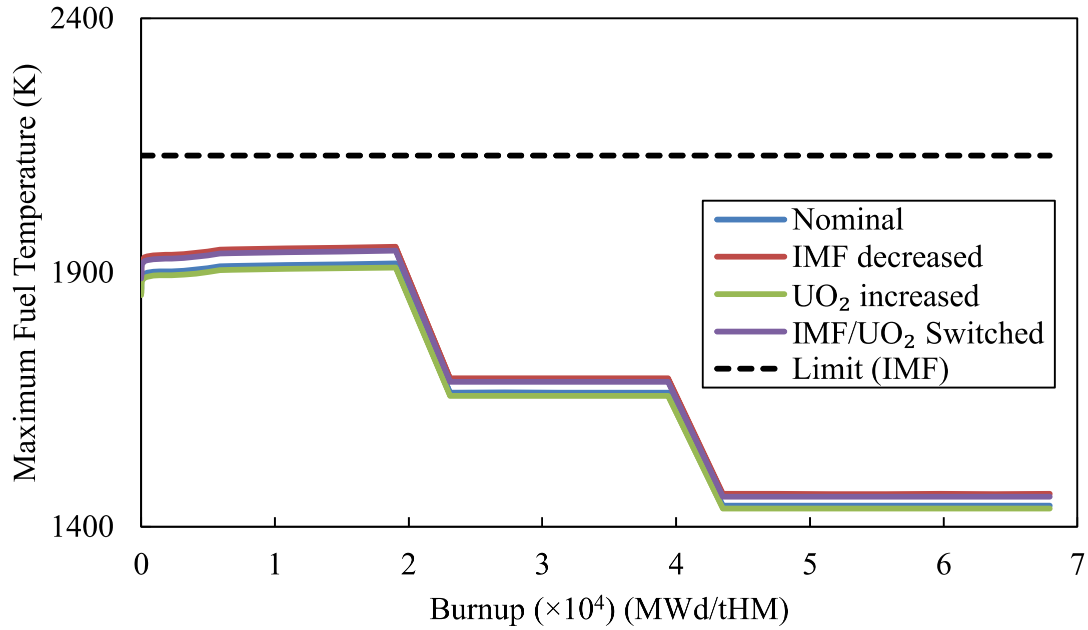


Figure 43. Steady-state scoping analsysis blanket region maximum fuel temperatures

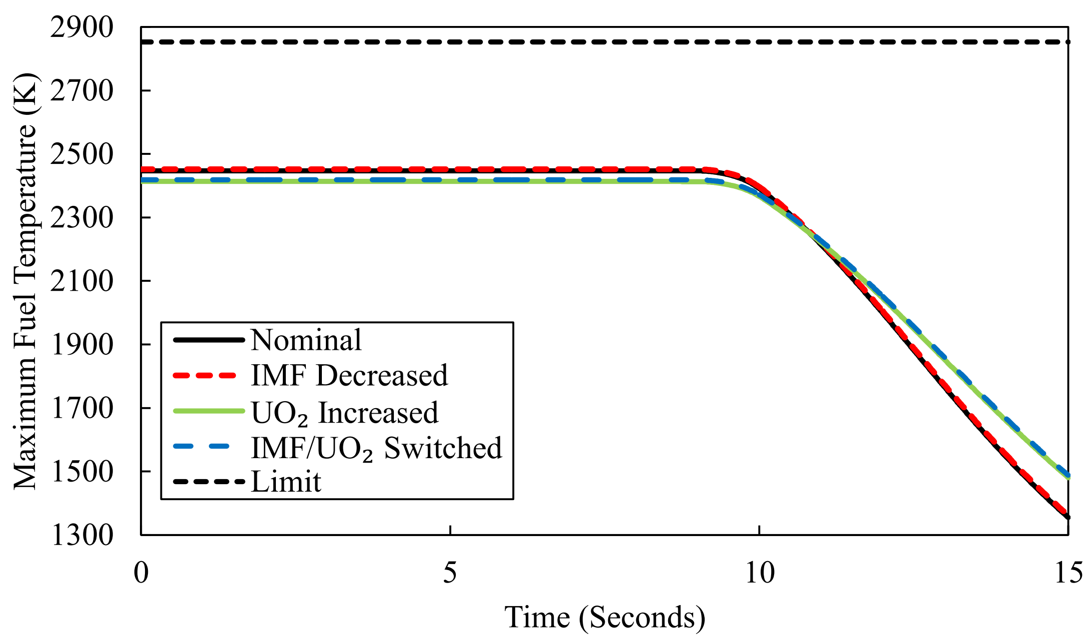


Figure 44. CLOFA transient analysis blanket region maximum temperatures

for the “IMF Decreased” case at 112% power. The maximum fuel temperature for this case does not begin to decrease until 9.15 seconds, which is slightly later than for the other cases. The nominal case initially has a constant maximum value of 2447 K until it begins to decrease at 9.02 seconds. The “UO_2 Increased” case has a maximum value of 2412 K, which starts to decrease at 9.12 seconds. Shortly after at 9.13 seconds, the “IMF/UO_2 Switched” case begins to decrease from its maximum value of 2417 K. For the cases in which the UO_2 diameter is increased, the rate at which the seed region maximum fuel temperature decreases is less than that for the cases that model the UO_2 diameter with the nominal value. This effect is due to an increased thermal transport time of the internal thermal energy, within the fuel pin, to the coolant when the fuel rod diameter is increased. Maximum fuel temperatures for each case are maintained below their respective limits during the transient.

MDNBR results for the CLOFA transient analysis from each case are shown in Figure 45. The most pronounced differences in thermal safety margin of the various cases are observed for these results. For this study, the overall minimum MDNBR is 1.54 for the “IMF Decreased” case, which is greater than the design limit of 1.3. In this case, both seed and blanket region fuel rod diameters are at their minimum values for the study. The decreased blanket region diameters result in a greater heat flux since the same power is being applied as in the nominal case while the heat transfer surface area is decreased. The minimum MDNBR values for the “UO_2 Increased” and “IMF/UO_2 Switched” cases are 1.73 and 1.67, respectively. Sufficient MDNBR thermal safety margin is maintained throughout the transient for all cases.

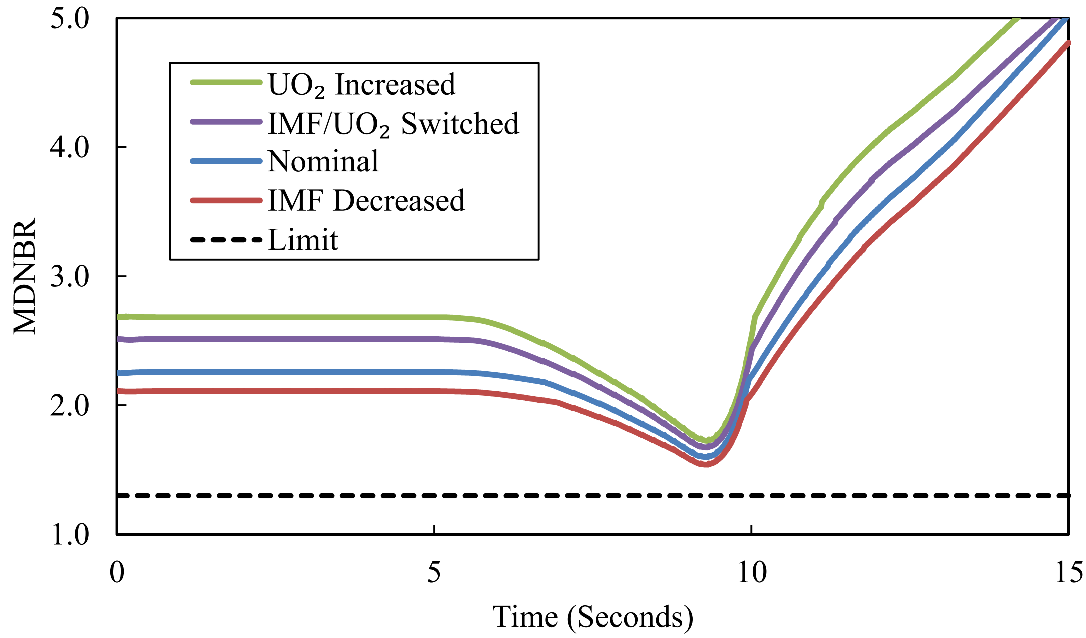


Figure 45. CLOFA transient MDNBR values for different rod dimensions

Another key parameter of interest that should be considered during pin diameter studies is the core pressure drop. In conventional PWRs, the fuel assemblies are kept from moving axially upward in the core, primarily by their own weight. Too great of a core pressure drop can result in an assembly lifting out of its location, causing adverse safety conditions. The estimated core pressure drop given in Table 1 is 0.12 MPa for the reference plant. However for the nominal DUPLEX design, the pressure drop is increased to 0.16 MPa. The increased pressure drop is due to a decrease in the fuel assembly effective flow area, increase in assembly surface area, and the greater form loss coefficient for the grid-spacers of 0.86 used in this analysis instead of the 0.61 value used for the reference case in the analysis performed by Bingham. A maximum pressure drop of 0.21 MPa is obtained for the "UO_2 increased" case, which is expected based on the above explanation. The pressure drop for the remaining "IMF Decreased" and "IMF/UO_2 switched" cases are 0.15 MPa and 0.19 MPa, respectively.

6.4. Discussion of Results

The results from the thermal-hydraulic analysis for the DUPLEX assembly design are summarized in Table 11. Results for the UO_2-loaded reference core are also included from the previous analysis performed by Bingham [4]. There are two different temperature limits for UO_2 which are established for the most limiting burnup of the designs: 19,362 MWd/tHM for the reference UO_2-loaded core [4] and 19,024 MWd/tHM for the DUPLEX assembly design. The most limiting seed and blanket region fuel temperatures occur during the steady-state analyses, while the most limiting PCT and MDNBR are obtained from the CLOFA transient analysis.

For each analysis type, the k_{eff} approach used for calculating IMF thermal conductivity had a negligible effect on the MDNBR, PCT, and UO_2 PFT. However, the IMF PFT was noticeably different between each method, which was expected due to the larger thermal conductivity values given by the *ME1* model relative to the *Series* model (see Figure 21). The largest maximum fuel temperatures observed for the blanket region $(Pu,Np,Am)O_2$-MgO-ZrO_2 fuel during the full thermal-hydraulic analysis is from the steady-state scoping analysis, while utilizing the *Series* model, at a value of 2118 K, which is below the 2130 K limit.

Table 11
DUPLEX design thermal-hydraulic analysis results

	Steady-state scoping analysis				PLOFA			CLOFA		
	UO_2 PFT (K)	IMF PFT (K)	PCT (K)	MDNBR	UO_2 PFT (K)	PCT (K)	MDNBR	UO_2 PFT (K)	PCT (K)	MDNBR
Limits	*2851*		*948*	*1.30*	*2851*	*948*	*1.30*	*2851*	*948*	*1.30*
UO_2 (Reference [4])	2581	----	621	1.87	2478	621	1.97	2478	622	1.74
Limits	*2852*	*2130*	*948*	*1.30*	*2852*	*948*	*1.30*	*2852*	*948*	*1.30*
UO_2 | $(Pu,Np,Am)O_2$-MgO-ZrO_2	2512	2118 *(Series)* 1918 *(ME1)*	643	2.02	2447	644	2.16	2447	647	1.60

The thermal-hydraulic analysis results indicate a reduction in the UO_2 maximum fuel temperatures compared to an updated UO_2-loaded reference core model (utilizing the enhanced framework), and previously investigated $(Am,Zr)O_2$-coated designs by Bingham, as shown in Figure 46. The maximum UO_2 fuel temperatures of the DUPLEX design are 69 K less than the reference design for the steady-state analysis and 31 K less for both transient analyses. However, thermal margin for the IMF fuel in the blanket region is poor and may outweigh the benefits of an increased UO_2 fuel temperature safety margin. This is most likely due to the extremely conservative assumptions made in relation to the development of the thermal conductivity modeling methodology described in Section 4.5.

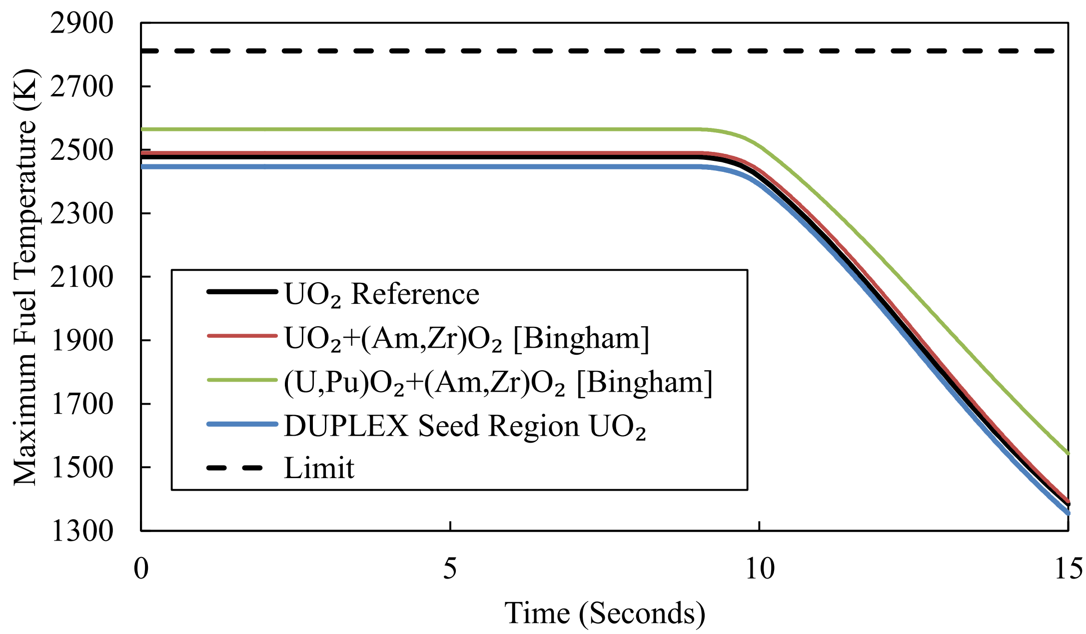


Figure 46. CLOFA maximum fuel temperature comparison

An increased MDNBR safety margin for the DUPLEX design, relative to the reference core, is observed for the steady-state and PLOFA analyses in which the minimum MDNBR is 0.15 and 0.19 less, respectively. However, In the case of the CLOFA transient analysis, there is less MDNBR safety margin with the DUPLEX design compared to the reference UO_2 design and previously studied designs by Bingham, as shown in Figure 47. A possible reason for this decreased safety performance is most likely due to the updated VIPRE input framework, specifically the difference in selected friction factor correlations and increased conservatism used in defining the grid loss coefficient.

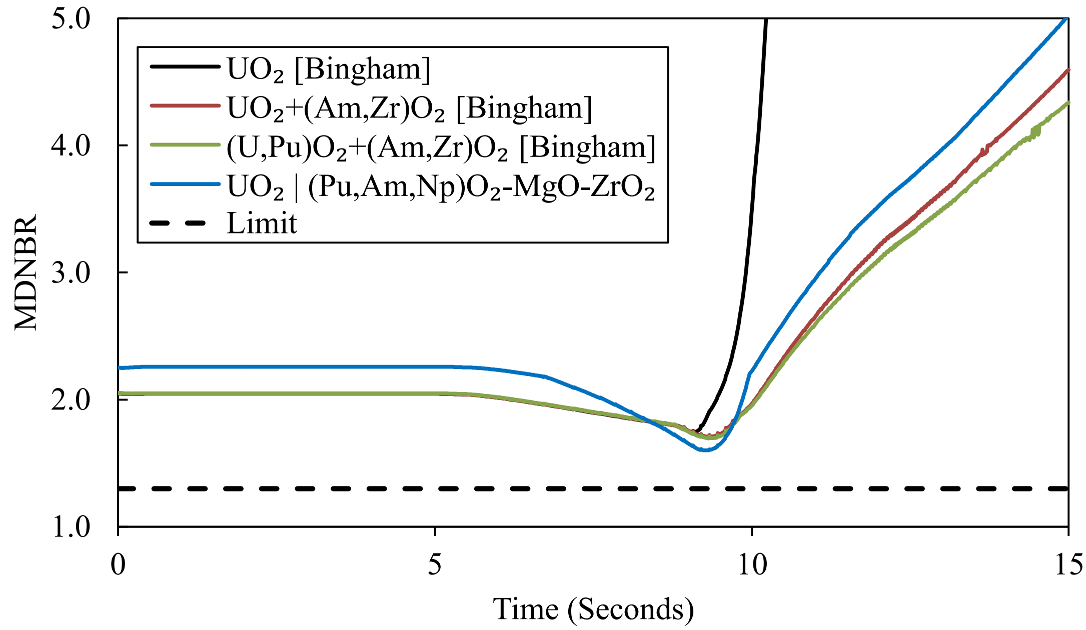


Figure 47. CLOFA MDNBR comparison

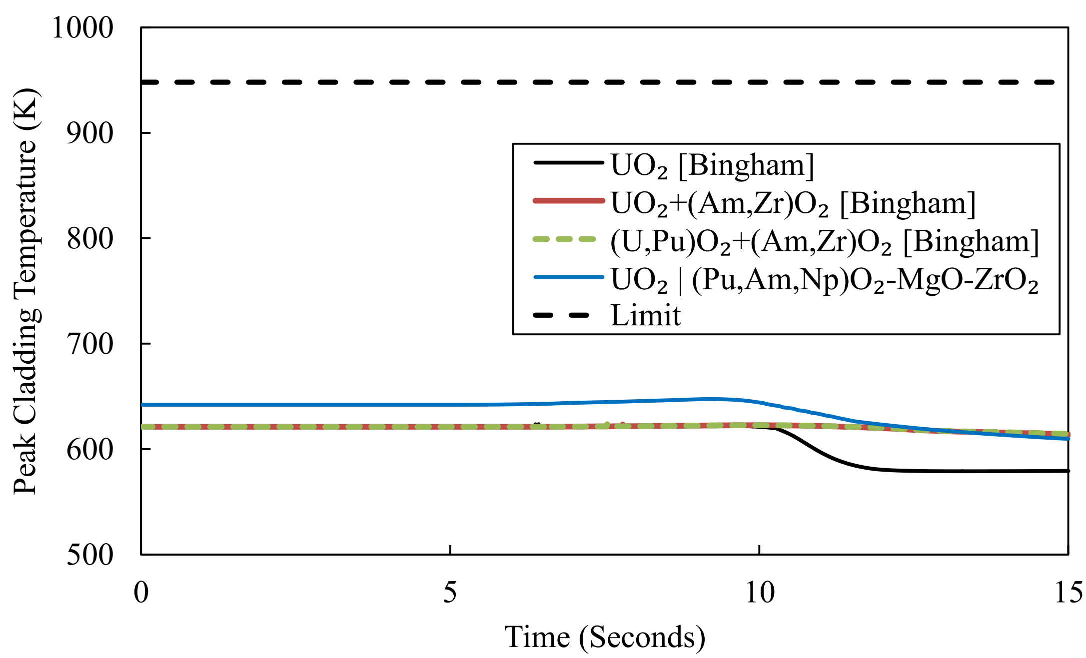


Figure 48. CLOFA cladding temperature comparison

The DUPLEX design PCT for all analyses is on the order of 22 to 25 K greater than the reference UO_2 design and the $(Am,Zr)O_2$-coated Bingham designs, but is still well below the imposed limit of 948 K, as shown in Figure 48.

6.5. Summary

Both steady-state and transient analyses have been performed utilizing the updated thermal-hydraulic analysis framework for heterogeneous fuel assembly designs. With the new framework, the DUPLEX fuel assembly design was studied, in which two different thermal conductivity models for estimating IMF properties were used to simulate the design's possible range of performance. In addition to the standard thermal-hydraulic analysis of the DUPLEX design, the effects of variations in seed and blanket region fuel rod diameters were also investigated. In all cases, the DUPLEX design was shown to satisfy design safety criteria with respect to PCT, seed and blanket region PFTs, and MDNBR thermal margins during simulated ANS Conditions I, II, and III transients. Specific to the DUPLEX design, the thermal margin of the IMF blanket region maximum fuel temperature, using the *Series* model, is the most limiting result at a value of only 12 K below the 2130 K imposed limit during the steady-state analysis. This is due to the conservative assumption of reduced thermal conductivity obtained by the *Series* model, which was made in order to account for the large uncertainty in IMF thermal conductivity values, combined with the relatively large rod diameter for the blanket region. However, if experimental data in fact confirms the *ME1* model to be more appropriate, the thermal margin is increased by an additional 200 K.

The second most limiting value is the MDNBR, which at its minimum value is 1.60 and is less than that of the UO_2-loaded reference core result. Reduction in the IMF maximum fuel temperature and PCT, while increasing the limiting MDNBR, can be obtained through the increase of the seed region fuel rod diameter as demonstrated in Section 6.3, which comes at the expense of UO_2 thermal margin and core pressure drop. An increase of only 32 K for the maximum UO_2 temperature would result if this were adopted. However, the resulting core pressure drop may become prohibitive.

7. SUMMARY

Innovative new fuel assembly designs have been proposed for use in standard PWRs in order to reduce the inventory of transuranic waste coming from discharged fuel assemblies at nuclear power plants. Many of these designs have only been studied in-depth from a neutronics point of view, neglecting the detailed thermal-hydraulic analysis required for the assurance of safe operation. Most thermal-hydraulic evaluations of advanced fuel designs have focused on simplified steady-state or limited transient analysis. The effect of material thermophysical property degradation, and variation over the assembly's life, on thermal-hydraulic safety parameters has traditionally been overlooked in advanced fuel assembly designs. Of the work that has considered the thermophysical properties of exotic theoretical IMF designs, overly simplified assumptions and a high dependency on experimental data have been used, which result in a restricted or unrealistic thermal-hydraulic analysis of the investigated designs.

The research efforts of this thesis are the first to consider the DUPLEX heterogeneous fuel assembly design while utilizing the latest burnup-dependent thermal-hydraulic analysis methodology to determine both performance and thermal safety margin over the entire 68 GWd/tHM assembly design operational lifetime. The DUPLEX IMF-UOX assembly design is unique compared to standard PWR fuel assemblies in that it contains two fuel regions, a "seed" region with standard UO_2 fuel and a "blanket" region with a larger diameter $(Pu,Np,Am)O_2$-MgO-ZrO_2 IMF design. In order to accomplish the goals of this thesis, pre-existing analysis techniques for both conventional and heterogeneous fuel assemblies were reviewed. In conjunction with the latest burnup-dependent thermal-hydraulic analysis methodology of homogeneous fuel assemblies and with available recommendations from similar heterogeneous assembly analysis work, an updated thermal-hydraulic analysis methodology was developed for the evaluation of heterogeneous fuel assemblies, specifically, of the SBU-type. The updated methodology includes increased flexibility for modeling assembly designs within VIPRE, which are evaluated for both steady-state and LOFA transient analyses.

An extensive literature survey was performed on the thermal properties of the proposed DUPLEX assembly blanket region $(Pu,Np,Am)O_2$-MgO-ZrO_2, referred to as "LWR-2-E", fuel design. However, the thermal conductivity of materials is not well understood due to material-specific characteristics which are difficult to quantify without experimentation. In the case of minor actinide dioxide fuels, there exist an even greater uncertainty in thermal conductivities relative to UOX or MOX-based fuels, due to related difficulties in their manufacturing and handling. Thus, a comprehensive review of several k_{eff} methods applicable to CERCER fuels was also performed, in order to calculate the thermal conductivity of the combined host and fissile phases from individual components in which data is available. A thermal conductivity modeling scheme was developed for estimating the properties of complex two-phase fuel designs in which limited data is available for the components. From the modeling scheme, two models were produced representing conservative and best-estimate predictions for $(Pu,Np,Am)O_2$-MgO-ZrO_2 which were shown to be in relatively good agreement with the observed experimental trends of similar fuel designs.

An existing VIPRE script-based thermal-hydraulic analysis framework was modified to allow for the analysis of heterogeneous fuel assembly designs through the implementation of more generalized equations and modeling techniques, which are applicable to both uniform and heterogeneous assembly layouts. Effective thermal conductivity models are also added to the framework, for which they can be used to determine the thermal conductivity of any two-phase system, not just the LWR-2-E design. Both of these features enhance the overall applicability of the original analysis framework such that nearly any homogeneous or heterogeneous PWR fuel assembly design, utilizing cylindrical fuel rods, can be analyzed. The modified analysis framework also maintains consistency between previous analyses of homogeneous fuel assembly designs, performed with the original framework, and DUPLEX design analyses by reducing the differences in VIPRE modeling approaches. Thus, the thermal-hydraulic characteristics of the DUPLEX assembly design can be compared directly to the characteristics of previously analyzed AMOX and UO_2-loaded reference core designs. The reference plant is the Comanche Peak Nuclear Power Plant Unit 1.

Steady-state, PLOFA, and CLOFA VIPRE input decks were created to model the DUPLEX assembly design which consists of a conventional inner UO_2 seed region and a nonconventional outer $(Pu,Np,Am)O_2$-MgO-ZrO_2 blanket region. Three additional cases were also modeled in which the diameters of the DUPLEX seed and blanket rods were varied. Inherited from the existing framework, VIPRE steady-state 1/8th core single-pass hot channel analysis was performed for the DUPLEX assembly design at 118% nominal core power in order to confirm that safety criteria are maintained under ANS Condition I and II events. Using boundary conditions supplied from previous MELCOR analysis, both partial and complete loss-of-flow-accident transient analyses were performed at 112% core power to account for ANS Condition II and III transient events. For each case, the steady-state scoping analysis was used to determine the DUPLEX design's thermal safety margin over the entire expected operational lifetime. Transient analyses were performed for the most limiting burnup based on steady-state scoping analysis results.

7.1. Conclusions

Using the VIPRE-01 thermal-hydraulic subchannel analysis code, steady-state and transient thermal-hydraulic analyses were performed for the DUPLEX IMF-UOX design using the updated burnup-dependent thermal-hydraulic analysis framework. Due to the large uncertainty in the evaluation of $(Pu,Np,Am)O_2$-MgO-ZrO_2 thermal conductivity, each analysis type was performed with two different thermal conductivity curves for the LWR-2-E fuel rods, which represent a conservative lower bound (*Series* model) and a best-estimate upper bound (*ME1* model). In addition to the standard thermal-hydraulic analysis of the DUPLEX design, the effects of variations in seed and blanket region fuel rod diameters were also investigated. In all cases, the DUPLEX design was shown to satisfy design safety criteria with respect to PCT, seed and blanket region PFTs, and MDNBR thermal margins during simulated ANS Conditions I, II, and III transients. Specific to the DUPLEX design, the thermal margin of the LWR-2-E maximum fuel temperature, using the *Series* model, is the most limiting result which occurs during the steady-state scoping analysis. However, a significant increase in LWR-2-E maximum fuel temperature thermal margin is observed for the *ME1* model. While the maximum blanket region fuel temperature is significantly affected by the selection of the thermal conductivity model, results from the steady-state scoping analysis and both LOFA transient analyses indicate that the thermal conductivity of the blanket region has negligible effect on the MDNBR, PCT, and seed region PFT.

Results from the rod diameter study confirmed the expected relationship between the MDNBR and changes in heat transfer surface area. The MDNBR was observed to be the most sensitive parameter of interest to changes in rod dimensions.

As with the original framework, there are many uncertainties associated with the modeling and thermal-hydraulic analysis of DUPLEX fuel assemblies. The greatest amount of uncertainty lies with the VIPRE model in terms of the supplied boundary conditions, including the generic PWR core transient boundary conditions supplied to VIPRE by MELCOR. Also, due to the lack of actual in-core use of the DUPLEX design, there exist large uncertainties in design parameters such as the grid form loss coefficient and the amount of turbulent mixing. In order to account for many of the uncertainties, conservative assumptions were applied to the model to provide reasonable assurances for the conservatism of the three parameters of interest. However, the validity of the updated framework has not been confirmed, requiring actual in-core experimentation of the DUPLEX design to do so. Thus, caution must be observed for future use of the updated framework for new SBU-type designs until confirmation of the validity of DUPLEX results contained within this thesis can be performed.

7.2. Future Work

Suggestions for future work coming from this thesis are:

1. To incorporate thermal conductivity data for $(Pu,Np,Am,Cm)O_2$-MgO within the developed thermal conductivity models once it becomes publicly available
2. To incorporate the analytical model for actinide dioxide thermal conductivity by Sobolev [34]
3. To validate the updated framework
4. To investigate the applicability of the updated thermal-hydraulic framework to other heterogeneous fuel assembly designs
5. To calculate thermal parameters at the exact burnups at which core reshuffling occurs. For each burnup step at which core reshuffling occurs, perform one calculation before reshuffling and one calculation after reshuffling in order to better reflect the true behavior of core reshuffling
6. To validate the DUPLEX UO_2 maximum temperature behavior during CLOFA transient simulations, or determine if the problem itself pushes the limitations of the code

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APPENDIX A

THERMAL CONDUCTIVITY MODELS AND DATA

The following is provided as supportive information for Sections 4.4.2 and 5.2. The thermal conductivity models of FRAPCON-3 [53] for UO_2 and MOX fuels are described for completeness.

A.1. FRAPCON-3: The Modified NFI Model for UO_2 [53]

Based on the analysis performed by Bingham [4] of UO_2 thermal conductivity model selection for use in the developed VIPRE-01 framework, the updated FRAPCON-3 model by Lanning [53], a modified version of the Nuclear Fuels Industries (NFI) model [64], has been selected for use in the current research efforts. The model was chosen over other models (Ronchi [65] and Popov [66]) due to its good agreement to recent experimental data, greater conservatism in thermal conductivity values, and its general applicability to UO_2 and MOX-based fuels [4]. The modified NFI (MNFI) model was developed and selected as a replacement to the previously used Lucuta model [67] in order to address two inaccuracies found in the original model: The original Lucuta model over predicts thermal conductivity values relative to current unirradiated fuel pellet material data at high temperatures (> 2200K) , and underestimates the burnup degradation of the thermal conductivity relative to current measurements taken at nominal to high burnup resulting in non-conservative values above ~30 GWd/tU burnup. The MNFI model is similar to other fuel thermal conductivity models used in fuel performance codes in that it consists of a lead phonon term (A + BT) that is inversely proportional to temperature, with modified burnup-dependent factors in the denominator, along with an additional modified term that models the electronic (ambipolar) contribution (which only becomes significant at T > ~1500 K) to conductive heat transfer at high temperature. The MNFI model is given by Eq. (A.1), and a definition of terms listed in Table A.1.

$$K_{95} = \frac{1}{A + BT + f(Bu) + (1 - 0.9e^{-0.04Bu})g(Bu)h(T)} + \frac{E}{T^2}e^{-\frac{F}{T}} \qquad \text{(A.1)}$$

In Eq. (A.1), the modified phonon-term $(1 - 0.9e^{-0.04Bu})$ applies nearly full irradiation defect annealing at low burnup, but restores the temperature-dependent annealing effect at higher burnups. The altered electronic terms, in the modified version of the NFI model were, were done so in order to reflect a more theoretically based equation by Hagraman et al. [68] and Popov et al. [66]. At high temperature, the magnitude of the modified model is slightly lower than the original NFI model, so as to better represent unirradiated PWR fuel pellet material data at temperatures approaching fuel melting [69]. Compared to the unmodified NFI model, the modified model is less conservative at low temperatures (< ~1200 K) and low burnup (< 20 GWd/MTU). However, at burnups greater than 30 GWd/MTU and higher temperatures, the modified model yields similar, yet slightly more conservative, values as those from the original NFI model. This greater conservatism of the modified model at higher temperatures and burnups makes the MNFI model more desirable for use in thermal-hydraulic safety analysis, such as that performed in this thesis.

Table A.1
FRAPCON-3 MNFI UO_2 Thermal conductivity model variables (from [53])

Variable	Meaning
K_{95}	Urania thermal conductivity at 95% TD, W/m-K
T	Temperature, K
Bu	Burnup, GWd/MTU
$f(Bu)$	0.00187·Bu, effect of fission products in crystal matrix (solution)
$g(Bu)$	$0.038 \cdot Bu^{0.28}$, effect of irradiation defects
$h(T)$	$1/(1 + 396 \cdot e^{-Q/T})$, temperature dependence of annealing on irradiation defects
Q	6380 K, temperature dependence parameter (“Q/R”)
A	0.0452 m-K/W
B	2.46×10^{-4} m-K/W/K
C	5.47×10^{-9} W/m-K^3
D	2.29×10^{14} W/m-K^5
E	3.5×10^{9} W-K/m
F	16361 K

The recommended application limits for the UO_2 fuel thermal conductivity model, Eq. (A.1), are given in Table A.2.

Table A.2
UO_2 Thermal conductivity ranges of application (from [53])

Variable	Meaning
Temperature:	300 – 3000 K
Rod-Average Burnup:	0 – 62 GWd/MTU
As-fabricated Density:	92 – 97% TD

A.2. FRAPCON-3: MOX Thermal conductivity models [53]

The Duriez-Modified NFI MOX model [70] has been modified by PNNL to include a burnup dependency, a gadolinia dependency, and a slightly reduced high-temperature term. The modified model has been verified against in-reactor fuel temperature data and is recommended for use by Lanning et al. [53]. The Duriez-Modified NFI model is given by Eq. (A.2) below with a brief description of terms in Table A.3

$$K_{95} = \frac{1}{A(x) + a \cdot gad + B(x)T + f(Bu) + (1 - 0.9e^{-0.04Bu})g(Bu)h(T)} + \frac{C_{mod}}{T^2}e^{-\frac{D}{T}} \qquad \text{(A.2)}$$

Table A.3
Duriez-Modified NFI MOX Thermal conductivity model variables (from [53])

Variable	Meaning
K_{95}	MOX thermal conductivity at 95% TD, W/m-K
x	2.00 – O/M (i.e., oxygen-to-metal ratio)
T	Temperature, K
$A(x)$	2.85x + 0.035, m-K/W
$B(x)$	(2.86 – 7.15x)×10^{-4}, m/W
C	1.689×10^{9} W-K/m
D	13520 K
a	1.1599
gad	Weight fraction gadolinia (not expected in MOX)
Bu	Burnup, GWd/tHM
$f(Bu)$	0.00187·Bu, effect of fission products in crystal matrix (solution)
$g(Bu)$	0.038·$Bu^{0.28}$, effect of irradiation defects
$h(T)$	1/(1 + 396·$e^{-Q/T}$), temperature dependence of annealing on irradiation defects
Q	6380 K, temperature dependence parameter ("Q/R")
C_{mod}	1.5×10^{9} W-K/m

The Halden Reactor Project has derived its own MOX fuel thermal conductivity model from a variant of their urania fuel pellet thermal conductivity model, based on their own extensive in-reactor database for fuel temperatures and linear heat generation rates (LHGRs):

$$K_{95} = \frac{0.92}{0.1148 + a \cdot gad + 1.1599x + 0.0040 \cdot B + 2.475 \cdot 10^{-4} \cdot (1 - 0.00333 \cdot B) \cdot \vartheta} + 0.0132 \cdot e^{0.00188 \cdot T} \quad \text{(A.3)}$$

Table A.4
Halden MOX Thermal conductivity model variables (from [53])

Variable	Meaning
K_{95}	MOX thermal conductivity at 95% TD, W/m-K
a	1.1599
gad	Weight fraction gadolinia (not expected in MOX)
Bu	Burnup, GWd/kg(urania)
x	2.00 – O/M (i.e., oxygen-to-metal ratio)
ϑ	Minimum {1650ºC, current temperature in degrees Celsius}
T	Temperature, ºC

The recommended application limits for the MOX fuel thermal conductivity models Eqs. (A.2) and (A.3) are given in Table A.5 below. These ranges are based on PNNL-estimated limits for reliable model-to-data comparisons to date. Both models produce similar results at normal operating fuel temperatures (< 2000 K). However, at higher temperatures the two models diverge. Also, the thermal conductivity degradation due to burnup in the Duriez-Modified NFI model is greater than in the Halden model [53].

Table A.5
MOX Thermal conductivity ranges of application (from [53])

Variable	Meaning
Temperature:	300 – 3000 K
Rod-Average Burnup:	0 – 62 GWd/MTU
Plutonia Content:	0 – 7 wt.%
As-fabricated Density:	92 – 97% TD
Plutonia Particle Size:	< 20 microns*

* The majority of the code-data comparison involves EdF fuel rod sections, for which the plutonia particle size is reported at 15 – 18 μm.

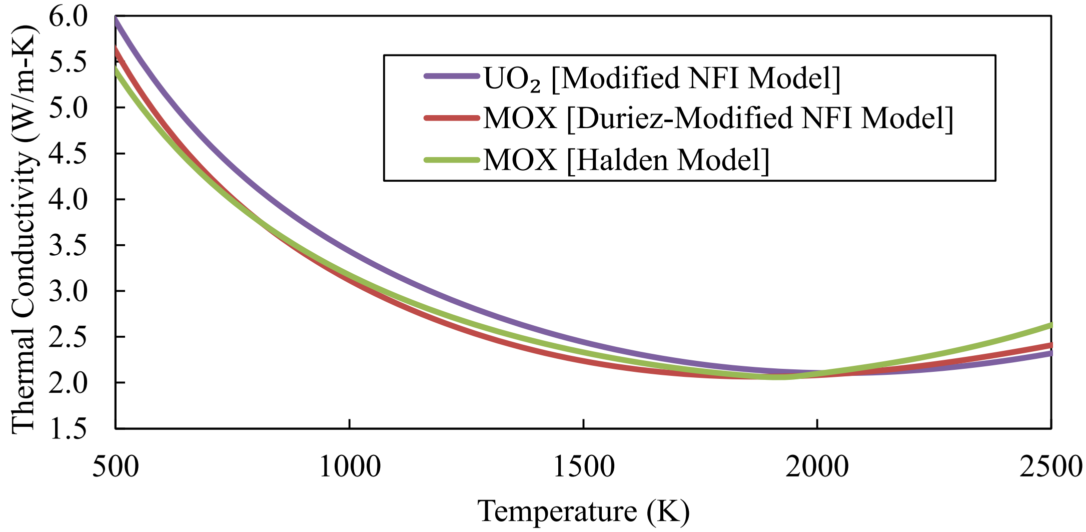

Figure A.1 FRAPCON-3 updated thermal conductivity models for UO_2 and MOX fuels compared at 0 GWd/tU Burnup

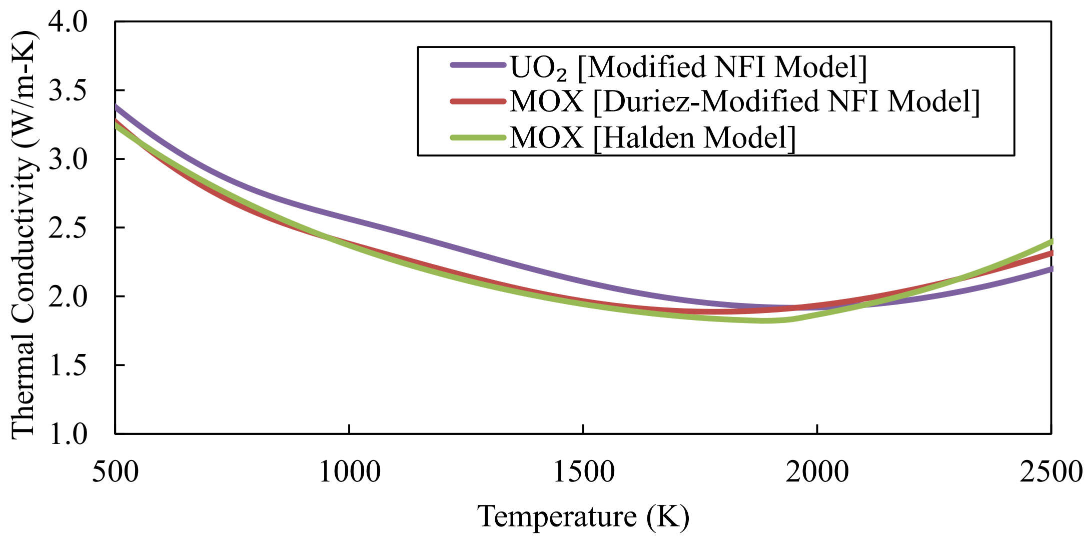

Figure A.2 FRAPCON-3 updated thermal conductivity models for UO_2 and MOX fuels compared at 30 GWd/tU Burnup

APPENDIX B

1/8TH CORE ASSEMBLY RADIAL POWER FACTORS

The 1/8th core assembly relative radial power factors for 1st cycle steady-state, 2nd cycle steady-state, 3rd cycle steady-state, and transient analyses from Bingham [4] are depicted in Figures B.1, B.2, B.3, and B.4, respectively.

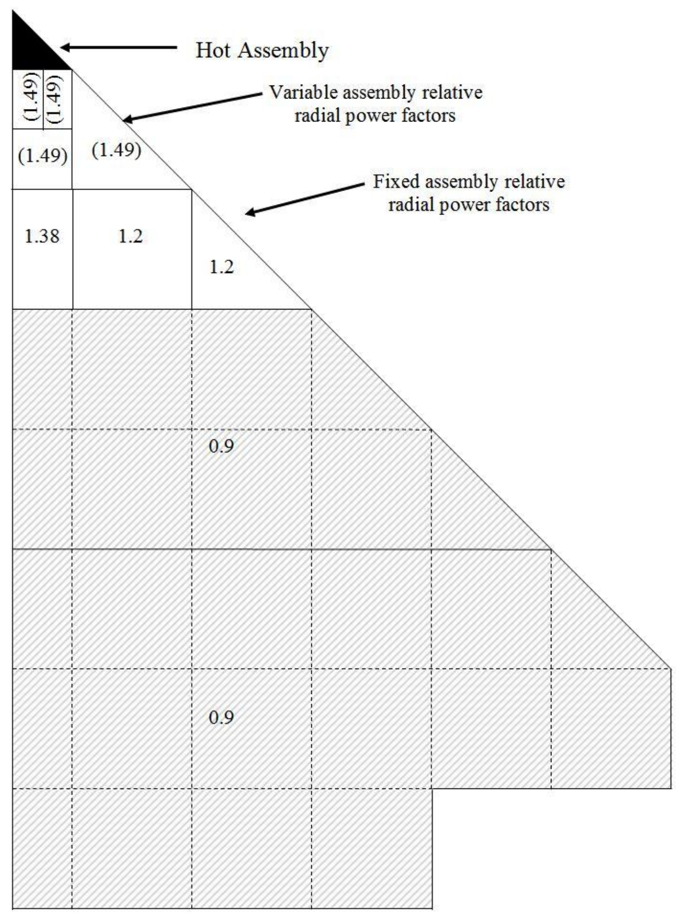

Figure B.1. VIPRE 1/8th Core steady-state scoping analysis assembly relative radial power factors (F_A^N) for 1st cycle assembly (From [4])

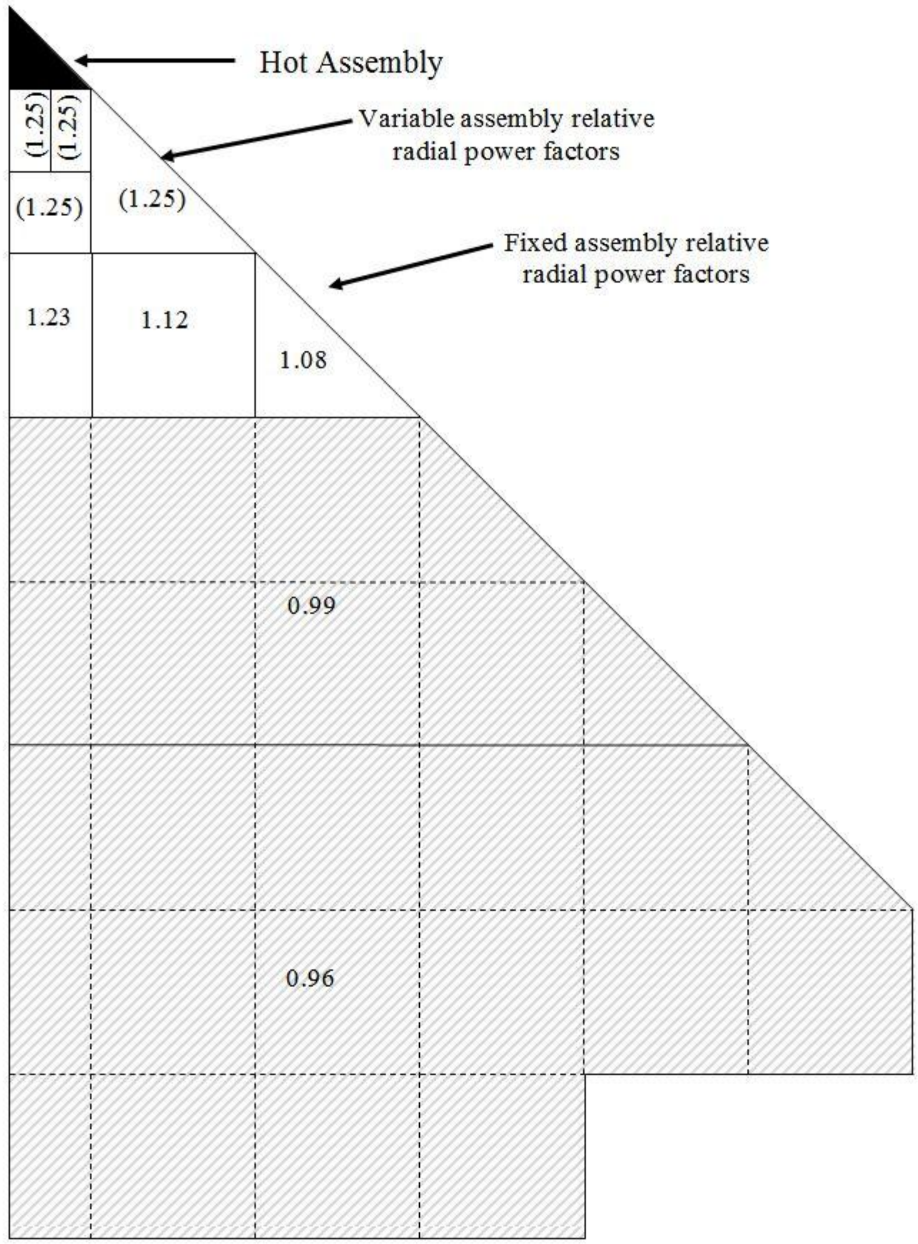

Figure B.2. VIPRE 1/8th Core steady-state scoping analysis assembly relative radial power factors (F_A^N) for 2nd cycle assembly (From [4])

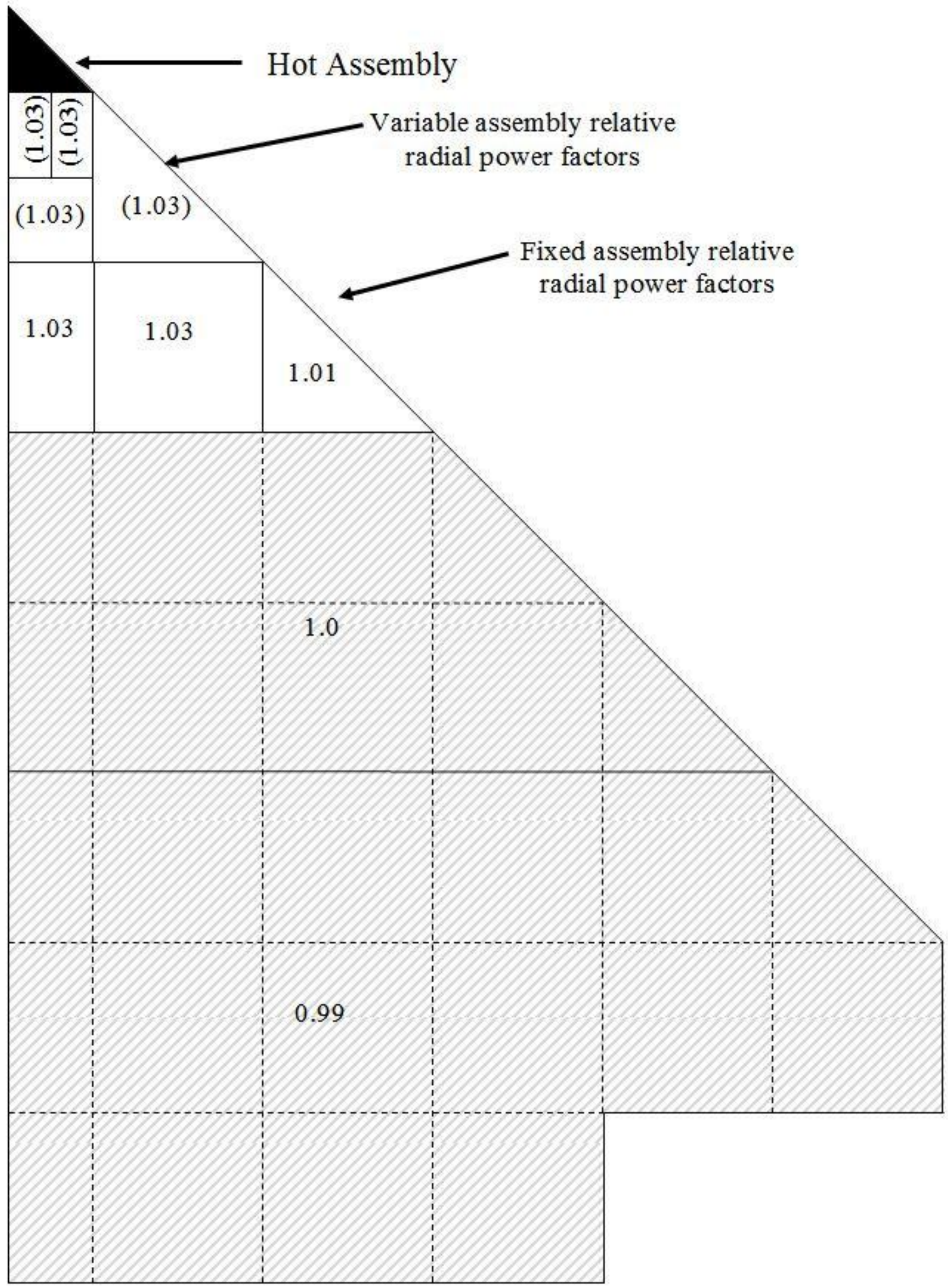

Figure B.3. VIPRE 1/8th Core steady-state scoping analysis assembly relative radial power factors (F_A^N) for 3rd cycle assembly (From [4])

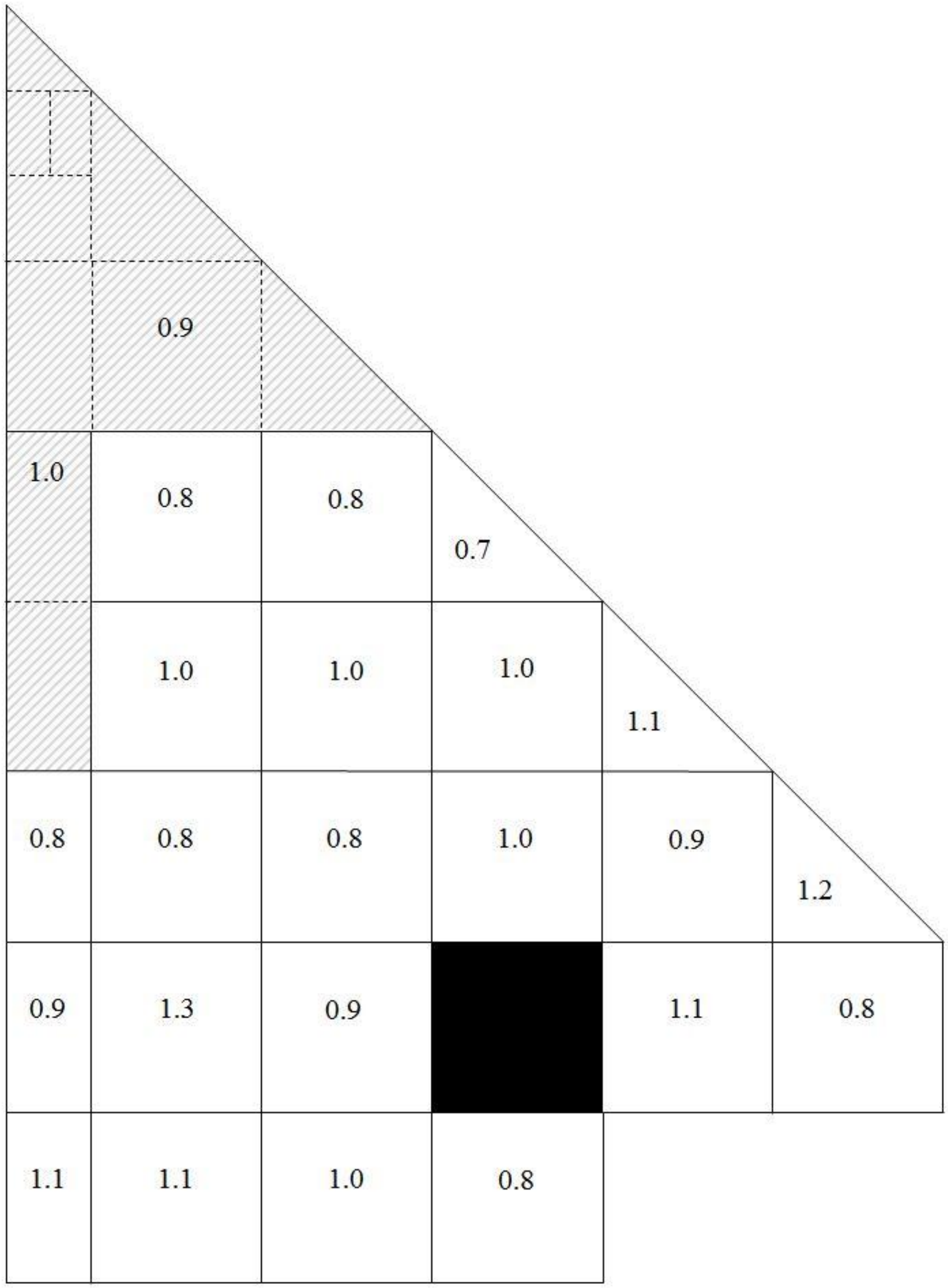

Figure B.4. VIPRE 1/8th Core transient analysis assembly relative radial power factors (F_A^N) (From [4])

APPENDIX C

VIPRE INPUT FILES

The following section provides the representative VIPRE-01 MOD2.3 input decks described in Section 5. The three VIPRE input decks are: a steady-state scoping analysis input deck, a PLOFA transient analysis input deck, and a CLOFA transient analysis input deck

C.1. Steady-state Scoping Analysis (Complete Burnup Lifetime)

```
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
1,0,0,-1,0    *vipre.1
1/8 17x17 PWR DUPLEX IMF-UOX Hot Bundle Analysis - LiC     *vipre.2
*
*   channel geometry -  45 channels , 31 equally spaced axial nodes
* Fuel Rod length is 152 inches, heated length is 144 inches
geom,45,45,31,0,0,0    *geom.1
152,0,0.5 * core height = 152 inches sl ratio = 0.5 *geom.2
*      channel dimensions
1,0.0590,0.6299,0.4406,1,2,0.121984252,0    *geom.4
2,0.1361,1.1750,1.1750,2,3,0.121984252,0,4,0.121984252,0    *geom.4
3,0.0681,0.5875,0.5875,1,5,0.121984252,0    *geom.4
4,0.1180,1.2598,0.8813,2,5,0.121984252,0,7,0.067992126,0    *geom.4
5,0.1361,1.1750,1.1750,2,6,0.121984252,0,8,0.121984252,0    *geom.4
6,0.0590,0.6299,0.4406,1,9,0.067992126,0    *geom.4
7,0.1180,1.2598,0.8813,2,8,0.121984252,0,11,0.121984252,0    *geom.4
8,0.1361,1.1750,1.1750,2,9,0.121984252,0,12,0.121984252,0    *geom.4
9,0.1180,1.2598,0.8813,2,10,0.067992126,0,13,0.121984252,0    *geom.4
10,0.0590,0.6299,0.4406,1,14,0.121984252,0    *geom.4
11,0.1361,1.1750,1.1750,2,12,0.121984252,0,16,0.121984252,0    *geom.4
12,0.1361,1.1750,1.1750,2,13,0.121984252,0,17,0.121984252,0    *geom.4
13,0.1361,1.1750,1.1750,2,14,0.121984252,0,18,0.121984252,0    *geom.4
14,0.1361,1.1750,1.1750,2,15,0.121984252,0,19,0.121984252,0    *geom.4
15,0.0590,0.6299,0.4406,1,20,0.067992126,0    *geom.4
16,0.1180,1.2598,0.8813,2,17,0.121984252,0,22,0.067992126,0    *geom.4
```

```
17,0.1361,1.1750,1.1750,2,18,0.121984252,0,23,0.121984252,0    *geom.4
18,0.1180,1.2598,0.8813,2,19,0.067992126,0,24,0.067992126,0    *geom.4
19,0.1180,1.2598,0.8813,2,20,0.121984252,0,25,0.067992126,0    *geom.4
20,0.1180,1.2598,0.8813,2,21,0.067992126,0,26,0.121984252,0    *geom.4
21,0.0590,0.6299,0.4406,1,27,0.121984252,0    *geom.4
22,0.1180,1.2598,0.8813,2,23,0.121984252,0,29,0.121984252,0    *geom.4
23,0.1361,1.1750,1.1750,2,24,0.121984252,0,30,0.121984252,0    *geom.4
24,0.1180,1.2598,0.8813,2,25,0.067992126,0,31,0.121984252,0    *geom.4
25,0.1180,1.2598,0.8813,2,26,0.121984252,0,32,0.121984252,0    *geom.4
26,0.1312,1.2003,1.2003,2,27,0.105858268,0,33,0.105858268,0    *geom.4
27,0.1263,1.2257,1.2257,2,28,0.105858268,0,34,0.089732283,0    *geom.4
28,0.0607,0.6255,0.6255,1,35,0.089732283,0    *geom.4
29,0.1263,1.2257,1.2257,2,30,0.105858268,0,37,0.122,0    *geom.4
30,0.1263,1.2257,1.2257,2,31,0.105858268,0,37,0.089732283,0    *geom.4
31,0.1263,1.2257,1.2257,2,32,0.105858268,0,37,0.089732283,0    *geom.4
32,0.1263,1.2257,1.2257,2,33,0.105858268,0,37,0.089732283,0    *geom.4
33,0.1213,1.2510,1.2510,2,34,0.089732283,0,38,0.089732283,0    *geom.4
34,0.1164,1.2763,1.2763,2,35,0.089732283,0,38,0.089732283,0    *geom.4
35,0.1164,1.2763,1.2763,2,36,0.089732283,0,38,0.089732283,0    *geom.4
36,0.0582,0.6382,0.6382,1,38,0.089732283,0    *geom.4
37,5.0984,49.825,44.806,2,38,0.779724409,0,39,0.487937008,3.968    *geom.4
38,5.1156,49.994,44.957,2,39,0.54980315,3.968,40,0.779724409,4    *geom.4
39,9.3780,89.142,79.678,2,40,0.779724409,4.99,41,0.779724409,6.482    *geom.4
40,18.490,178.28,159.36,1,42,1.559448819,6.978    *geom.4
41,18.490,178.28,159.36,2,42,1.559448819,6.482,44,0.779724409,12.434    *geom.4
42,36.713,356.57,318.71,2,43,1.559448819,6.978,44,1.559448819,12.434    *geom.4
43,18.490,178.28,159.36,1,44,1.559448819,10.946    *geom.4
44,255.39,2496.0,2231.0,1,45,7.017519685,20.9    *geom.4
45,510.25,4992.0,4462.0    *geom.4
*
prop,30,1,1,1,*,create,table,from,functions    *prop.1
203.32,729.1,1800.    *prop.3
*
drag,1,0,1    *drag.1
.18,-.2,0.,64.,-1.,0.,*,axial,friction,correlation    *drag.2
.5,.496,*,pitch,=,.496,,kij,=,.5l/p    *drag.5
*
grid,0,1    *grid.1
0.86    *grid.2
-1,8    *grid.4
6,1,26,1,46,1,66,1,86,1,106,1,126,1,146,1    *grid.6
*           *grid.6
0    *grid.4
```

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*
corr,1,0,    *corr.1
epri,epri,epri,none,    *corr.2
0.2    *corr.3
ditb    *corr.6
w-3l    *corr.9
0.043,0.066,0.986    *corr.11
*
*       Operating Conditions
oper,1,1,0,0,0,1,0,0,0,0    *oper.1
*
0,0,0,0.005,0    *oper.2
2235,563.2,4941,6.290,640.5    *oper.5
0    *oper.12
*
cont    *cont.1
0.0,0,40,60,2,1,0,0    *cont.2
0.1,0.0001,0.0015,0.05,0.01,0.8,1.5,1    *cont.3
5,1,0,2,0,0,1,1,0,0,0,1,0,0,0    *cont.6
1000,0,0,0,0,0    *cont.7
15    *cont.8
*            *cont.9
2,34    *cont.10
*            *cont.11
*            *cont.12
summ,3    *summ.1
6,1,1    *summ.2
8,1,1    *summ.2
8,2,-1    *summ.3
*
34
37
*
*          Rod Layout - mixed nuclear and control rods
*
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
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*
*          Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5091,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5469,1,2,0.25,4,0.25    *rods.9
5,1,1.4956,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4823,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5168,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5033,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4734,1,7,0.25,11,0.25    *rods.9
12,1,1.4235,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4110,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4341,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3543,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3856,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3397,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3261,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3444,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2857,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2403,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2227,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0017,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1178,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9650,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7583,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0086,1,22,0.25,29,0.25    *rods.9
30,1,0.9713,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9550,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9484,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8265,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5071,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2083,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.9931,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5197,1,29,0.25,37,0.25    *rods.9
38,3,1.5017,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.4793,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4380,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3106,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
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42,3,1.1010,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.9801,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9162,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.8944,1,36,0.125,38,0.375    *rods.9
46,4,1.09491,1,37,38.31439394    *rods.9
47,4,1.09491,1,38,38.45123106    *rods.9
48,4,1.09491,1,39,72.25    *rods.9
49,4,1.09491,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*            Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,4.0236,
620.6,0.0698,2.9968,710.6,0.0707,2.8171,
800.6,0.0715,2.6577,890.6,0.0722,2.5154,
980.6,0.0729,2.3875,1070.6,0.0735,2.2720,
1160.6,0.0740,2.1672,1250.6,0.0745,2.0717,
1340.6,0.0750,1.9843,1430.6,0.0754,1.9040,
1520.6,0.0758,1.8301,1610.6,0.0762,1.7620,
1700.6,0.0767,1.6990,1790.6,0.0771,1.6408,
1880.6,0.0775,1.5870,1970.6,0.0779,1.5374,
2060.6,0.0783,1.4917,2150.6,0.0788,1.4497,
2240.6,0.0793,1.4114,2330.6,0.0799,1.3766,
2420.6,0.0805,1.3453,2510.6,0.0813,1.3175,
2600.6,0.0821,1.2931,2690.6,0.0830,1.2720,
2780.6,0.0840,1.2544,2870.6,0.0851,1.2401,
2960.6,0.0864,1.2291,3050.6,0.0879,1.2215,
3140.6,0.0895,1.2171,3230.6,0.0914,1.2160,
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3320.6,0.0934,1.2180,3410.6,0.0956,1.2232,
3500.6,0.0980,1.2314,3590.6,0.1006,1.2427,
3680.6,0.1035,1.2568,3770.6,0.1066,1.2737,
3860.6,0.1099,1.2934,3950.6,0.1134,1.3157,
4040.6,0.1172,1.3405,4130.6,0.1212,1.3676,
4220.6,0.1254,1.3970,4310.6,0.1299,1.4286,
4400.6,0.1346,1.4622,4490.6,0.1395,1.4977,
4580.6,0.1446,1.5350,4670.6,0.1499,1.5740,
4760.6,0.1555,1.6144,4850.6,0.1612,1.6563,
4940.6,0.1671,1.6995,5030.6,0.1732,1.7439,
5120.6,0.1794,1.7893,5210.6,0.1858,1.8356,
5300.6,0.1924,1.8828,5390.6,0.1990,1.9307,
5480.6,0.2059,1.9792,5570.6,0.2128,2.0283,
5660.6,0.2199,2.0778,5750.6,0.2270,2.1276,
13940.,0.6954,4.3746,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
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5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3883,
620.6,0.0925,3.1423,710.6,0.0937,2.9389,
800.6,0.0948,2.7646,890.6,0.0957,2.6144,
980.6,0.0966,2.4840,1070.6,0.0974,2.3701,
1160.6,0.0981,2.2698,1250.6,0.0987,2.1808,
1340.6,0.0993,2.1011,1430.6,0.0999,2.0290,
1520.6,0.1004,1.9634,1610.6,0.1009,1.9032,
1700.6,0.1015,1.8476,1790.6,0.1020,1.7961,
1880.6,0.1025,1.7483,1970.6,0.1030,1.7039,
2060.6,0.1034,1.6627,2150.6,0.1040,1.6246,
2240.6,0.1045,1.5897,2330.6,0.1051,1.5580,
2420.6,0.1057,1.5296,2510.6,0.1065,1.5046,
2600.6,0.1072,1.4830,2690.6,0.1080,1.4649,
2780.6,0.1089,1.4506,2870.6,0.1098,1.4399,
2960.6,0.1109,1.4329,3050.6,0.1121,1.4296,
3140.6,0.1134,1.4299,3230.6,0.1148,1.4337,
3320.6,0.1164,1.4408,3410.6,0.1181,1.4511,
3500.6,0.1199,1.4643,3590.6,0.1219,1.4802,
3680.6,0.1241,1.4985,3770.6,0.1264,1.5189,
3860.6,0.1289,1.5411,3950.6,0.1314,1.5649,
4040.6,0.1343,1.5898,4130.6,0.1372,1.6155,
4220.6,0.1403,1.6420,4310.6,0.1436,1.6690,
4400.6,0.1471,1.6962,4490.6,0.1507,1.7238,
4580.6,0.1544,1.7517,4670.6,0.1583,1.7802,
4760.6,0.1624,1.8094,4850.6,0.1666,1.8400,
4940.6,0.1709,1.8725,5030.6,0.1754,1.9079,
5120.6,0.1799,1.9471,5210.6,0.1846,1.9915,
5300.6,0.1894,2.0428,5390.6,0.1942,2.1029,
5480.6,0.1993,2.1741,5570.6,0.2043,2.2591,
5660.6,0.2096,2.3609,5750.6,0.2148,2.4829,
13940.0,0.5882,4919.2100,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
2,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 9.058822E+00
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
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144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5611,1,1,0.25,2,0.25    *rods.9
3,1,1.5089,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5470,1,2,0.25,4,0.25    *rods.9
5,1,1.4955,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4825,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5172,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5039,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4742,1,7,0.25,11,0.25    *rods.9
12,1,1.4241,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4118,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4354,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3558,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3867,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3407,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3273,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3461,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2877,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2420,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2245,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0017,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1202,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9675,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7607,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0106,1,22,0.25,29,0.25    *rods.9
30,1,0.9731,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9569,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9506,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8287,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5126,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2135,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
```

36,3,0.9982,1,28,0.125,35,0.25,36,0.125   *rods.9
37,3,1.5246,1,29,0.25,37,0.25   *rods.9
38,3,1.5065,1,29,0.25,30,0.25,37,0.5   *rods.9
39,3,1.4842,1,30,0.25,31,0.25,37,0.5   *rods.9
40,3,1.4432,1,31,0.25,32,0.25,37,0.5   *rods.9
41,3,1.3158,1,32,0.25,33,0.25,37,0.25,38,0.25   *rods.9
42,3,1.1060,1,33,0.25,34,0.25,38,0.5   *rods.9
43,3,0.9851,1,34,0.25,35,0.25,38,0.5   *rods.9
44,3,0.9212,1,35,0.25,36,0.25,38,0.5   *rods.9
45,3,0.8995,1,36,0.125,38,0.375   *rods.9
46,4,1.09701,1,37,38.31439394   *rods.9
47,4,1.09701,1,38,38.45123106   *rods.9
48,4,1.09701,1,39,72.25   *rods.9
49,4,1.09701,1,40,144.5   *rods.9
50,4,1.382,1,41,144.5   *rods.9
51,4,1.261,1,42,289   *rods.9
52,4,1.226,1,43,144.5   *rods.9
53,4,0.941,1,44,2023   *rods.9
54,4,0.942,1,45,4046   *rods.9
0   *rods.9
*   Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685   *rods.62
0,1,0,0,0,2000,0.95,0   *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685   *rods.62
0,2,0,0,0,2000,0.95,0   *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685   *rods.62
0,3,0,0,0,2000,0.95,0   *rods.63
* 0.4 0.00004 0.00002   *rods.65
* 0.05 0 0 0 0   *rods.66
* 0.0026   *rods.67
2,dumy,0.482,0,0   *rods.68
1,61,651.186,UO2   *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.9947,
620.6,0.0698,2.9809,710.6,0.0707,2.8032,
800.6,0.0715,2.6456,890.6,0.0722,2.5049,
980.6,0.0729,2.3785,1070.6,0.0735,2.2644,
1160.6,0.0740,2.1609,1250.6,0.0745,2.0665,
1340.6,0.0750,1.9800,1430.6,0.0754,1.9006,
1520.6,0.0758,1.8273,1610.6,0.0762,1.7597,
1700.6,0.0767,1.6972,1790.6,0.0771,1.6393,
1880.6,0.0775,1.5858,1970.6,0.0779,1.5364,
2060.6,0.0783,1.4908,2150.6,0.0788,1.4490,

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2240.6,0.0793,1.4108,2330.6,0.0799,1.3761,
2420.6,0.0805,1.3449,2510.6,0.0813,1.3171,
2600.6,0.0821,1.2927,2690.6,0.0830,1.2718,
2780.6,0.0840,1.2541,2870.6,0.0851,1.2399,
2960.6,0.0864,1.2289,3050.6,0.0879,1.2213,
3140.6,0.0895,1.2169,3230.6,0.0914,1.2158,
3320.6,0.0934,1.2179,3410.6,0.0956,1.2231,
3500.6,0.0980,1.2313,3590.6,0.1006,1.2426,
3680.6,0.1035,1.2567,3770.6,0.1066,1.2737,
3860.6,0.1099,1.2933,3950.6,0.1134,1.3156,
4040.6,0.1172,1.3404,4130.6,0.1212,1.3676,
4220.6,0.1254,1.3970,4310.6,0.1299,1.4286,
4400.6,0.1346,1.4622,4490.6,0.1395,1.4977,
4580.6,0.1446,1.5350,4670.6,0.1499,1.5739,
4760.6,0.1555,1.6144,4850.6,0.1612,1.6563,
4940.6,0.1671,1.6995,5030.6,0.1732,1.7438,
5120.6,0.1794,1.7892,5210.6,0.1858,1.8356,
5300.6,0.1924,1.8827,5390.6,0.1990,1.9306,
5480.6,0.2059,1.9792,5570.6,0.2128,2.0282,
5660.6,0.2199,2.0777,5750.6,0.2270,2.1276,
13940.,0.6954,4.3746,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
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4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3686,
620.6,0.0925,3.1314,710.6,0.0937,2.9295,
800.6,0.0948,2.7563,890.6,0.0957,2.6072,
980.6,0.0966,2.4778,1070.6,0.0974,2.3649,
1160.6,0.0981,2.2655,1250.6,0.0987,2.1773,
1340.6,0.0993,2.0982,1430.6,0.0999,2.0267,
1520.6,0.1004,1.9615,1610.6,0.1009,1.9016,
1700.6,0.1015,1.8464,1790.6,0.1020,1.7951,
1880.6,0.1025,1.7475,1970.6,0.1030,1.7032,
2060.6,0.1034,1.6621,2150.6,0.1040,1.6241,
2240.6,0.1045,1.5893,2330.6,0.1051,1.5577,
2420.6,0.1057,1.5293,2510.6,0.1065,1.5043,
2600.6,0.1072,1.4828,2690.6,0.1080,1.4648,
2780.6,0.1089,1.4504,2870.6,0.1098,1.4398,
2960.6,0.1109,1.4328,3050.6,0.1121,1.4295,
3140.6,0.1134,1.4298,3230.6,0.1148,1.4336,
3320.6,0.1164,1.4407,3410.6,0.1181,1.4510,
3500.6,0.1199,1.4642,3590.6,0.1219,1.4802,
3680.6,0.1241,1.4984,3770.6,0.1264,1.5189,
3860.6,0.1289,1.5411,3950.6,0.1314,1.5648,
4040.6,0.1343,1.5897,4130.6,0.1372,1.6155,
4220.6,0.1403,1.6420,4310.6,0.1436,1.6690,
4400.6,0.1471,1.6962,4490.6,0.1507,1.7238,
4580.6,0.1544,1.7517,4670.6,0.1583,1.7801,
4760.6,0.1624,1.8094,4850.6,0.1666,1.8400,
4940.6,0.1709,1.8725,5030.6,0.1754,1.9078,
5120.6,0.1799,1.9470,5210.6,0.1846,1.9915,
5300.6,0.1894,2.0427,5390.6,0.1942,2.1029,
5480.6,0.1993,2.1741,5570.6,0.2043,2.2591,
5660.6,0.2096,2.3609,5750.6,0.2148,2.4829,
13940.0,0.5882,4919.2100,
endd
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*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
3,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.811764E+01
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*         Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*         Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5088,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5474,1,2,0.25,4,0.25    *rods.9
5,1,1.4957,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4829,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5181,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5050,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4755,1,7,0.25,11,0.25    *rods.9
12,1,1.4252,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4131,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4374,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3581,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3887,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3424,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3292,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3487,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2908,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2446,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2274,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0017,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1237,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9712,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7642,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0136,1,22,0.25,29,0.25    *rods.9
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30,1,0.9760,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9599,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9541,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8321,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5207,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2213,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0056,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5317,1,29,0.25,37,0.25    *rods.9
38,3,1.5136,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.4915,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4507,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3233,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1134,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.9925,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9287,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9070,1,36,0.125,38,0.375    *rods.9
46,4,1.10021,1,37,38.31439394    *rods.9
47,4,1.10021,1,38,38.45123106    *rods.9
48,4,1.10021,1,39,72.25    *rods.9
49,4,1.10021,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.9881,
620.6,0.0698,2.9772,710.6,0.0707,2.8000,
800.6,0.0715,2.6428,890.6,0.0722,2.5024,
980.6,0.0729,2.3764,1070.6,0.0735,2.2626,
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1160.6,0.0740,2.1594,1250.6,0.0745,2.0652,
1340.6,0.0750,1.9790,1430.6,0.0754,1.8997,
1520.6,0.0758,1.8267,1610.6,0.0762,1.7592,
1700.6,0.0767,1.6967,1790.6,0.0771,1.6390,
1880.6,0.0775,1.5855,1970.6,0.0779,1.5361,
2060.6,0.0783,1.4906,2150.6,0.0788,1.4488,
2240.6,0.0793,1.4106,2330.6,0.0799,1.3760,
2420.6,0.0805,1.3448,2510.6,0.0813,1.3170,
2600.6,0.0821,1.2926,2690.6,0.0830,1.2717,
2780.6,0.0840,1.2541,2870.6,0.0851,1.2398,
2960.6,0.0864,1.2289,3050.6,0.0879,1.2212,
3140.6,0.0895,1.2169,3230.6,0.0914,1.2158,
3320.6,0.0934,1.2178,3410.6,0.0956,1.2230,
3500.6,0.0980,1.2313,3590.6,0.1006,1.2425,
3680.6,0.1035,1.2567,3770.6,0.1066,1.2736,
3860.6,0.1099,1.2933,3950.6,0.1134,1.3156,
4040.6,0.1172,1.3404,4130.6,0.1212,1.3675,
4220.6,0.1254,1.3970,4310.6,0.1299,1.4285,
4400.6,0.1346,1.4622,4490.6,0.1395,1.4977,
4580.6,0.1446,1.5350,4670.6,0.1499,1.5739,
4760.6,0.1555,1.6144,4850.6,0.1612,1.6563,
4940.6,0.1671,1.6995,5030.6,0.1732,1.7438,
5120.6,0.1794,1.7892,5210.6,0.1858,1.8355,
5300.6,0.1924,1.8827,5390.6,0.1990,1.9306,
5480.6,0.2059,1.9792,5570.6,0.2128,2.0282,
5660.6,0.2199,2.0777,5750.6,0.2270,2.1276,
13940.,0.6954,4.3746,
2,61,359.929,IMF   *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
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1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
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2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,

3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX   *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3641,
620.6,0.0925,3.1289,710.6,0.0937,2.9273,
800.6,0.0948,2.7544,890.6,0.0957,2.6055,
980.6,0.0966,2.4764,1070.6,0.0974,2.3637,
1160.6,0.0981,2.2645,1250.6,0.0987,2.1764,
1340.6,0.0993,2.0975,1430.6,0.0999,2.0261,
1520.6,0.1004,1.9611,1610.6,0.1009,1.9013,
1700.6,0.1015,1.8461,1790.6,0.1020,1.7949,
1880.6,0.1025,1.7473,1970.6,0.1030,1.7030,
2060.6,0.1034,1.6619,2150.6,0.1040,1.6240,
2240.6,0.1045,1.5892,2330.6,0.1051,1.5576,
2420.6,0.1057,1.5292,2510.6,0.1065,1.5042,
2600.6,0.1072,1.4827,2690.6,0.1080,1.4647,
2780.6,0.1089,1.4504,2870.6,0.1098,1.4397,
2960.6,0.1109,1.4328,3050.6,0.1121,1.4294,
3140.6,0.1134,1.4298,3230.6,0.1148,1.4336,
3320.6,0.1164,1.4407,3410.6,0.1181,1.4509,
3500.6,0.1199,1.4642,3590.6,0.1219,1.4801,
3680.6,0.1241,1.4984,3770.6,0.1264,1.5188,
3860.6,0.1289,1.5411,3950.6,0.1314,1.5648,
4040.6,0.1343,1.5897,4130.6,0.1372,1.6155,
4220.6,0.1403,1.6420,4310.6,0.1436,1.6689,
4400.6,0.1471,1.6962,4490.6,0.1507,1.7238,
4580.6,0.1544,1.7517,4670.6,0.1583,1.7801,
4760.6,0.1624,1.8094,4850.6,0.1666,1.8400,
4940.6,0.1709,1.8725,5030.6,0.1754,1.9078,

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5120.6,0.1799,1.9470,5210.6,0.1846,1.9914,
5300.6,0.1894,2.0427,5390.6,0.1942,2.1029,
5480.6,0.1993,2.1741,5570.6,0.2043,2.2591,
5660.6,0.2096,2.3609,5750.6,0.2148,2.4829,
13940.0,0.5882,4919.2100,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
4,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.717646E+01
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5086,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5476,1,2,0.25,4,0.25    *rods.9
5,1,1.4958,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4831,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5186,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5057,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4764,1,7,0.25,11,0.25    *rods.9
12,1,1.4260,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4141,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4389,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3599,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3901,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3437,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3307,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3507,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2932,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2467,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
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24,1,1.2296,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0017,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1265,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9742,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7670,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0160,1,22,0.25,29,0.25    *rods.9
30,1,0.9783,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9623,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9568,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8348,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5271,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2274,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0116,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5372,1,29,0.25,37,0.25    *rods.9
38,3,1.5191,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.4971,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4566,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3293,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1193,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.9984,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9346,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9131,1,36,0.125,38,0.375    *rods.9
46,4,1.10271,1,37,38.31439394    *rods.9
47,4,1.10271,1,38,38.45123106    *rods.9
48,4,1.10271,1,39,72.25    *rods.9
49,4,1.10271,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
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2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.9834,
620.6,0.0698,2.9746,710.6,0.0707,2.7977,
800.6,0.0715,2.6408,890.6,0.0722,2.5007,
980.6,0.0729,2.3749,1070.6,0.0735,2.2614,
1160.6,0.0740,2.1583,1250.6,0.0745,2.0643,
1340.6,0.0750,1.9782,1430.6,0.0754,1.8991,
1520.6,0.0758,1.8262,1610.6,0.0762,1.7588,
1700.6,0.0767,1.6964,1790.6,0.0771,1.6387,
1880.6,0.0775,1.5853,1970.6,0.0779,1.5359,
2060.6,0.0783,1.4904,2150.6,0.0788,1.4487,
2240.6,0.0793,1.4105,2330.6,0.0799,1.3758,
2420.6,0.0805,1.3447,2510.6,0.0813,1.3169,
2600.6,0.0821,1.2926,2690.6,0.0830,1.2716,
2780.6,0.0840,1.2540,2870.6,0.0851,1.2397,
2960.6,0.0864,1.2288,3050.6,0.0879,1.2212,
3140.6,0.0895,1.2168,3230.6,0.0914,1.2157,
3320.6,0.0934,1.2178,3410.6,0.0956,1.2230,
3500.6,0.0980,1.2312,3590.6,0.1006,1.2425,
3680.6,0.1035,1.2566,3770.6,0.1066,1.2736,
3860.6,0.1099,1.2933,3950.6,0.1134,1.3155,
4040.6,0.1172,1.3403,4130.6,0.1212,1.3675,
4220.6,0.1254,1.3969,4310.6,0.1299,1.4285,
4400.6,0.1346,1.4621,4490.6,0.1395,1.4976,
4580.6,0.1446,1.5349,4670.6,0.1499,1.5739,
4760.6,0.1555,1.6144,4850.6,0.1612,1.6563,
4940.6,0.1671,1.6994,5030.6,0.1732,1.7438,
5120.6,0.1794,1.7892,5210.6,0.1858,1.8355,
5300.6,0.1924,1.8827,5390.6,0.1990,1.9306,
5480.6,0.2059,1.9791,5570.6,0.2128,2.0282,
5660.6,0.2199,2.0777,5750.6,0.2270,2.1275,
13940.,0.6954,4.3746,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
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2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3609,
620.6,0.0925,3.1271,710.6,0.0937,2.9257,
800.6,0.0948,2.7531,890.6,0.0957,2.6043,
980.6,0.0966,2.4754,1070.6,0.0974,2.3629,
1160.6,0.0981,2.2638,1250.6,0.0987,2.1758,
1340.6,0.0993,2.0969,1430.6,0.0999,2.0257,
1520.6,0.1004,1.9607,1610.6,0.1009,1.9010,
1700.6,0.1015,1.8459,1790.6,0.1020,1.7947,
1880.6,0.1025,1.7471,1970.6,0.1030,1.7028,
2060.6,0.1034,1.6618,2150.6,0.1040,1.6239,
2240.6,0.1045,1.5891,2330.6,0.1051,1.5574,
2420.6,0.1057,1.5292,2510.6,0.1065,1.5041,
2600.6,0.1072,1.4827,2690.6,0.1080,1.4647,
2780.6,0.1089,1.4503,2870.6,0.1098,1.4397,
2960.6,0.1109,1.4327,3050.6,0.1121,1.4294,
3140.6,0.1134,1.4297,3230.6,0.1148,1.4335,
3320.6,0.1164,1.4407,3410.6,0.1181,1.4509,
3500.6,0.1199,1.4641,3590.6,0.1219,1.4801,
3680.6,0.1241,1.4984,3770.6,0.1264,1.5188,
3860.6,0.1289,1.5411,3950.6,0.1314,1.5647,
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4040.6,0.1343,1.5896,4130.6,0.1372,1.6155,
4220.6,0.1403,1.6419,4310.6,0.1436,1.6689,
4400.6,0.1471,1.6962,4490.6,0.1507,1.7237,
4580.6,0.1544,1.7517,4670.6,0.1583,1.7801,
4760.6,0.1624,1.8094,4850.6,0.1666,1.8400,
4940.6,0.1709,1.8725,5030.6,0.1754,1.9078,
5120.6,0.1799,1.9470,5210.6,0.1846,1.9914,
5300.6,0.1894,2.0427,5390.6,0.1942,2.1029,
5480.6,0.1993,2.1740,5570.6,0.2043,2.2591,
5660.6,0.2096,2.3609,5750.6,0.2148,2.4829,
13940.0,0.5882,4919.2100,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
5,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.623529E+01
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5611,1,1,0.25,2,0.25    *rods.9
3,1,1.5085,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5476,1,2,0.25,4,0.25    *rods.9
5,1,1.4957,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4832,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5189,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5062,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4770,1,7,0.25,11,0.25    *rods.9
12,1,1.4265,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4147,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4400,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3612,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3911,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3446,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
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18,1,1.3317,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3521,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2949,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2481,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2311,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1284,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9762,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7690,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0177,1,22,0.25,29,0.25    *rods.9
30,1,0.9798,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9639,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9587,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8367,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5314,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2316,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0158,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5409,1,29,0.25,37,0.25    *rods.9
38,3,1.5228,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5009,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4606,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3333,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1233,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0024,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9388,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9173,1,36,0.125,38,0.375    *rods.9
46,4,1.10441,1,37,38.31439394    *rods.9
47,4,1.10441,1,38,38.45123106    *rods.9
48,4,1.10441,1,39,72.25    *rods.9
49,4,1.10441,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*          Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
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0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.9795,
620.6,0.0698,2.9725,710.6,0.0707,2.7958,
800.6,0.0715,2.6392,890.6,0.0722,2.4993,
980.6,0.0729,2.3737,1070.6,0.0735,2.2603,
1160.6,0.0740,2.1574,1250.6,0.0745,2.0636,
1340.6,0.0750,1.9776,1430.6,0.0754,1.8986,
1520.6,0.0758,1.8257,1610.6,0.0762,1.7584,
1700.6,0.0767,1.6961,1790.6,0.0771,1.6384,
1880.6,0.0775,1.5851,1970.6,0.0779,1.5357,
2060.6,0.0783,1.4903,2150.6,0.0788,1.4485,
2240.6,0.0793,1.4104,2330.6,0.0799,1.3757,
2420.6,0.0805,1.3446,2510.6,0.0813,1.3168,
2600.6,0.0821,1.2925,2690.6,0.0830,1.2715,
2780.6,0.0840,1.2539,2870.6,0.0851,1.2397,
2960.6,0.0864,1.2287,3050.6,0.0879,1.2211,
3140.6,0.0895,1.2168,3230.6,0.0914,1.2157,
3320.6,0.0934,1.2177,3410.6,0.0956,1.2229,
3500.6,0.0980,1.2312,3590.6,0.1006,1.2424,
3680.6,0.1035,1.2566,3770.6,0.1066,1.2736,
3860.6,0.1099,1.2932,3950.6,0.1134,1.3155,
4040.6,0.1172,1.3403,4130.6,0.1212,1.3675,
4220.6,0.1254,1.3969,4310.6,0.1299,1.4285,
4400.6,0.1346,1.4621,4490.6,0.1395,1.4976,
4580.6,0.1446,1.5349,4670.6,0.1499,1.5739,
4760.6,0.1555,1.6143,4850.6,0.1612,1.6562,
4940.6,0.1671,1.6994,5030.6,0.1732,1.7438,
5120.6,0.1794,1.7892,5210.6,0.1858,1.8355,
5300.6,0.1924,1.8827,5390.6,0.1990,1.9306,
5480.6,0.2059,1.9791,5570.6,0.2128,2.0282,
5660.6,0.2199,2.0777,5750.6,0.2270,2.1275,
13940.,0.6954,4.3746,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
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800.6,0.1447,2.9936,890.6,0.1462,2.8264,
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980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3582,
620.6,0.0925,3.1257,710.6,0.0937,2.9244,
800.6,0.0948,2.7520,890.6,0.0957,2.6034,
980.6,0.0966,2.4746,1070.6,0.0974,2.3621,
1160.6,0.0981,2.2632,1250.6,0.0987,2.1753,
1340.6,0.0993,2.0965,1430.6,0.0999,2.0254,
1520.6,0.1004,1.9604,1610.6,0.1009,1.9008,
1700.6,0.1015,1.8456,1790.6,0.1020,1.7945,
1880.6,0.1025,1.7470,1970.6,0.1030,1.7027,
2060.6,0.1034,1.6617,2150.6,0.1040,1.6238,
2240.6,0.1045,1.5890,2330.6,0.1051,1.5574,
2420.6,0.1057,1.5291,2510.6,0.1065,1.5041,
2600.6,0.1072,1.4826,2690.6,0.1080,1.4646,
2780.6,0.1089,1.4503,2870.6,0.1098,1.4397,
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2960.6,0.1109,1.4327,3050.6,0.1121,1.4293,
3140.6,0.1134,1.4297,3230.6,0.1148,1.4335,
3320.6,0.1164,1.4406,3410.6,0.1181,1.4509,
3500.6,0.1199,1.4641,3590.6,0.1219,1.4800,
3680.6,0.1241,1.4984,3770.6,0.1264,1.5188,
3860.6,0.1289,1.5410,3950.6,0.1314,1.5647,
4040.6,0.1343,1.5896,4130.6,0.1372,1.6155,
4220.6,0.1403,1.6419,4310.6,0.1436,1.6689,
4400.6,0.1471,1.6962,4490.6,0.1507,1.7237,
4580.6,0.1544,1.7517,4670.6,0.1583,1.7801,
4760.6,0.1624,1.8093,4850.6,0.1666,1.8399,
4940.6,0.1709,1.8725,5030.6,0.1754,1.9078,
5120.6,0.1799,1.9470,5210.6,0.1846,1.9914,
5300.6,0.1894,2.0427,5390.6,0.1942,2.1029,
5480.6,0.1993,2.1740,5570.6,0.2043,2.2591,
5660.6,0.2096,2.3609,5750.6,0.2148,2.4829,
13940.0,0.5882,4919.2100,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
6,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.529411E+01
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5085,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5478,1,2,0.25,4,0.25    *rods.9
5,1,1.4958,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4834,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5193,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5067,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4776,1,7,0.25,11,0.25    *rods.9
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12,1,1.4269,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4153,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4408,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3621,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3919,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3453,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3325,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3531,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2961,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2491,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2322,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1298,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9777,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7704,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0189,1,22,0.25,29,0.25    *rods.9
30,1,0.9809,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9651,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9600,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8380,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5343,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2345,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0185,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5433,1,29,0.25,37,0.25    *rods.9
38,3,1.5253,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5034,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4632,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3360,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1260,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0052,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9416,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9201,1,36,0.125,38,0.375    *rods.9
46,4,1.10561,1,37,38.31439394    *rods.9
47,4,1.10561,1,38,38.45123106    *rods.9
48,4,1.10561,1,39,72.25    *rods.9
49,4,1.10561,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
```

```
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.9762,
620.6,0.0698,2.9707,710.6,0.0707,2.7943,
800.6,0.0715,2.6378,890.6,0.0722,2.4981,
980.6,0.0729,2.3727,1070.6,0.0735,2.2594,
1160.6,0.0740,2.1567,1250.6,0.0745,2.0630,
1340.6,0.0750,1.9771,1430.6,0.0754,1.8982,
1520.6,0.0758,1.8254,1610.6,0.0762,1.7581,
1700.6,0.0767,1.6958,1790.6,0.0771,1.6382,
1880.6,0.0775,1.5849,1970.6,0.0779,1.5356,
2060.6,0.0783,1.4901,2150.6,0.0788,1.4484,
2240.6,0.0793,1.4103,2330.6,0.0799,1.3756,
2420.6,0.0805,1.3445,2510.6,0.0813,1.3167,
2600.6,0.0821,1.2924,2690.6,0.0830,1.2715,
2780.6,0.0840,1.2539,2870.6,0.0851,1.2396,
2960.6,0.0864,1.2287,3050.6,0.0879,1.2211,
3140.6,0.0895,1.2167,3230.6,0.0914,1.2156,
3320.6,0.0934,1.2177,3410.6,0.0956,1.2229,
3500.6,0.0980,1.2312,3590.6,0.1006,1.2424,
3680.6,0.1035,1.2566,3770.6,0.1066,1.2735,
3860.6,0.1099,1.2932,3950.6,0.1134,1.3155,
4040.6,0.1172,1.3403,4130.6,0.1212,1.3674,
4220.6,0.1254,1.3969,4310.6,0.1299,1.4285,
4400.6,0.1346,1.4621,4490.6,0.1395,1.4976,
4580.6,0.1446,1.5349,4670.6,0.1499,1.5738,
4760.6,0.1555,1.6143,4850.6,0.1612,1.6562,
4940.6,0.1671,1.6994,5030.6,0.1732,1.7437,
5120.6,0.1794,1.7891,5210.6,0.1858,1.8355,
5300.6,0.1924,1.8827,5390.6,0.1990,1.9306,
5480.6,0.2059,1.9791,5570.6,0.2128,2.0282,
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5660.6,0.2199,2.0777,5750.6,0.2270,2.1275,
13940.,0.6954,4.3746,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
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1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
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2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3560,
620.6,0.0925,3.1245,710.6,0.0937,2.9234,
800.6,0.0948,2.7510,890.6,0.0957,2.6026,
980.6,0.0966,2.4739,1070.6,0.0974,2.3615,
1160.6,0.0981,2.2627,1250.6,0.0987,2.1749,
1340.6,0.0993,2.0962,1430.6,0.0999,2.0251,
1520.6,0.1004,1.9602,1610.6,0.1009,1.9006,
1700.6,0.1015,1.8454,1790.6,0.1020,1.7944,
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1880.6,0.1025,1.7469,1970.6,0.1030,1.7026,
2060.6,0.1034,1.6616,2150.6,0.1040,1.6237,
2240.6,0.1045,1.5890,2330.6,0.1051,1.5573,
2420.6,0.1057,1.5290,2510.6,0.1065,1.5040,
2600.6,0.1072,1.4825,2690.6,0.1080,1.4646,
2780.6,0.1089,1.4503,2870.6,0.1098,1.4396,
2960.6,0.1109,1.4327,3050.6,0.1121,1.4293,
3140.6,0.1134,1.4296,3230.6,0.1148,1.4334,
3320.6,0.1164,1.4406,3410.6,0.1181,1.4509,
3500.6,0.1199,1.4641,3590.6,0.1219,1.4800,
3680.6,0.1241,1.4984,3770.6,0.1264,1.5188,
3860.6,0.1289,1.5410,3950.6,0.1314,1.5647,
4040.6,0.1343,1.5896,4130.6,0.1372,1.6154,
4220.6,0.1403,1.6419,4310.6,0.1436,1.6689,
4400.6,0.1471,1.6962,4490.6,0.1507,1.7237,
4580.6,0.1544,1.7517,4670.6,0.1583,1.7801,
4760.6,0.1624,1.8093,4850.6,0.1666,1.8399,
4940.6,0.1709,1.8725,5030.6,0.1754,1.9077,
5120.6,0.1799,1.9469,5210.6,0.1846,1.9914,
5300.6,0.1894,2.0427,5390.6,0.1942,2.1029,
5480.6,0.1993,2.1740,5570.6,0.2043,2.2591,
5660.6,0.2096,2.3609,5750.6,0.2148,2.4829,
13940.0,0.5882,4919.2100,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
7,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.264702E+02
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0023,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5083,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5479,1,2,0.25,4,0.25    *rods.9
5,1,1.4958,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
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6,1,1.4836,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5199,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5075,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4785,1,7,0.25,11,0.25    *rods.9
12,1,1.4278,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4163,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4424,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3640,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3934,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3467,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3341,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3553,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2988,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2513,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2346,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1329,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9809,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7734,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0214,1,22,0.25,29,0.25    *rods.9
30,1,0.9833,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9675,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9630,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8408,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5406,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2408,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0250,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5485,1,29,0.25,37,0.25    *rods.9
38,3,1.5305,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5088,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4690,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3421,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1322,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0116,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9482,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9269,1,36,0.125,38,0.375    *rods.9
46,4,1.10821,1,37,38.31439394    *rods.9
47,4,1.10821,1,38,38.45123106    *rods.9
48,4,1.10821,1,39,72.25    *rods.9
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49,4,1.10821,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*          Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.9376,
620.6,0.0698,2.9492,710.6,0.0707,2.7754,
800.6,0.0715,2.6212,890.6,0.0722,2.4836,
980.6,0.0729,2.3601,1070.6,0.0735,2.2486,
1160.6,0.0740,2.1474,1250.6,0.0745,2.0551,
1340.6,0.0750,1.9704,1430.6,0.0754,1.8925,
1520.6,0.0758,1.8206,1610.6,0.0762,1.7540,
1700.6,0.0767,1.6923,1790.6,0.0771,1.6352,
1880.6,0.0775,1.5822,1970.6,0.0779,1.5332,
2060.6,0.0783,1.4881,2150.6,0.0788,1.4465,
2240.6,0.0793,1.4086,2330.6,0.0799,1.3741,
2420.6,0.0805,1.3431,2510.6,0.0813,1.3155,
2600.6,0.0821,1.2912,2690.6,0.0830,1.2703,
2780.6,0.0840,1.2528,2870.6,0.0851,1.2386,
2960.6,0.0864,1.2278,3050.6,0.0879,1.2202,
3140.6,0.0895,1.2159,3230.6,0.0914,1.2149,
3320.6,0.0934,1.2170,3410.6,0.0956,1.2222,
3500.6,0.0980,1.2305,3590.6,0.1006,1.2418,
3680.6,0.1035,1.2560,3770.6,0.1066,1.2730,
3860.6,0.1099,1.2927,3950.6,0.1134,1.3150,
4040.6,0.1172,1.3398,4130.6,0.1212,1.3670,
4220.6,0.1254,1.3964,4310.6,0.1299,1.4280,
4400.6,0.1346,1.4617,4490.6,0.1395,1.4972,
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4580.6,0.1446,1.5345,4670.6,0.1499,1.5735,
4760.6,0.1555,1.6140,4850.6,0.1612,1.6559,
4940.6,0.1671,1.6991,5030.6,0.1732,1.7434,
5120.6,0.1794,1.7888,5210.6,0.1858,1.8352,
5300.6,0.1924,1.8824,5390.6,0.1990,1.9303,
5480.6,0.2059,1.9788,5570.6,0.2128,2.0279,
5660.6,0.2199,2.0774,5750.6,0.2270,2.1273,
13940.,0.6954,4.3745,
2,61,359.929,IMF *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3296,
620.6,0.0925,3.1098,710.6,0.0937,2.9105,

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800.6,0.0948,2.7397,890.6,0.0957,2.5927,
980.6,0.0966,2.4653,1070.6,0.0974,2.3541,
1160.6,0.0981,2.2563,1250.6,0.0987,2.1695,
1340.6,0.0993,2.0916,1430.6,0.0999,2.0212,
1520.6,0.1004,1.9569,1610.6,0.1009,1.8978,
1700.6,0.1015,1.8431,1790.6,0.1020,1.7923,
1880.6,0.1025,1.7450,1970.6,0.1030,1.7010,
2060.6,0.1034,1.6602,2150.6,0.1040,1.6224,
2240.6,0.1045,1.5878,2330.6,0.1051,1.5563,
2420.6,0.1057,1.5281,2510.6,0.1065,1.5032,
2600.6,0.1072,1.4817,2690.6,0.1080,1.4638,
2780.6,0.1089,1.4495,2870.6,0.1098,1.4389,
2960.6,0.1109,1.4320,3050.6,0.1121,1.4287,
3140.6,0.1134,1.4291,3230.6,0.1148,1.4329,
3320.6,0.1164,1.4401,3410.6,0.1181,1.4504,
3500.6,0.1199,1.4637,3590.6,0.1219,1.4796,
3680.6,0.1241,1.4979,3770.6,0.1264,1.5184,
3860.6,0.1289,1.5407,3950.6,0.1314,1.5644,
4040.6,0.1343,1.5893,4130.6,0.1372,1.6151,
4220.6,0.1403,1.6416,4310.6,0.1436,1.6685,
4400.6,0.1471,1.6959,4490.6,0.1507,1.7235,
4580.6,0.1544,1.7514,4670.6,0.1583,1.7799,
4760.6,0.1624,1.8091,4850.6,0.1666,1.8397,
4940.6,0.1709,1.8723,5030.6,0.1754,1.9075,
5120.6,0.1799,1.9467,5210.6,0.1846,1.9912,
5300.6,0.1894,2.0425,5390.6,0.1942,2.1027,
5480.6,0.1993,2.1738,5570.6,0.2043,2.2589,
5660.6,0.2096,2.3606,5750.6,0.2148,2.4827,
13940.0,0.5882,4919.2099,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
8,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.529406E+02
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
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*            Normal Rod input
1,2,0.0023,1,1,0.125    *rods.9
2,1,1.5611,1,1,0.25,2,0.25    *rods.9
3,1,1.5081,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5480,1,2,0.25,4,0.25    *rods.9
5,1,1.4958,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4837,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5201,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5079,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4790,1,7,0.25,11,0.25    *rods.9
12,1,1.4281,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4168,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4432,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3650,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3941,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3474,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3349,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3564,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3001,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2524,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2358,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1344,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9825,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7749,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0227,1,22,0.25,29,0.25    *rods.9
30,1,0.9845,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9688,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9644,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8422,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5427,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2433,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0276,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5504,1,29,0.25,37,0.25    *rods.9
38,3,1.5323,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5108,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4711,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3443,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1347,1,33,0.25,34,0.25,38,0.5    *rods.9
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43,3,1.0142,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9508,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9296,1,36,0.125,38,0.375    *rods.9
46,4,1.10931,1,37,38.31439394    *rods.9
47,4,1.10931,1,38,38.45123106    *rods.9
48,4,1.10931,1,39,72.25    *rods.9
49,4,1.10931,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.9044,
620.6,0.0698,2.9307,710.6,0.0707,2.7591,
800.6,0.0715,2.6069,890.6,0.0722,2.4710,
980.6,0.0729,2.3491,1070.6,0.0735,2.2390,
1160.6,0.0740,2.1391,1250.6,0.0745,2.0479,
1340.6,0.0750,1.9643,1430.6,0.0754,1.8872,
1520.6,0.0758,1.8160,1610.6,0.0762,1.7500,
1700.6,0.0767,1.6889,1790.6,0.0771,1.6321,
1880.6,0.0775,1.5795,1970.6,0.0779,1.5308,
2060.6,0.0783,1.4858,2150.6,0.0788,1.4445,
2240.6,0.0793,1.4067,2330.6,0.0799,1.3724,
2420.6,0.0805,1.3415,2510.6,0.0813,1.3140,
2600.6,0.0821,1.2899,2690.6,0.0830,1.2691,
2780.6,0.0840,1.2516,2870.6,0.0851,1.2375,
2960.6,0.0864,1.2267,3050.6,0.0879,1.2192,
3140.6,0.0895,1.2150,3230.6,0.0914,1.2140,
3320.6,0.0934,1.2161,3410.6,0.0956,1.2214,
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3500.6,0.0980,1.2297,3590.6,0.1006,1.2411,
3680.6,0.1035,1.2553,3770.6,0.1066,1.2723,
3860.6,0.1099,1.2920,3950.6,0.1134,1.3144,
4040.6,0.1172,1.3392,4130.6,0.1212,1.3664,
4220.6,0.1254,1.3959,4310.6,0.1299,1.4275,
4400.6,0.1346,1.4612,4490.6,0.1395,1.4967,
4580.6,0.1446,1.5340,4670.6,0.1499,1.5730,
4760.6,0.1555,1.6135,4850.6,0.1612,1.6554,
4940.6,0.1671,1.6986,5030.6,0.1732,1.7430,
5120.6,0.1794,1.7884,5210.6,0.1858,1.8348,
5300.6,0.1924,1.8820,5390.6,0.1990,1.9299,
5480.6,0.2059,1.9785,5570.6,0.2128,2.0276,
5660.6,0.2199,2.0771,5750.6,0.2270,2.1269,
13940.,0.6954,4.3744,
2,61,359.929,IMF   *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,

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5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.3070,
620.6,0.0925,3.0972,710.6,0.0937,2.8994,
800.6,0.0948,2.7299,890.6,0.0957,2.5841,
980.6,0.0966,2.4578,1070.6,0.0974,2.3476,
1160.6,0.0981,2.2507,1250.6,0.0987,2.1646,
1340.6,0.0993,2.0875,1430.6,0.0999,2.0176,
1520.6,0.1004,1.9538,1610.6,0.1009,1.8950,
1700.6,0.1015,1.8407,1790.6,0.1020,1.7902,
1880.6,0.1025,1.7432,1970.6,0.1030,1.6994,
2060.6,0.1034,1.6587,2150.6,0.1040,1.6211,
2240.6,0.1045,1.5865,2330.6,0.1051,1.5551,
2420.6,0.1057,1.5270,2510.6,0.1065,1.5022,
2600.6,0.1072,1.4808,2690.6,0.1080,1.4630,
2780.6,0.1089,1.4487,2870.6,0.1098,1.4382,
2960.6,0.1109,1.4313,3050.6,0.1121,1.4281,
3140.6,0.1134,1.4285,3230.6,0.1148,1.4323,
3320.6,0.1164,1.4395,3410.6,0.1181,1.4499,
3500.6,0.1199,1.4631,3590.6,0.1219,1.4791,
3680.6,0.1241,1.4975,3770.6,0.1264,1.5179,
3860.6,0.1289,1.5402,3950.6,0.1314,1.5640,
4040.6,0.1343,1.5889,4130.6,0.1372,1.6147,
4220.6,0.1403,1.6412,4310.6,0.1436,1.6682,
4400.6,0.1471,1.6955,4490.6,0.1507,1.7231,
4580.6,0.1544,1.7511,4670.6,0.1583,1.7795,
4760.6,0.1624,1.8088,4850.6,0.1666,1.8394,
4940.6,0.1709,1.8719,5030.6,0.1754,1.9072,
5120.6,0.1799,1.9464,5210.6,0.1846,1.9909,
5300.6,0.1894,2.0423,5390.6,0.1942,2.1024,
5480.6,0.1993,2.1736,5570.6,0.2043,2.2587,
5660.6,0.2096,2.3604,5750.6,0.2148,2.4825,
13940.0,0.5882,4919.2098,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
9,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 9.058812E+02
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
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*
*          Nuclear Fuel Rod Power Profile
-1,3   *rods.3
*
1.55   *rods.5
*
*          Normal Rod input
1,2,0.0023,1,1,0.125   *rods.9
2,1,1.5611,1,1,0.25,2,0.25   *rods.9
3,1,1.5080,1,1,0.125,2,0.25,3,0.125   *rods.9
4,1,1.5482,1,2,0.25,4,0.25   *rods.9
5,1,1.4958,1,2,0.25,3,0.25,4,0.25,5,0.25   *rods.9
6,1,1.4838,1,3,0.125,5,0.25,6,0.125   *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0   *rods.9
8,1,1.5206,1,4,0.25,5,0.25,7,0.25,8,0.25   *rods.9
9,1,1.5085,1,5,0.25,6,0.25,8,0.25,9,0.25   *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125   *rods.9
11,1,1.4798,1,7,0.25,11,0.25   *rods.9
12,1,1.4288,1,7,0.25,8,0.25,11,0.25,12,0.25   *rods.9
13,1,1.4176,1,8,0.25,9,0.25,12,0.25,13,0.25   *rods.9
14,1,1.4446,1,9,0.25,10,0.25,13,0.25,14,0.25   *rods.9
15,1,1.3667,1,10,0.125,14,0.25,15,0.125   *rods.9
16,1,1.3955,1,11,0.25,16,0.25,0,0   *rods.9
17,1,1.3485,1,11,0.25,12,0.25,16,0.25,17,0.25   *rods.9
18,1,1.3362,1,12,0.25,13,0.25,17,0.25,18,0.25   *rods.9
19,1,1.3583,1,13,0.25,14,0.25,18,0.25,19,0.25   *rods.9
20,1,1.3024,1,14,0.25,15,0.25,19,0.25,20,0.25   *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125   *rods.9
22,2,0.0018,1,16,0.25,22,0.25   *rods.9
23,1,1.2544,1,16,0.25,17,0.25,22,0.25,23,0.25   *rods.9
24,1,1.2379,1,17,0.25,18,0.25,23,0.25,24,0.25   *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25   *rods.9
26,1,1.1371,1,19,0.25,20,0.25,25,0.25,26,0.25   *rods.9
27,1,0.9852,1,20,0.25,21,0.25,26,0.25,27,0.25   *rods.9
28,1,0.7774,1,21,0.125,27,0.25,28,0.125   *rods.9
29,1,1.0250,1,22,0.25,29,0.25   *rods.9
30,1,0.9866,1,22,0.25,23,0.25,29,0.25,30,0.25   *rods.9
31,1,0.9710,1,23,0.25,24,0.25,30,0.25,31,0.25   *rods.9
32,1,0.9670,1,24,0.25,25,0.25,31,0.25,32,0.25   *rods.9
33,1,0.8447,1,25,0.25,26,0.25,32,0.25,33,0.25   *rods.9
34,3,1.5447,1,26,0.25,27,0.25,33,0.25,34,0.25   *rods.9
35,3,1.2462,1,27,0.25,28,0.25,34,0.25,35,0.25   *rods.9
36,3,1.0313,1,28,0.125,35,0.25,36,0.125   *rods.9
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37,3,1.5521,1,29,0.25,37,0.25    *rods.9
38,3,1.5340,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5126,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4734,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3470,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1381,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0179,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9547,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9336,1,36,0.125,38,0.375    *rods.9
46,4,1.11091,1,37,38.31439394    *rods.9
47,4,1.11091,1,38,38.45123106    *rods.9
48,4,1.11091,1,39,72.25    *rods.9
49,4,1.11091,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.8474,
620.6,0.0698,2.8986,710.6,0.0707,2.7309,
800.6,0.0715,2.5820,890.6,0.0722,2.4491,
980.6,0.0729,2.3299,1070.6,0.0735,2.2222,
1160.6,0.0740,2.1245,1250.6,0.0745,2.0353,
1340.6,0.0750,1.9533,1430.6,0.0754,1.8777,
1520.6,0.0758,1.8077,1610.6,0.0762,1.7428,
1700.6,0.0767,1.6825,1790.6,0.0771,1.6264,
1880.6,0.0775,1.5744,1970.6,0.0779,1.5262,
2060.6,0.0783,1.4817,2150.6,0.0788,1.4407,
2240.6,0.0793,1.4032,2330.6,0.0799,1.3692,
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2420.6,0.0805,1.3385,2510.6,0.0813,1.3112,
2600.6,0.0821,1.2873,2690.6,0.0830,1.2666,
2780.6,0.0840,1.2493,2870.6,0.0851,1.2354,
2960.6,0.0864,1.2247,3050.6,0.0879,1.2173,
3140.6,0.0895,1.2132,3230.6,0.0914,1.2122,
3320.6,0.0934,1.2145,3410.6,0.0956,1.2198,
3500.6,0.0980,1.2282,3590.6,0.1006,1.2396,
3680.6,0.1035,1.2539,3770.6,0.1066,1.2710,
3860.6,0.1099,1.2907,3950.6,0.1134,1.3131,
4040.6,0.1172,1.3380,4130.6,0.1212,1.3653,
4220.6,0.1254,1.3948,4310.6,0.1299,1.4265,
4400.6,0.1346,1.4601,4490.6,0.1395,1.4957,
4580.6,0.1446,1.5331,4670.6,0.1499,1.5721,
4760.6,0.1555,1.6126,4850.6,0.1612,1.6546,
4940.6,0.1671,1.6978,5030.6,0.1732,1.7422,
5120.6,0.1794,1.7877,5210.6,0.1858,1.8341,
5300.6,0.1924,1.8813,5390.6,0.1990,1.9292,
5480.6,0.2059,1.9778,5570.6,0.2128,2.0269,
5660.6,0.2199,2.0764,5750.6,0.2270,2.1263,
13940.,0.6954,4.3743,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
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1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
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4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.2681,
620.6,0.0925,3.0753,710.6,0.0937,2.8802,
800.6,0.0948,2.7130,890.6,0.0957,2.5692,
980.6,0.0966,2.4447,1070.6,0.0974,2.3361,
1160.6,0.0981,2.2407,1250.6,0.0987,2.1560,
1340.6,0.0993,2.0800,1430.6,0.0999,2.0111,
1520.6,0.1004,1.9481,1610.6,0.1009,1.8901,
1700.6,0.1015,1.8364,1790.6,0.1020,1.7863,
1880.6,0.1025,1.7397,1970.6,0.1030,1.6962,
2060.6,0.1034,1.6559,2150.6,0.1040,1.6185,
2240.6,0.1045,1.5841,2330.6,0.1051,1.5529,
2420.6,0.1057,1.5249,2510.6,0.1065,1.5003,
2600.6,0.1072,1.4791,2690.6,0.1080,1.4613,
2780.6,0.1089,1.4471,2870.6,0.1098,1.4367,
2960.6,0.1109,1.4299,3050.6,0.1121,1.4268,
3140.6,0.1134,1.4272,3230.6,0.1148,1.4311,
3320.6,0.1164,1.4384,3410.6,0.1181,1.4488,
3500.6,0.1199,1.4621,3590.6,0.1219,1.4781,
3680.6,0.1241,1.4965,3770.6,0.1264,1.5170,
3860.6,0.1289,1.5393,3950.6,0.1314,1.5631,
4040.6,0.1343,1.5881,4130.6,0.1372,1.6140,
4220.6,0.1403,1.6405,4310.6,0.1436,1.6675,
4400.6,0.1471,1.6948,4490.6,0.1507,1.7224,
4580.6,0.1544,1.7504,4670.6,0.1583,1.7789,
4760.6,0.1624,1.8082,4850.6,0.1666,1.8388,
4940.6,0.1709,1.8714,5030.6,0.1754,1.9067,
5120.6,0.1799,1.9460,5210.6,0.1846,1.9905,
5300.6,0.1894,2.0418,5390.6,0.1942,2.1019,
5480.6,0.1993,2.1732,5570.6,0.2043,2.2582,
5660.6,0.2096,2.3600,5750.6,0.2148,2.4821,
13940.0,0.5882,4919.2098,
endd
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* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
10,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.358822E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5611,1,1,0.25,2,0.25    *rods.9
3,1,1.5078,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5483,1,2,0.25,4,0.25    *rods.9
5,1,1.4957,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4839,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5209,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5090,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4804,1,7,0.25,11,0.25    *rods.9
12,1,1.4292,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4181,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4456,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3679,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3964,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3493,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3371,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3597,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3041,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2559,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2395,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1391,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9873,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7792,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0267,1,22,0.25,29,0.25    *rods.9
30,1,0.9881,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
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31,1,0.9726,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9689,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8465,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5453,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2478,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0335,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5524,1,29,0.25,37,0.25    *rods.9
38,3,1.5344,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5131,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4742,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3483,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1401,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0203,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9573,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9363,1,36,0.125,38,0.375    *rods.9
46,4,1.11191,1,37,38.31439394    *rods.9
47,4,1.11191,1,38,38.45123106    *rods.9
48,4,1.11191,1,39,72.25    *rods.9
49,4,1.11191,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.7949,
620.6,0.0698,2.8689,710.6,0.0707,2.7047,
800.6,0.0715,2.5588,890.6,0.0722,2.4287,
980.6,0.0729,2.3118,1070.6,0.0735,2.2064,
1160.6,0.0740,2.1107,1250.6,0.0745,2.0233,
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1340.6,0.0750,1.9429,1430.6,0.0754,1.8687,
1520.6,0.0758,1.7998,1610.6,0.0762,1.7358,
1700.6,0.0767,1.6763,1790.6,0.0771,1.6209,
1880.6,0.0775,1.5695,1970.6,0.0779,1.5217,
2060.6,0.0783,1.4776,2150.6,0.0788,1.4370,
2240.6,0.0793,1.3998,2330.6,0.0799,1.3660,
2420.6,0.0805,1.3356,2510.6,0.0813,1.3085,
2600.6,0.0821,1.2847,2690.6,0.0830,1.2642,
2780.6,0.0840,1.2471,2870.6,0.0851,1.2332,
2960.6,0.0864,1.2227,3050.6,0.0879,1.2154,
3140.6,0.0895,1.2113,3230.6,0.0914,1.2105,
3320.6,0.0934,1.2128,3410.6,0.0956,1.2183,
3500.6,0.0980,1.2267,3590.6,0.1006,1.2382,
3680.6,0.1035,1.2525,3770.6,0.1066,1.2696,
3860.6,0.1099,1.2895,3950.6,0.1134,1.3119,
4040.6,0.1172,1.3368,4130.6,0.1212,1.3641,
4220.6,0.1254,1.3937,4310.6,0.1299,1.4254,
4400.6,0.1346,1.4591,4490.6,0.1395,1.4948,
4580.6,0.1446,1.5322,4670.6,0.1499,1.5712,
4760.6,0.1555,1.6118,4850.6,0.1612,1.6537,
4940.6,0.1671,1.6970,5030.6,0.1732,1.7414,
5120.6,0.1794,1.7869,5210.6,0.1858,1.8333,
5300.6,0.1924,1.8806,5390.6,0.1990,1.9285,
5480.6,0.2059,1.9771,5570.6,0.2128,2.0263,
5660.6,0.2199,2.0758,5750.6,0.2270,2.1257,
13940.,0.6954,4.3742,
2,61,359.929,IMF   *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,

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3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.2323,
620.6,0.0925,3.0551,710.6,0.0937,2.8623,
800.6,0.0948,2.6971,890.6,0.0957,2.5552,
980.6,0.0966,2.4324,1070.6,0.0974,2.3254,
1160.6,0.0981,2.2313,1250.6,0.0987,2.1478,
1340.6,0.0993,2.0729,1430.6,0.0999,2.0050,
1520.6,0.1004,1.9427,1610.6,0.1009,1.8853,
1700.6,0.1015,1.8321,1790.6,0.1020,1.7826,
1880.6,0.1025,1.7364,1970.6,0.1030,1.6932,
2060.6,0.1034,1.6531,2150.6,0.1040,1.6159,
2240.6,0.1045,1.5818,2330.6,0.1051,1.5508,
2420.6,0.1057,1.5229,2510.6,0.1065,1.4984,
2600.6,0.1072,1.4773,2690.6,0.1080,1.4596,
2780.6,0.1089,1.4456,2870.6,0.1098,1.4352,
2960.6,0.1109,1.4286,3050.6,0.1121,1.4255,
3140.6,0.1134,1.4259,3230.6,0.1148,1.4299,
3320.6,0.1164,1.4372,3410.6,0.1181,1.4477,
3500.6,0.1199,1.4611,3590.6,0.1219,1.4772,
3680.6,0.1241,1.4956,3770.6,0.1264,1.5161,
3860.6,0.1289,1.5385,3950.6,0.1314,1.5623,
4040.6,0.1343,1.5872,4130.6,0.1372,1.6131,
4220.6,0.1403,1.6397,4310.6,0.1436,1.6668,
4400.6,0.1471,1.6941,4490.6,0.1507,1.7218,
4580.6,0.1544,1.7498,4670.6,0.1583,1.7783,
4760.6,0.1624,1.8076,4850.6,0.1666,1.8382,
4940.6,0.1709,1.8708,5030.6,0.1754,1.9062,
5120.6,0.1799,1.9454,5210.6,0.1846,1.9899,
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5300.6,0.1894,2.0413,5390.6,0.1942,2.1014,
5480.6,0.1993,2.1727,5570.6,0.2043,2.2578,
5660.6,0.2096,2.3596,5750.6,0.2148,2.4817,
13940.0,0.5882,4919.2097,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
11,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.811763E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5611,1,1,0.25,2,0.25    *rods.9
3,1,1.5077,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5484,1,2,0.25,4,0.25    *rods.9
5,1,1.4957,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4840,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5212,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5093,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4809,1,7,0.25,11,0.25    *rods.9
12,1,1.4296,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4186,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4464,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3689,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3973,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3500,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3380,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3609,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3056,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2571,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2408,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
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25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1408,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9890,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7808,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0281,1,22,0.25,29,0.25    *rods.9
30,1,0.9895,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9740,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9706,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8480,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5454,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2489,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0353,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5525,1,29,0.25,37,0.25    *rods.9
38,3,1.5344,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5133,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4746,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3491,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1416,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0221,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9593,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9384,1,36,0.125,38,0.375    *rods.9
46,4,1.11271,1,37,38.31439394    *rods.9
47,4,1.11271,1,38,38.45123106    *rods.9
48,4,1.11271,1,39,72.25    *rods.9
49,4,1.11271,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
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1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.7445,
620.6,0.0698,2.8402,710.6,0.0707,2.6793,
800.6,0.0715,2.5364,890.6,0.0722,2.4088,
980.6,0.0729,2.2944,1070.6,0.0735,2.1911,
1160.6,0.0740,2.0973,1250.6,0.0745,2.0116,
1340.6,0.0750,1.9328,1430.6,0.0754,1.8598,
1520.6,0.0758,1.7921,1610.6,0.0762,1.7290,
1700.6,0.0767,1.6702,1790.6,0.0771,1.6155,
1880.6,0.0775,1.5646,1970.6,0.0779,1.5173,
2060.6,0.0783,1.4736,2150.6,0.0788,1.4333,
2240.6,0.0793,1.3964,2330.6,0.0799,1.3629,
2420.6,0.0805,1.3326,2510.6,0.0813,1.3057,
2600.6,0.0821,1.2821,2690.6,0.0830,1.2618,
2780.6,0.0840,1.2448,2870.6,0.0851,1.2311,
2960.6,0.0864,1.2206,3050.6,0.0879,1.2135,
3140.6,0.0895,1.2095,3230.6,0.0914,1.2088,
3320.6,0.0934,1.2112,3410.6,0.0956,1.2167,
3500.6,0.0980,1.2252,3590.6,0.1006,1.2367,
3680.6,0.1035,1.2511,3770.6,0.1066,1.2683,
3860.6,0.1099,1.2882,3950.6,0.1134,1.3107,
4040.6,0.1172,1.3357,4130.6,0.1212,1.3630,
4220.6,0.1254,1.3926,4310.6,0.1299,1.4244,
4400.6,0.1346,1.4581,4490.6,0.1395,1.4938,
4580.6,0.1446,1.5312,4670.6,0.1499,1.5703,
4760.6,0.1555,1.6109,4850.6,0.1612,1.6529,
4940.6,0.1671,1.6962,5030.6,0.1732,1.7406,
5120.6,0.1794,1.7861,5210.6,0.1858,1.8326,
5300.6,0.1924,1.8798,5390.6,0.1990,1.9278,
5480.6,0.2059,1.9765,5570.6,0.2128,2.0256,
5660.6,0.2199,2.0752,5750.6,0.2270,2.1251,
13940.,0.6954,4.3741,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
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2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.1980,
620.6,0.0925,3.0355,710.6,0.0937,2.8450,
800.6,0.0948,2.6819,890.6,0.0957,2.5417,
980.6,0.0966,2.4205,1070.6,0.0974,2.3149,
1160.6,0.0981,2.2222,1250.6,0.0987,2.1399,
1340.6,0.0993,2.0660,1430.6,0.0999,1.9989,
1520.6,0.1004,1.9375,1610.6,0.1009,1.8807,
1700.6,0.1015,1.8280,1790.6,0.1020,1.7789,
1880.6,0.1025,1.7330,1970.6,0.1030,1.6902,
2060.6,0.1034,1.6504,2150.6,0.1040,1.6134,
2240.6,0.1045,1.5795,2330.6,0.1051,1.5487,
2420.6,0.1057,1.5209,2510.6,0.1065,1.4965,
2600.6,0.1072,1.4755,2690.6,0.1080,1.4580,
2780.6,0.1089,1.4441,2870.6,0.1098,1.4338,
2960.6,0.1109,1.4271,3050.6,0.1121,1.4242,
3140.6,0.1134,1.4247,3230.6,0.1148,1.4288,
3320.6,0.1164,1.4362,3410.6,0.1181,1.4467,
3500.6,0.1199,1.4600,3590.6,0.1219,1.4761,
3680.6,0.1241,1.4946,3770.6,0.1264,1.5152,
3860.6,0.1289,1.5376,3950.6,0.1314,1.5615,
4040.6,0.1343,1.5865,4130.6,0.1372,1.6124,
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4220.6,0.1403,1.6390,4310.6,0.1436,1.6661,
4400.6,0.1471,1.6934,4490.6,0.1507,1.7211,
4580.6,0.1544,1.7492,4670.6,0.1583,1.7777,
4760.6,0.1624,1.8070,4850.6,0.1666,1.8377,
4940.6,0.1709,1.8703,5030.6,0.1754,1.9056,
5120.6,0.1799,1.9449,5210.6,0.1846,1.9894,
5300.6,0.1894,2.0408,5390.6,0.1942,2.1010,
5480.6,0.1993,2.1723,5570.6,0.2043,2.2573,
5660.6,0.2096,2.3591,5750.6,0.2148,2.4812,
13940.0,0.5882,4919.2096,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
12,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.264703E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5611,1,1,0.25,2,0.25    *rods.9
3,1,1.5076,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5485,1,2,0.25,4,0.25    *rods.9
5,1,1.4957,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4840,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5215,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5097,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4813,1,7,0.25,11,0.25    *rods.9
12,1,1.4299,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4191,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4473,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3699,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3981,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3507,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3387,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
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19,1,1.3621,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3070,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2583,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2421,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1424,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9907,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7822,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0296,1,22,0.25,29,0.25    *rods.9
30,1,0.9907,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9754,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9721,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8494,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5456,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2501,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0371,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5526,1,29,0.25,37,0.25    *rods.9
38,3,1.5346,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5135,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4751,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3500,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1432,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0240,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9614,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9406,1,36,0.125,38,0.375    *rods.9
46,4,1.11351,1,37,38.31439394    *rods.9
47,4,1.11351,1,38,38.45123106    *rods.9
48,4,1.11351,1,39,72.25    *rods.9
49,4,1.11351,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
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4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0       *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.6958,
620.6,0.0698,2.8122,710.6,0.0707,2.6545,
800.6,0.0715,2.5145,890.6,0.0722,2.3894,
980.6,0.0729,2.2773,1070.6,0.0735,2.1761,
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1880.6,0.0775,1.5597,1970.6,0.0779,1.5129,
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2420.6,0.0805,1.3297,2510.6,0.0813,1.3030,
2600.6,0.0821,1.2796,2690.6,0.0830,1.2594,
2780.6,0.0840,1.2426,2870.6,0.0851,1.2290,
2960.6,0.0864,1.2186,3050.6,0.0879,1.2116,
3140.6,0.0895,1.2077,3230.6,0.0914,1.2071,
3320.6,0.0934,1.2095,3410.6,0.0956,1.2151,
3500.6,0.0980,1.2237,3590.6,0.1006,1.2353,
3680.6,0.1035,1.2498,3770.6,0.1066,1.2670,
3860.6,0.1099,1.2870,3950.6,0.1134,1.3095,
4040.6,0.1172,1.3345,4130.6,0.1212,1.3619,
4220.6,0.1254,1.3916,4310.6,0.1299,1.4233,
4400.6,0.1346,1.4571,4490.6,0.1395,1.4928,
4580.6,0.1446,1.5303,4670.6,0.1499,1.5694,
4760.6,0.1555,1.6100,4850.6,0.1612,1.6521,
4940.6,0.1671,1.6954,5030.6,0.1732,1.7399,
5120.6,0.1794,1.7854,5210.6,0.1858,1.8318,
5300.6,0.1924,1.8791,5390.6,0.1990,1.9271,
5480.6,0.2059,1.9758,5570.6,0.2128,2.0249,
5660.6,0.2199,2.0745,5750.6,0.2270,2.1245,
13940.,0.6954,4.3740,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
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1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
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4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.1648,
620.6,0.0925,3.0164,710.6,0.0937,2.8281,
800.6,0.0948,2.6669,890.6,0.0957,2.5284,
980.6,0.0966,2.4088,1070.6,0.0974,2.3047,
1160.6,0.0981,2.2133,1250.6,0.0987,2.1320,
1340.6,0.0993,2.0591,1430.6,0.0999,1.9929,
1520.6,0.1004,1.9322,1610.6,0.1009,1.8761,
1700.6,0.1015,1.8239,1790.6,0.1020,1.7752,
1880.6,0.1025,1.7297,1970.6,0.1030,1.6872,
2060.6,0.1034,1.6476,2150.6,0.1040,1.6109,
2240.6,0.1045,1.5772,2330.6,0.1051,1.5465,
2420.6,0.1057,1.5189,2510.6,0.1065,1.4947,
2600.6,0.1072,1.4738,2690.6,0.1080,1.4564,
2780.6,0.1089,1.4426,2870.6,0.1098,1.4324,
2960.6,0.1109,1.4258,3050.6,0.1121,1.4229,
```

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3140.6,0.1134,1.4235,3230.6,0.1148,1.4276,
3320.6,0.1164,1.4350,3410.6,0.1181,1.4456,
3500.6,0.1199,1.4590,3590.6,0.1219,1.4752,
3680.6,0.1241,1.4937,3770.6,0.1264,1.5143,
3860.6,0.1289,1.5368,3950.6,0.1314,1.5606,
4040.6,0.1343,1.5857,4130.6,0.1372,1.6116,
4220.6,0.1403,1.6383,4310.6,0.1436,1.6653,
4400.6,0.1471,1.6927,4490.6,0.1507,1.7205,
4580.6,0.1544,1.7485,4670.6,0.1583,1.7771,
4760.6,0.1624,1.8064,4850.6,0.1666,1.8371,
4940.6,0.1709,1.8697,5030.6,0.1754,1.9051,
5120.6,0.1799,1.9444,5210.6,0.1846,1.9889,
5300.6,0.1894,2.0403,5390.6,0.1942,2.1005,
5480.6,0.1993,2.1718,5570.6,0.2043,2.2568,
5660.6,0.2096,2.3587,5750.6,0.2148,2.4808,
13940.0,0.5882,4919.2095,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
13,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.170585E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5074,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5487,1,2,0.25,4,0.25    *rods.9
5,1,1.4957,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4842,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5221,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5105,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4823,1,7,0.25,11,0.25    *rods.9
12,1,1.4306,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
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13,1,1.4200,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4489,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3719,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3996,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3520,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3402,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3643,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3098,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0018,1,16,0.25,22,0.25    *rods.9
23,1,1.2607,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2446,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1457,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9940,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7852,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0323,1,22,0.25,29,0.25    *rods.9
30,1,0.9932,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9780,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9752,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8523,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5468,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2529,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0410,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5536,1,29,0.25,37,0.25    *rods.9
38,3,1.5355,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5147,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4768,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3524,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1467,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0281,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9657,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9450,1,36,0.125,38,0.375    *rods.9
46,4,1.11521,1,37,38.31439394    *rods.9
47,4,1.11521,1,38,38.45123106    *rods.9
48,4,1.11521,1,39,72.25    *rods.9
49,4,1.11521,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
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*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.6020,
620.6,0.0698,2.7579,710.6,0.0707,2.6064,
800.6,0.0715,2.4718,890.6,0.0722,2.3516,
980.6,0.0729,2.2438,1070.6,0.0735,2.1466,
1160.6,0.0740,2.0583,1250.6,0.0745,1.9775,
1340.6,0.0750,1.9030,1430.6,0.0754,1.8338,
1520.6,0.0758,1.7692,1610.6,0.0762,1.7088,
1700.6,0.0767,1.6523,1790.6,0.0771,1.5995,
1880.6,0.0775,1.5502,1970.6,0.0779,1.5043,
2060.6,0.0783,1.4617,2150.6,0.0788,1.4224,
2240.6,0.0793,1.3863,2330.6,0.0799,1.3535,
2420.6,0.0805,1.3240,2510.6,0.0813,1.2976,
2600.6,0.0821,1.2745,2690.6,0.0830,1.2547,
2780.6,0.0840,1.2381,2870.6,0.0851,1.2248,
2960.6,0.0864,1.2147,3050.6,0.0879,1.2078,
3140.6,0.0895,1.2041,3230.6,0.0914,1.2036,
3320.6,0.0934,1.2063,3410.6,0.0956,1.2120,
3500.6,0.0980,1.2208,3590.6,0.1006,1.2325,
3680.6,0.1035,1.2471,3770.6,0.1066,1.2644,
3860.6,0.1099,1.2845,3950.6,0.1134,1.3071,
4040.6,0.1172,1.3322,4130.6,0.1212,1.3597,
4220.6,0.1254,1.3894,4310.6,0.1299,1.4213,
4400.6,0.1346,1.4552,4490.6,0.1395,1.4909,
4580.6,0.1446,1.5284,4670.6,0.1499,1.5676,
4760.6,0.1555,1.6083,4850.6,0.1612,1.6504,
4940.6,0.1671,1.6938,5030.6,0.1732,1.7383,
5120.6,0.1794,1.7839,5210.6,0.1858,1.8304,
5300.6,0.1924,1.8777,5390.6,0.1990,1.9258,
5480.6,0.2059,1.9744,5570.6,0.2128,2.0236,
5660.6,0.2199,2.0733,5750.6,0.2270,2.1232,
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13940.,0.6954,4.3737,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.1008,
620.6,0.0925,2.9794,710.6,0.0937,2.7953,
800.6,0.0948,2.6378,890.6,0.0957,2.5027,
980.6,0.0966,2.3860,1070.6,0.0974,2.2846,
1160.6,0.0981,2.1956,1250.6,0.0987,2.1166,
1340.6,0.0993,2.0457,1430.6,0.0999,1.9812,
1520.6,0.1004,1.9219,1610.6,0.1009,1.8669,
1700.6,0.1015,1.8158,1790.6,0.1020,1.7680,
1880.6,0.1025,1.7232,1970.6,0.1030,1.6813,
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2060.6,0.1034,1.6422,2150.6,0.1040,1.6060,
2240.6,0.1045,1.5726,2330.6,0.1051,1.5422,
2420.6,0.1057,1.5150,2510.6,0.1065,1.4910,
2600.6,0.1072,1.4703,2690.6,0.1080,1.4531,
2780.6,0.1089,1.4395,2870.6,0.1098,1.4295,
2960.6,0.1109,1.4231,3050.6,0.1121,1.4203,
3140.6,0.1134,1.4210,3230.6,0.1148,1.4252,
3320.6,0.1164,1.4328,3410.6,0.1181,1.4434,
3500.6,0.1199,1.4571,3590.6,0.1219,1.4733,
3680.6,0.1241,1.4919,3770.6,0.1264,1.5125,
3860.6,0.1289,1.5351,3950.6,0.1314,1.5590,
4040.6,0.1343,1.5841,4130.6,0.1372,1.6101,
4220.6,0.1403,1.6368,4310.6,0.1436,1.6640,
4400.6,0.1471,1.6915,4490.6,0.1507,1.7192,
4580.6,0.1544,1.7472,4670.6,0.1583,1.7759,
4760.6,0.1624,1.8053,4850.6,0.1666,1.8360,
4940.6,0.1709,1.8686,5030.6,0.1754,1.9040,
5120.6,0.1799,1.9434,5210.6,0.1846,1.9879,
5300.6,0.1894,2.0393,5390.6,0.1942,2.0996,
5480.6,0.1993,2.1708,5570.6,0.2043,2.2559,
5660.6,0.2096,2.3579,5750.6,0.2148,2.4799,
13940.0,0.5882,4919.2093,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
14,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.076466E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5072,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5489,1,2,0.25,4,0.25    *rods.9
5,1,1.4956,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4843,1,3,0.125,5,0.25,6,0.125    *rods.9
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7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5227,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5113,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4833,1,7,0.25,11,0.25    *rods.9
12,1,1.4313,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4209,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4505,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3739,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.4012,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3533,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3418,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3666,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3126,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0019,1,16,0.25,22,0.25    *rods.9
23,1,1.2630,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2472,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1489,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.9973,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7881,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0350,1,22,0.25,29,0.25    *rods.9
30,1,0.9957,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9806,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9783,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8552,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5489,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2564,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0455,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5554,1,29,0.25,37,0.25    *rods.9
38,3,1.5374,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5168,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4793,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3555,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1508,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0326,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9705,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9500,1,36,0.125,38,0.375    *rods.9
46,4,1.11711,1,37,38.31439394    *rods.9
47,4,1.11711,1,38,38.45123106    *rods.9
48,4,1.11711,1,39,72.25    *rods.9
49,4,1.11711,1,40,144.5    *rods.9
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50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.5128,
620.6,0.0698,2.7055,710.6,0.0707,2.5599,
800.6,0.0715,2.4304,890.6,0.0722,2.3148,
980.6,0.0729,2.2112,1070.6,0.0735,2.1179,
1160.6,0.0740,2.0331,1250.6,0.0745,1.9554,
1340.6,0.0750,1.8837,1430.6,0.0754,1.8168,
1520.6,0.0758,1.7543,1610.6,0.0762,1.6957,
1700.6,0.0767,1.6406,1790.6,0.0771,1.5890,
1880.6,0.0775,1.5407,1970.6,0.0779,1.4957,
2060.6,0.0783,1.4538,2150.6,0.0788,1.4152,
2240.6,0.0793,1.3797,2330.6,0.0799,1.3474,
2420.6,0.0805,1.3182,2510.6,0.0813,1.2923,
2600.6,0.0821,1.2695,2690.6,0.0830,1.2500,
2780.6,0.0840,1.2337,2870.6,0.0851,1.2206,
2960.6,0.0864,1.2107,3050.6,0.0879,1.2040,
3140.6,0.0895,1.2006,3230.6,0.0914,1.2002,
3320.6,0.0934,1.2031,3410.6,0.0956,1.2089,
3500.6,0.0980,1.2178,3590.6,0.1006,1.2297,
3680.6,0.1035,1.2444,3770.6,0.1066,1.2618,
3860.6,0.1099,1.2820,3950.6,0.1134,1.3047,
4040.6,0.1172,1.3299,4130.6,0.1212,1.3575,
4220.6,0.1254,1.3873,4310.6,0.1299,1.4192,
4400.6,0.1346,1.4532,4490.6,0.1395,1.4890,
4580.6,0.1446,1.5266,4670.6,0.1499,1.5658,
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4760.6,0.1555,1.6066,4850.6,0.1612,1.6487,
4940.6,0.1671,1.6921,5030.6,0.1732,1.7367,
5120.6,0.1794,1.7823,5210.6,0.1858,1.8289,
5300.6,0.1924,1.8763,5390.6,0.1990,1.9244,
5480.6,0.2059,1.9731,5570.6,0.2128,2.0223,
5660.6,0.2199,2.0720,5750.6,0.2270,2.1220,
13940.,0.6954,4.3735,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,4.0400,
620.6,0.0925,2.9437,710.6,0.0937,2.7636,
800.6,0.0948,2.6096,890.6,0.0957,2.4776,
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980.6,0.0966,2.3638,1070.6,0.0974,2.2650,
1160.6,0.0981,2.1784,1250.6,0.0987,2.1015,
1340.6,0.0993,2.0325,1430.6,0.0999,1.9696,
1520.6,0.1004,1.9117,1610.6,0.1009,1.8580,
1700.6,0.1015,1.8078,1790.6,0.1020,1.7608,
1880.6,0.1025,1.7167,1970.6,0.1030,1.6754,
2060.6,0.1034,1.6368,2150.6,0.1040,1.6011,
2240.6,0.1045,1.5681,2330.6,0.1051,1.5381,
2420.6,0.1057,1.5111,2510.6,0.1065,1.4874,
2600.6,0.1072,1.4669,2690.6,0.1080,1.4499,
2780.6,0.1089,1.4365,2870.6,0.1098,1.4267,
2960.6,0.1109,1.4204,3050.6,0.1121,1.4177,
3140.6,0.1134,1.4187,3230.6,0.1148,1.4229,
3320.6,0.1164,1.4306,3410.6,0.1181,1.4413,
3500.6,0.1199,1.4550,3590.6,0.1219,1.4714,
3680.6,0.1241,1.4900,3770.6,0.1264,1.5108,
3860.6,0.1289,1.5334,3950.6,0.1314,1.5574,
4040.6,0.1343,1.5825,4130.6,0.1372,1.6086,
4220.6,0.1403,1.6354,4310.6,0.1436,1.6625,
4400.6,0.1471,1.6901,4490.6,0.1507,1.7179,
4580.6,0.1544,1.7460,4670.6,0.1583,1.7746,
4760.6,0.1624,1.8041,4850.6,0.1666,1.8348,
4940.6,0.1709,1.8675,5030.6,0.1754,1.9029,
5120.6,0.1799,1.9423,5210.6,0.1846,1.9869,
5300.6,0.1894,2.0384,5390.6,0.1942,2.0986,
5480.6,0.1993,2.1700,5570.6,0.2043,2.2550,
5660.6,0.2096,2.3570,5750.6,0.2148,2.4791,
13940.0,0.5882,4919.2092,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
15,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.982347E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
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1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5612,1,1,0.25,2,0.25    *rods.9
3,1,1.5070,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5490,1,2,0.25,4,0.25    *rods.9
5,1,1.4956,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4845,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5232,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5120,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4841,1,7,0.25,11,0.25    *rods.9
12,1,1.4320,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4218,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4521,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3757,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.4027,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3546,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3433,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3688,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3154,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0017,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0019,1,16,0.25,22,0.25    *rods.9
23,1,1.2653,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2496,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1521,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0006,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7911,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0377,1,22,0.25,29,0.25    *rods.9
30,1,0.9982,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9832,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9814,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8581,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5517,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2604,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0503,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5579,1,29,0.25,37,0.25    *rods.9
38,3,1.5398,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5195,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4825,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3592,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1554,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0376,1,34,0.25,35,0.25,38,0.5    *rods.9
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44,3,0.9756,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9552,1,36,0.125,38,0.375    *rods.9
46,4,1.11911,1,37,38.31439394    *rods.9
47,4,1.11911,1,38,38.45123106    *rods.9
48,4,1.11911,1,39,72.25    *rods.9
49,4,1.11911,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0       *rods.66
* 0.0026          *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.4277,
620.6,0.0698,2.6550,710.6,0.0707,2.5150,
800.6,0.0715,2.3904,890.6,0.0722,2.2792,
980.6,0.0729,2.1796,1070.6,0.0735,2.0899,
1160.6,0.0740,2.0084,1250.6,0.0745,1.9338,
1340.6,0.0750,1.8647,1430.6,0.0754,1.8002,
1520.6,0.0758,1.7396,1610.6,0.0762,1.6827,
1700.6,0.0767,1.6291,1790.6,0.0771,1.5786,
1880.6,0.0775,1.5314,1970.6,0.0779,1.4872,
2060.6,0.0783,1.4461,2150.6,0.0788,1.4081,
2240.6,0.0793,1.3731,2330.6,0.0799,1.3413,
2420.6,0.0805,1.3126,2510.6,0.0813,1.2870,
2600.6,0.0821,1.2646,2690.6,0.0830,1.2453,
2780.6,0.0840,1.2293,2870.6,0.0851,1.2164,
2960.6,0.0864,1.2068,3050.6,0.0879,1.2003,
3140.6,0.0895,1.1970,3230.6,0.0914,1.1969,
3320.6,0.0934,1.1998,3410.6,0.0956,1.2059,
3500.6,0.0980,1.2149,3590.6,0.1006,1.2269,
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3680.6,0.1035,1.2417,3770.6,0.1066,1.2593,
3860.6,0.1099,1.2795,3950.6,0.1134,1.3023,
4040.6,0.1172,1.3276,4130.6,0.1212,1.3553,
4220.6,0.1254,1.3852,4310.6,0.1299,1.4172,
4400.6,0.1346,1.4512,4490.6,0.1395,1.4871,
4580.6,0.1446,1.5248,4670.6,0.1499,1.5641,
4760.6,0.1555,1.6049,4850.6,0.1612,1.6471,
4940.6,0.1671,1.6905,5030.6,0.1732,1.7352,
5120.6,0.1794,1.7808,5210.6,0.1858,1.8274,
5300.6,0.1924,1.8749,5390.6,0.1990,1.9230,
5480.6,0.2059,1.9718,5570.6,0.2128,2.0210,
5660.6,0.2199,2.0707,5750.6,0.2270,2.1208,
13940.,0.6954,4.3732,
2,61,359.929,IMF *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,

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5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.9820,
620.6,0.0925,2.9092,710.6,0.0937,2.7330,
800.6,0.0948,2.5823,890.6,0.0957,2.4533,
980.6,0.0966,2.3422,1070.6,0.0974,2.2459,
1160.6,0.0981,2.1616,1250.6,0.0987,2.0868,
1340.6,0.0993,2.0196,1430.6,0.0999,1.9583,
1520.6,0.1004,1.9017,1610.6,0.1009,1.8491,
1700.6,0.1015,1.8000,1790.6,0.1020,1.7537,
1880.6,0.1025,1.7104,1970.6,0.1030,1.6696,
2060.6,0.1034,1.6316,2150.6,0.1040,1.5962,
2240.6,0.1045,1.5636,2330.6,0.1051,1.5339,
2420.6,0.1057,1.5073,2510.6,0.1065,1.4838,
2600.6,0.1072,1.4636,2690.6,0.1080,1.4467,
2780.6,0.1089,1.4335,2870.6,0.1098,1.4238,
2960.6,0.1109,1.4177,3050.6,0.1121,1.4152,
3140.6,0.1134,1.4162,3230.6,0.1148,1.4207,
3320.6,0.1164,1.4284,3410.6,0.1181,1.4393,
3500.6,0.1199,1.4530,3590.6,0.1219,1.4694,
3680.6,0.1241,1.4882,3770.6,0.1264,1.5091,
3860.6,0.1289,1.5317,3950.6,0.1314,1.5557,
4040.6,0.1343,1.5810,4130.6,0.1372,1.6071,
4220.6,0.1403,1.6340,4310.6,0.1436,1.6612,
4400.6,0.1471,1.6887,4490.6,0.1507,1.7166,
4580.6,0.1544,1.7448,4670.6,0.1583,1.7735,
4760.6,0.1624,1.8029,4850.6,0.1666,1.8337,
4940.6,0.1709,1.8664,5030.6,0.1754,1.9019,
5120.6,0.1799,1.9413,5210.6,0.1846,1.9859,
5300.6,0.1894,2.0374,5390.6,0.1942,2.0977,
5480.6,0.1993,2.1691,5570.6,0.2043,2.2542,
5660.6,0.2096,2.3561,5750.6,0.2148,2.4783,
13940.0,0.5882,4919.2090,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
16,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 5.888227E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
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*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5611,1,1,0.25,2,0.25    *rods.9
3,1,1.5067,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5492,1,2,0.25,4,0.25    *rods.9
5,1,1.4955,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4845,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5237,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5127,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4850,1,7,0.25,11,0.25    *rods.9
12,1,1.4327,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4227,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4537,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3776,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.4042,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3559,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3448,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3710,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3180,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0018,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0019,1,16,0.25,22,0.25    *rods.9
23,1,1.2675,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2520,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1552,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0039,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7940,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0404,1,22,0.25,29,0.25    *rods.9
30,1,1.0006,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9857,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9844,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8609,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5551,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2648,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0554,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5610,1,29,0.25,37,0.25    *rods.9
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38,3,1.5429,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5227,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4861,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3633,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1603,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0428,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9810,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9607,1,36,0.125,38,0.375    *rods.9
46,4,1.12121,1,37,38.31439394    *rods.9
47,4,1.12121,1,38,38.45123106    *rods.9
48,4,1.12121,1,39,72.25    *rods.9
49,4,1.12121,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*        Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002        *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026        *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.3467,
620.6,0.0698,2.6064,710.6,0.0707,2.4716,
800.6,0.0715,2.3516,890.6,0.0722,2.2446,
980.6,0.0729,2.1488,1070.6,0.0735,2.0626,
1160.6,0.0740,1.9844,1250.6,0.0745,1.9126,
1340.6,0.0750,1.8461,1430.6,0.0754,1.7838,
1520.6,0.0758,1.7252,1610.6,0.0762,1.6699,
1700.6,0.0767,1.6177,1790.6,0.0771,1.5684,
1880.6,0.0775,1.5221,1970.6,0.0779,1.4788,
2060.6,0.0783,1.4384,2150.6,0.0788,1.4010,
2240.6,0.0793,1.3666,2330.6,0.0799,1.3352,
2420.6,0.0805,1.3069,2510.6,0.0813,1.2817,
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2600.6,0.0821,1.2596,2690.6,0.0830,1.2407,
2780.6,0.0840,1.2249,2870.6,0.0851,1.2123,
2960.6,0.0864,1.2029,3050.6,0.0879,1.1966,
3140.6,0.0895,1.1935,3230.6,0.0914,1.1935,
3320.6,0.0934,1.1967,3410.6,0.0956,1.2028,
3500.6,0.0980,1.2120,3590.6,0.1006,1.2241,
3680.6,0.1035,1.2390,3770.6,0.1066,1.2567,
3860.6,0.1099,1.2771,3950.6,0.1134,1.3000,
4040.6,0.1172,1.3254,4130.6,0.1212,1.3531,
4220.6,0.1254,1.3831,4310.6,0.1299,1.4152,
4400.6,0.1346,1.4493,4490.6,0.1395,1.4852,
4580.6,0.1446,1.5229,4670.6,0.1499,1.5623,
4760.6,0.1555,1.6032,4850.6,0.1612,1.6454,
4940.6,0.1671,1.6889,5030.6,0.1732,1.7336,
5120.6,0.1794,1.7793,5210.6,0.1858,1.8260,
5300.6,0.1924,1.8734,5390.6,0.1990,1.9216,
5480.6,0.2059,1.9704,5570.6,0.2128,2.0197,
5660.6,0.2199,2.0695,5750.6,0.2270,2.1195,
13940.,0.6954,4.3730,
2,61,359.929,IMF   *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,

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4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.9267,
620.6,0.0925,2.8761,710.6,0.0937,2.7034,
800.6,0.0948,2.5559,890.6,0.0957,2.4297,
980.6,0.0966,2.3212,1070.6,0.0974,2.2273,
1160.6,0.0981,2.1452,1250.6,0.0987,2.0724,
1340.6,0.0993,2.0069,1430.6,0.0999,1.9471,
1520.6,0.1004,1.8919,1610.6,0.1009,1.8404,
1700.6,0.1015,1.7922,1790.6,0.1020,1.7468,
1880.6,0.1025,1.7040,1970.6,0.1030,1.6639,
2060.6,0.1034,1.6264,2150.6,0.1040,1.5914,
2240.6,0.1045,1.5592,2330.6,0.1051,1.5298,
2420.6,0.1057,1.5034,2510.6,0.1065,1.4802,
2600.6,0.1072,1.4602,2690.6,0.1080,1.4436,
2780.6,0.1089,1.4305,2870.6,0.1098,1.4210,
2960.6,0.1109,1.4151,3050.6,0.1121,1.4126,
3140.6,0.1134,1.4138,3230.6,0.1148,1.4184,
3320.6,0.1164,1.4263,3410.6,0.1181,1.4372,
3500.6,0.1199,1.4511,3590.6,0.1219,1.4675,
3680.6,0.1241,1.4864,3770.6,0.1264,1.5073,
3860.6,0.1289,1.5300,3950.6,0.1314,1.5542,
4040.6,0.1343,1.5795,4130.6,0.1372,1.6056,
4220.6,0.1403,1.6325,4310.6,0.1436,1.6598,
4400.6,0.1471,1.6874,4490.6,0.1507,1.7153,
4580.6,0.1544,1.7435,4670.6,0.1583,1.7722,
4760.6,0.1624,1.8018,4850.6,0.1666,1.8326,
4940.6,0.1709,1.8653,5030.6,0.1754,1.9008,
5120.6,0.1799,1.9402,5210.6,0.1846,1.9849,
5300.6,0.1894,2.0364,5390.6,0.1942,2.0967,
5480.6,0.1993,2.1681,5570.6,0.2043,2.2533,
5660.6,0.2096,2.3553,5750.6,0.2148,2.4774,
13940.0,0.5882,4919.2089,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
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17,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 6.794108E+03
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*            Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*            Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5578,1,1,0.25,2,0.25    *rods.9
3,1,1.5033,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5461,1,2,0.25,4,0.25    *rods.9
5,1,1.4923,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4816,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5209,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5102,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4827,1,7,0.25,11,0.25    *rods.9
12,1,1.4303,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4205,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4521,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3766,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.4026,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3543,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3434,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3702,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3179,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0018,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0019,1,16,0.25,22,0.25    *rods.9
23,1,1.2670,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2517,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1559,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0049,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7953,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0408,1,22,0.25,29,0.25    *rods.9
30,1,1.0009,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9861,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
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32,1,0.9852,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8619,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5557,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2669,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0585,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5612,1,29,0.25,37,0.25    *rods.9
38,3,1.5431,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5231,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4870,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3648,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1629,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0460,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9845,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9643,1,36,0.125,38,0.375    *rods.9
46,4,1.12101,1,37,38.31439394    *rods.9
47,4,1.12101,1,38,38.45123106    *rods.9
48,4,1.12101,1,39,72.25    *rods.9
49,4,1.12101,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*         Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002        *rods.65
* 0.05 0 0 0 0       *rods.66
* 0.0026          *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,3.2695,
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1160.6,0.0740,1.9609,1250.6,0.0745,1.8919,
1340.6,0.0750,1.8279,1430.6,0.0754,1.7678,
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1520.6,0.0758,1.7110,1610.6,0.0762,1.6573,
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2240.6,0.0793,1.3602,2330.6,0.0799,1.3293,
2420.6,0.0805,1.3014,2510.6,0.0813,1.2765,
2600.6,0.0821,1.2548,2690.6,0.0830,1.2361,
2780.6,0.0840,1.2206,2870.6,0.0851,1.2082,
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3140.6,0.0895,1.1900,3230.6,0.0914,1.1902,
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3500.6,0.0980,1.2091,3590.6,0.1006,1.2213,
3680.6,0.1035,1.2364,3770.6,0.1066,1.2542,
3860.6,0.1099,1.2746,3950.6,0.1134,1.2976,
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endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
18,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.087057E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5397,1,1,0.25,2,0.25    *rods.9
3,1,1.4850,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5288,1,2,0.25,4,0.25    *rods.9
5,1,1.4748,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4650,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5054,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.4956,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4691,1,7,0.25,11,0.25    *rods.9
12,1,1.4165,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4078,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4417,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3684,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3924,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3437,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3338,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3632,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3135,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0018,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0019,1,16,0.25,22,0.25    *rods.9
23,1,1.2613,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2470,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
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26,1,1.1552,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0065,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7982,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0395,1,22,0.25,29,0.25    *rods.9
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31,1,0.9851,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9861,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
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34,3,1.5575,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2747,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0706,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5612,1,29,0.25,37,0.25    *rods.9
38,3,1.5432,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5242,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4901,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3706,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1733,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0585,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.9981,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9786,1,36,0.125,38,0.375    *rods.9
46,4,1.11781,1,37,38.31439394    *rods.9
47,4,1.11781,1,38,38.45123106    *rods.9
48,4,1.11781,1,39,72.25    *rods.9
49,4,1.11781,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
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5120.6,0.1799,1.9347,5210.6,0.1846,1.9795,
5300.6,0.1894,2.0312,5390.6,0.1942,2.0917,
5480.6,0.1993,2.1632,5570.6,0.2043,2.2485,
5660.6,0.2096,2.3506,5750.6,0.2148,2.4729,
13940.0,0.5882,4919.2080,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
19,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.494704E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5202,1,1,0.25,2,0.25    *rods.9
3,1,1.4656,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5101,1,2,0.25,4,0.25    *rods.9
5,1,1.4562,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4471,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.4883,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.4793,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0021,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4537,1,7,0.25,11,0.25    *rods.9
12,1,1.4011,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.3932,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.4289,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3577,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3799,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3312,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3222,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3535,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
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20,1,1.3063,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0018,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0019,1,16,0.25,22,0.25    *rods.9
23,1,1.2530,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2395,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1514,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0052,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7987,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0355,1,22,0.25,29,0.25    *rods.9
30,1,0.9950,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9816,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9842,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8630,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5590,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2813,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0806,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5611,1,29,0.25,37,0.25    *rods.9
38,3,1.5433,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5251,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4926,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3755,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1818,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0689,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,1.0094,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.9905,1,36,0.125,38,0.375    *rods.9
46,4,1.11301,1,37,38.31439394    *rods.9
47,4,1.11301,1,38,38.45123106    *rods.9
48,4,1.11301,1,39,72.25    *rods.9
49,4,1.11301,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
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0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,2.7193,
620.6,0.0698,2.2113,710.6,0.0707,2.1156,
800.6,0.0715,2.0304,890.6,0.0722,1.9550,
980.6,0.0729,1.8883,1070.6,0.0735,1.8292,
1160.6,0.0740,1.7761,1250.6,0.0745,1.7273,
1340.6,0.0750,1.6815,1430.6,0.0754,1.6376,
1520.6,0.0758,1.5950,1610.6,0.0762,1.5536,
1700.6,0.0767,1.5132,1790.6,0.0771,1.4741,
1880.6,0.0775,1.4364,1970.6,0.0779,1.4005,
2060.6,0.0783,1.3666,2150.6,0.0788,1.3347,
2240.6,0.0793,1.3052,2330.6,0.0799,1.2781,
2420.6,0.0805,1.2536,2510.6,0.0813,1.2318,
2600.6,0.0821,1.2127,2690.6,0.0830,1.1965,
2780.6,0.0840,1.1831,2870.6,0.0851,1.1728,
2960.6,0.0864,1.1654,3050.6,0.0879,1.1610,
3140.6,0.0895,1.1596,3230.6,0.0914,1.1613,
3320.6,0.0934,1.1659,3410.6,0.0956,1.1734,
3500.6,0.0980,1.1839,3590.6,0.1006,1.1971,
3680.6,0.1035,1.2132,3770.6,0.1066,1.2319,
3860.6,0.1099,1.2532,3950.6,0.1134,1.2771,
4040.6,0.1172,1.3033,4130.6,0.1212,1.3319,
4220.6,0.1254,1.3626,4310.6,0.1299,1.3954,
4400.6,0.1346,1.4302,4490.6,0.1395,1.4668,
4580.6,0.1446,1.5052,4670.6,0.1499,1.5451,
4760.6,0.1555,1.5865,4850.6,0.1612,1.6293,
4940.6,0.1671,1.6733,5030.6,0.1732,1.7185,
5120.6,0.1794,1.7647,5210.6,0.1858,1.8118,
5300.6,0.1924,1.8596,5390.6,0.1990,1.9082,
5480.6,0.2059,1.9574,5570.6,0.2128,2.0071,
5660.6,0.2199,2.0572,5750.6,0.2270,2.1076,
13940.,0.6954,4.3706,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
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1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.4990,
620.6,0.0925,2.6067,710.6,0.0937,2.4606,
800.6,0.0948,2.3369,890.6,0.0957,2.2323,
980.6,0.0966,2.1436,1070.6,0.0974,2.0682,
1160.6,0.0981,2.0032,1250.6,0.0987,1.9460,
1340.6,0.0993,1.8946,1430.6,0.0999,1.8474,
1520.6,0.1004,1.8031,1610.6,0.1009,1.7611,
1700.6,0.1015,1.7209,1790.6,0.1020,1.6825,
1880.6,0.1025,1.6456,1970.6,0.1030,1.6105,
2060.6,0.1034,1.5774,2150.6,0.1040,1.5462,
2240.6,0.1045,1.5173,2330.6,0.1051,1.4908,
2420.6,0.1057,1.4670,2510.6,0.1065,1.4461,
2600.6,0.1072,1.4282,2690.6,0.1080,1.4135,
2780.6,0.1089,1.4020,2870.6,0.1098,1.3941,
2960.6,0.1109,1.3895,3050.6,0.1121,1.3884,
3140.6,0.1134,1.3907,3230.6,0.1148,1.3964,
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3320.6,0.1164,1.4053,3410.6,0.1181,1.4171,
3500.6,0.1199,1.4319,3590.6,0.1219,1.4491,
3680.6,0.1241,1.4688,3770.6,0.1264,1.4904,
3860.6,0.1289,1.5137,3950.6,0.1314,1.5385,
4040.6,0.1343,1.5644,4130.6,0.1372,1.5912,
4220.6,0.1403,1.6185,4310.6,0.1436,1.6463,
4400.6,0.1471,1.6744,4490.6,0.1507,1.7027,
4580.6,0.1544,1.7314,4670.6,0.1583,1.7605,
4760.6,0.1624,1.7904,4850.6,0.1666,1.8216,
4940.6,0.1709,1.8547,5030.6,0.1754,1.8905,
5120.6,0.1799,1.9303,5210.6,0.1846,1.9752,
5300.6,0.1894,2.0270,5390.6,0.1942,2.0876,
5480.6,0.1993,2.1593,5570.6,0.2043,2.2447,
5660.6,0.2096,2.3469,5750.6,0.2148,2.4693,
13940.0,0.5882,4919.2072,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
20,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.902350E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0022,1,1,0.125    *rods.9
2,1,1.5009,1,1,0.25,2,0.25    *rods.9
3,1,1.4466,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.4915,1,2,0.25,4,0.25    *rods.9
5,1,1.4379,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4294,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0022,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.4711,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.4629,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0022,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.4380,1,7,0.25,11,0.25    *rods.9
12,1,1.3856,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.3784,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
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14,1,1.4156,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.3463,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.3669,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.3182,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.3100,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.3429,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.2977,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0018,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0019,1,16,0.25,22,0.25    *rods.9
23,1,1.2437,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2309,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0018,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.1461,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0023,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.7977,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0303,1,22,0.25,29,0.25    *rods.9
30,1,0.9897,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.9769,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.9808,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.8609,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.5605,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.2871,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,1.0891,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.5612,1,29,0.25,37,0.25    *rods.9
38,3,1.5435,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.5260,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.4948,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.3797,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.1892,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,1.0777,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,1.0190,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,1.0005,1,36,0.125,38,0.375    *rods.9
46,4,1.10761,1,37,38.31439394    *rods.9
47,4,1.10761,1,38,38.45123106    *rods.9
48,4,1.10761,1,39,72.25    *rods.9
49,4,1.10761,1,40,144.5    *rods.9
50,4,1.382,1,41,144.5    *rods.9
51,4,1.261,1,42,289    *rods.9
52,4,1.226,1,43,144.5    *rods.9
53,4,0.941,1,44,2023    *rods.9
54,4,0.942,1,45,4046    *rods.9
0    *rods.9
*          Fuel Geometry Types
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*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,2.5185,
620.6,0.0698,2.0773,710.6,0.0707,1.9934,
800.6,0.0715,1.9188,890.6,0.0722,1.8531,
980.6,0.0729,1.7955,1070.6,0.0735,1.7449,
1160.6,0.0740,1.6997,1250.6,0.0745,1.6583,
1340.6,0.0750,1.6193,1430.6,0.0754,1.5816,
1520.6,0.0758,1.5445,1610.6,0.0762,1.5079,
1700.6,0.0767,1.4717,1790.6,0.0771,1.4362,
1880.6,0.0775,1.4018,1970.6,0.0779,1.3687,
2060.6,0.0783,1.3371,2150.6,0.0788,1.3074,
2240.6,0.0793,1.2798,2330.6,0.0799,1.2543,
2420.6,0.0805,1.2313,2510.6,0.0813,1.2108,
2600.6,0.0821,1.1929,2690.6,0.0830,1.1778,
2780.6,0.0840,1.1655,2870.6,0.0851,1.1560,
2960.6,0.0864,1.1495,3050.6,0.0879,1.1459,
3140.6,0.0895,1.1452,3230.6,0.0914,1.1475,
3320.6,0.0934,1.1527,3410.6,0.0956,1.1608,
3500.6,0.0980,1.1718,3590.6,0.1006,1.1856,
3680.6,0.1035,1.2021,3770.6,0.1066,1.2212,
3860.6,0.1099,1.2430,3950.6,0.1134,1.2672,
4040.6,0.1172,1.2938,4130.6,0.1212,1.3227,
4220.6,0.1254,1.3538,4310.6,0.1299,1.3869,
4400.6,0.1346,1.4220,4490.6,0.1395,1.4589,
4580.6,0.1446,1.4975,4670.6,0.1499,1.5377,
4760.6,0.1555,1.5793,4850.6,0.1612,1.6223,
4940.6,0.1671,1.6666,5030.6,0.1732,1.7119,
5120.6,0.1794,1.7583,5210.6,0.1858,1.8056,
5300.6,0.1924,1.8536,5390.6,0.1990,1.9024,
5480.6,0.2059,1.9517,5570.6,0.2128,2.0015,
5660.6,0.2199,2.0518,5750.6,0.2270,2.1023,
13940.,0.6954,4.3696,
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2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.3621,
620.6,0.0925,2.5153,710.6,0.0937,2.3773,
800.6,0.0948,2.2608,890.6,0.0957,2.1628,
980.6,0.0966,2.0803,1070.6,0.0974,2.0107,
1160.6,0.0981,1.9511,1250.6,0.0987,1.8990,
1340.6,0.0993,1.8522,1430.6,0.0999,1.8092,
1520.6,0.1004,1.7687,1610.6,0.1009,1.7300,
1700.6,0.1015,1.6926,1790.6,0.1020,1.6566,
1880.6,0.1025,1.6220,1970.6,0.1030,1.5888,
2060.6,0.1034,1.5573,2150.6,0.1040,1.5276,
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2240.6,0.1045,1.5000,2330.6,0.1051,1.4746,
2420.6,0.1057,1.4518,2510.6,0.1065,1.4318,
2600.6,0.1072,1.4147,2690.6,0.1080,1.4007,
2780.6,0.1089,1.3900,2870.6,0.1098,1.3826,
2960.6,0.1109,1.3787,3050.6,0.1121,1.3781,
3140.6,0.1134,1.3809,3230.6,0.1148,1.3870,
3320.6,0.1164,1.3963,3410.6,0.1181,1.4085,
3500.6,0.1199,1.4236,3590.6,0.1219,1.4413,
3680.6,0.1241,1.4612,3770.6,0.1264,1.4831,
3860.6,0.1289,1.5068,3950.6,0.1314,1.5318,
4040.6,0.1343,1.5579,4130.6,0.1372,1.5849,
4220.6,0.1403,1.6125,4310.6,0.1436,1.6405,
4400.6,0.1471,1.6688,4490.6,0.1507,1.6973,
4580.6,0.1544,1.7262,4670.6,0.1583,1.7555,
4760.6,0.1624,1.7855,4850.6,0.1666,1.8168,
4940.6,0.1709,1.8501,5030.6,0.1754,1.8860,
5120.6,0.1799,1.9259,5210.6,0.1846,1.9710,
5300.6,0.1894,2.0229,5390.6,0.1942,2.0836,
5480.6,0.1993,2.1554,5570.6,0.2043,2.2409,
5660.6,0.2096,2.3432,5750.6,0.2148,2.4657,
13940.0,0.5882,4919.2065,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
21,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.309997E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0019,1,1,0.125    *rods.9
2,1,1.2427,1,1,0.25,2,0.25    *rods.9
3,1,1.1975,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2353,1,2,0.25,4,0.25    *rods.9
5,1,1.1906,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.1840,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0018,1,4,0.25,7,0.25,0,0    *rods.9
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8,1,1.2192,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.2129,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0018,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.1926,1,7,0.25,11,0.25    *rods.9
12,1,1.1489,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.1434,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.1754,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.1188,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.1349,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0943,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0879,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.1166,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0803,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0015,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0016,1,16,0.25,22,0.25    *rods.9
23,1,1.0344,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0243,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0015,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.9556,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.8370,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.6672,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.8588,1,22,0.25,29,0.25    *rods.9
30,1,0.8248,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.8144,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.8187,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.7192,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.3095,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.0832,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.9193,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.3089,1,29,0.25,37,0.25    *rods.9
38,3,1.2942,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.2800,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.2549,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.1598,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.0023,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.9099,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.8612,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.8460,1,36,0.125,38,0.375    *rods.9
46,4,0.92381,1,37,38.31439394    *rods.9
47,4,0.92381,1,38,38.45123106    *rods.9
48,4,0.92381,1,39,72.25    *rods.9
49,4,0.92381,1,40,144.5    *rods.9
50,4,1.230,1,41,144.5    *rods.9
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51,4,1.120,1,42,289    *rods.9
52,4,1.080,1,43,144.5    *rods.9
53,4,0.990,1,44,2023    *rods.9
54,4,0.960,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,2.3522,
620.6,0.0698,1.9634,710.6,0.0707,1.8888,
800.6,0.0715,1.8228,890.6,0.0722,1.7649,
980.6,0.0729,1.7146,1070.6,0.0735,1.6708,
1160.6,0.0740,1.6321,1250.6,0.0745,1.5968,
1340.6,0.0750,1.5634,1430.6,0.0754,1.5308,
1520.6,0.0758,1.4983,1610.6,0.0762,1.4658,
1700.6,0.0767,1.4333,1790.6,0.0771,1.4010,
1880.6,0.0775,1.3694,1970.6,0.0779,1.3387,
2060.6,0.0783,1.3093,2150.6,0.0788,1.2815,
2240.6,0.0793,1.2556,2330.6,0.0799,1.2317,
2420.6,0.0805,1.2100,2510.6,0.0813,1.1908,
2600.6,0.0821,1.1740,2690.6,0.0830,1.1599,
2780.6,0.0840,1.1485,2870.6,0.0851,1.1399,
2960.6,0.0864,1.1341,3050.6,0.0879,1.1312,
3140.6,0.0895,1.1312,3230.6,0.0914,1.1342,
3320.6,0.0934,1.1399,3410.6,0.0956,1.1486,
3500.6,0.0980,1.1601,3590.6,0.1006,1.1743,
3680.6,0.1035,1.1913,3770.6,0.1066,1.2109,
3860.6,0.1099,1.2330,3950.6,0.1134,1.2576,
4040.6,0.1172,1.2846,4130.6,0.1212,1.3138,
4220.6,0.1254,1.3452,4310.6,0.1299,1.3786,
4400.6,0.1346,1.4139,4490.6,0.1395,1.4511,
4580.6,0.1446,1.4899,4670.6,0.1499,1.5304,
4760.6,0.1555,1.5722,4850.6,0.1612,1.6155,
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4940.6,0.1671,1.6599,5030.6,0.1732,1.7055,
5120.6,0.1794,1.7520,5210.6,0.1858,1.7995,
5300.6,0.1924,1.8477,5390.6,0.1990,1.8966,
5480.6,0.2059,1.9461,5570.6,0.2128,1.9961,
5660.6,0.2199,2.0465,5750.6,0.2270,2.0972,
13940.,0.6954,4.3685,
2,61,359.929,IMF   *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX   *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.2487,
620.6,0.0925,2.4377,710.6,0.0937,2.3060,
800.6,0.0948,2.1953,890.6,0.0957,2.1026,
980.6,0.0966,2.0252,1070.6,0.0974,1.9602,

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1160.6,0.0981,1.9050,1250.6,0.0987,1.8570,
1340.6,0.0993,1.8141,1430.6,0.0999,1.7746,
1520.6,0.1004,1.7372,1610.6,0.1009,1.7013,
1700.6,0.1015,1.6665,1790.6,0.1020,1.6326,
1880.6,0.1025,1.5999,1970.6,0.1030,1.5684,
2060.6,0.1034,1.5383,2150.6,0.1040,1.5099,
2240.6,0.1045,1.4835,2330.6,0.1051,1.4592,
2420.6,0.1057,1.4373,2510.6,0.1065,1.4182,
2600.6,0.1072,1.4018,2690.6,0.1080,1.3885,
2780.6,0.1089,1.3784,2870.6,0.1098,1.3716,
2960.6,0.1109,1.3682,3050.6,0.1121,1.3681,
3140.6,0.1134,1.3713,3230.6,0.1148,1.3779,
3320.6,0.1164,1.3875,3410.6,0.1181,1.4002,
3500.6,0.1199,1.4157,3590.6,0.1219,1.4336,
3680.6,0.1241,1.4538,3770.6,0.1264,1.4761,
3860.6,0.1289,1.5000,3950.6,0.1314,1.5253,
4040.6,0.1343,1.5517,4130.6,0.1372,1.5788,
4220.6,0.1403,1.6067,4310.6,0.1436,1.6349,
4400.6,0.1471,1.6633,4490.6,0.1507,1.6920,
4580.6,0.1544,1.7210,4670.6,0.1583,1.7505,
4760.6,0.1624,1.7806,4850.6,0.1666,1.8122,
4940.6,0.1709,1.8455,5030.6,0.1754,1.8817,
5120.6,0.1799,1.9216,5210.6,0.1846,1.9669,
5300.6,0.1894,2.0189,5390.6,0.1942,2.0797,
5480.6,0.1993,2.1515,5570.6,0.2043,2.2372,
5660.6,0.2096,2.3396,5750.6,0.2148,2.4622,
13940.0,0.5882,4919.2058,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
22,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.717644E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0019,1,1,0.125    *rods.9
```

2,1,1.2266,1,1,0.25,2,0.25   *rods.9
3,1,1.1818,1,1,0.125,2,0.25,3,0.125   *rods.9
4,1,1.2198,1,2,0.25,4,0.25   *rods.9
5,1,1.1754,1,2,0.25,3,0.25,4,0.25,5,0.25   *rods.9
6,1,1.1693,1,3,0.125,5,0.25,6,0.125   *rods.9
7,2,0.0018,1,4,0.25,7,0.25,0,0   *rods.9
8,1,1.2045,1,4,0.25,5,0.25,7,0.25,8,0.25   *rods.9
9,1,1.1987,1,5,0.25,6,0.25,8,0.25,9,0.25   *rods.9
10,2,0.0018,1,6,0.125,9,0.25,10,0.125   *rods.9
11,1,1.1789,1,7,0.25,11,0.25   *rods.9
12,1,1.1356,1,7,0.25,8,0.25,11,0.25,12,0.25   *rods.9
13,1,1.1306,1,8,0.25,9,0.25,12,0.25,13,0.25   *rods.9
14,1,1.1633,1,9,0.25,10,0.25,13,0.25,14,0.25   *rods.9
15,1,1.1081,1,10,0.125,14,0.25,15,0.125   *rods.9
16,1,1.1231,1,11,0.25,16,0.25,0,0   *rods.9
17,1,1.0827,1,11,0.25,12,0.25,16,0.25,17,0.25   *rods.9
18,1,1.0768,1,12,0.25,13,0.25,17,0.25,18,0.25   *rods.9
19,1,1.1063,1,13,0.25,14,0.25,18,0.25,19,0.25   *rods.9
20,1,1.0714,1,14,0.25,15,0.25,19,0.25,20,0.25   *rods.9
21,2,0.0015,1,15,0.125,20,0.25,21,0.125   *rods.9
22,2,0.0016,1,16,0.25,22,0.25   *rods.9
23,1,1.0252,1,16,0.25,17,0.25,22,0.25,23,0.25   *rods.9
24,1,1.0156,1,17,0.25,18,0.25,23,0.25,24,0.25   *rods.9
25,2,0.0015,1,18,0.25,19,0.25,24,0.25,25,0.25   *rods.9
26,1,0.9492,1,19,0.25,20,0.25,25,0.25,26,0.25   *rods.9
27,1,0.8325,1,20,0.25,21,0.25,26,0.25,27,0.25   *rods.9
28,1,0.6646,1,21,0.125,27,0.25,28,0.125   *rods.9
29,1,0.8528,1,22,0.25,29,0.25   *rods.9
30,1,0.8188,1,22,0.25,23,0.25,29,0.25,30,0.25   *rods.9
31,1,0.8089,1,23,0.25,24,0.25,30,0.25,31,0.25   *rods.9
32,1,0.8139,1,24,0.25,25,0.25,31,0.25,32,0.25   *rods.9
33,1,0.7157,1,25,0.25,26,0.25,32,0.25,33,0.25   *rods.9
34,3,1.3096,1,26,0.25,27,0.25,33,0.25,34,0.25   *rods.9
35,3,1.0860,1,27,0.25,28,0.25,34,0.25,35,0.25   *rods.9
36,3,0.9239,1,28,0.125,35,0.25,36,0.125   *rods.9
37,3,1.3080,1,29,0.25,37,0.25   *rods.9
38,3,1.2934,1,29,0.25,30,0.25,37,0.5   *rods.9
39,3,1.2797,1,30,0.25,31,0.25,37,0.5   *rods.9
40,3,1.2554,1,31,0.25,32,0.25,37,0.5   *rods.9
41,3,1.1616,1,32,0.25,33,0.25,37,0.25,38,0.25   *rods.9
42,3,1.0061,1,33,0.25,34,0.25,38,0.5   *rods.9
43,3,0.9147,1,34,0.25,35,0.25,38,0.5   *rods.9
44,3,0.8665,1,35,0.25,36,0.25,38,0.5   *rods.9

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45,3,0.8516,1,36,0.125,38,0.375    *rods.9
46,4,0.91821,1,37,38.31439394    *rods.9
47,4,0.91821,1,38,38.45123106    *rods.9
48,4,0.91821,1,39,72.25    *rods.9
49,4,0.91821,1,40,144.5    *rods.9
50,4,1.230,1,41,144.5    *rods.9
51,4,1.120,1,42,289    *rods.9
52,4,1.080,1,43,144.5    *rods.9
53,4,0.990,1,44,2023    *rods.9
54,4,0.960,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0       *rods.66
* 0.0026          *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,2.2125,
620.6,0.0698,1.8655,710.6,0.0707,1.7986,
800.6,0.0715,1.7395,890.6,0.0722,1.6879,
980.6,0.0729,1.6435,1070.6,0.0735,1.6053,
1160.6,0.0740,1.5719,1250.6,0.0745,1.5416,
1340.6,0.0750,1.5129,1430.6,0.0754,1.4846,
1520.6,0.0758,1.4560,1610.6,0.0762,1.4270,
1700.6,0.0767,1.3976,1790.6,0.0771,1.3682,
1880.6,0.0775,1.3390,1970.6,0.0779,1.3105,
2060.6,0.0783,1.2831,2150.6,0.0788,1.2570,
2240.6,0.0793,1.2326,2330.6,0.0799,1.2101,
2420.6,0.0805,1.1897,2510.6,0.0813,1.1715,
2600.6,0.0821,1.1558,2690.6,0.0830,1.1427,
2780.6,0.0840,1.1321,2870.6,0.0851,1.1243,
2960.6,0.0864,1.1193,3050.6,0.0879,1.1171,
3140.6,0.0895,1.1177,3230.6,0.0914,1.1212,
3320.6,0.0934,1.1276,3410.6,0.0956,1.1367,
3500.6,0.0980,1.1487,3590.6,0.1006,1.1634,
3680.6,0.1035,1.1808,3770.6,0.1066,1.2008,
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3860.6,0.1099,1.2233,3950.6,0.1134,1.2482,
4040.6,0.1172,1.2755,4130.6,0.1212,1.3051,
4220.6,0.1254,1.3367,4310.6,0.1299,1.3704,
4400.6,0.1346,1.4060,4490.6,0.1395,1.4435,
4580.6,0.1446,1.4826,4670.6,0.1499,1.5232,
4760.6,0.1555,1.5653,4850.6,0.1612,1.6088,
4940.6,0.1671,1.6534,5030.6,0.1732,1.6992,
5120.6,0.1794,1.7459,5210.6,0.1858,1.7935,
5300.6,0.1924,1.8419,5390.6,0.1990,1.8910,
5480.6,0.2059,1.9407,5570.6,0.2128,1.9908,
5660.6,0.2199,2.0413,5750.6,0.2270,2.0921,
13940.,0.6954,4.3675,
2,61,359.929,IMF *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,

```
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.1534,
620.6,0.0925,2.3709,710.6,0.0937,2.2445,
800.6,0.0948,2.1385,890.6,0.0957,2.0501,
980.6,0.0966,1.9767,1070.6,0.0974,1.9155,
1160.6,0.0981,1.8640,1250.6,0.0987,1.8194,
1340.6,0.0993,1.7797,1430.6,0.0999,1.7431,
1520.6,0.1004,1.7083,1610.6,0.1009,1.6748,
1700.6,0.1015,1.6421,1790.6,0.1020,1.6103,
1880.6,0.1025,1.5792,1970.6,0.1030,1.5492,
2060.6,0.1034,1.5205,2150.6,0.1040,1.4932,
2240.6,0.1045,1.4678,2330.6,0.1051,1.4445,
2420.6,0.1057,1.4235,2510.6,0.1065,1.4050,
2600.6,0.1072,1.3894,2690.6,0.1080,1.3768,
2780.6,0.1089,1.3672,2870.6,0.1098,1.3610,
2960.6,0.1109,1.3581,3050.6,0.1121,1.3584,
3140.6,0.1134,1.3621,3230.6,0.1148,1.3691,
3320.6,0.1164,1.3792,3410.6,0.1181,1.3921,
3500.6,0.1199,1.4079,3590.6,0.1219,1.4262,
3680.6,0.1241,1.4467,3770.6,0.1264,1.4692,
3860.6,0.1289,1.4933,3950.6,0.1314,1.5188,
4040.6,0.1343,1.5454,4130.6,0.1372,1.5729,
4220.6,0.1403,1.6009,4310.6,0.1436,1.6293,
4400.6,0.1471,1.6579,4490.6,0.1507,1.6868,
4580.6,0.1544,1.7160,4670.6,0.1583,1.7456,
4760.6,0.1624,1.7759,4850.6,0.1666,1.8076,
4940.6,0.1709,1.8411,5030.6,0.1754,1.8774,
5120.6,0.1799,1.9175,5210.6,0.1846,1.9628,
5300.6,0.1894,2.0149,5390.6,0.1942,2.0759,
5480.6,0.1993,2.1479,5570.6,0.2043,2.2336,
5660.6,0.2096,2.3360,5750.6,0.2148,2.4587,
13940.0,0.5882,4919.2051,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
23,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.125290E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
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```
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0019,1,1,0.125    *rods.9
2,1,1.2112,1,1,0.25,2,0.25    *rods.9
3,1,1.1668,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2047,1,2,0.25,4,0.25    *rods.9
5,1,1.1608,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.1551,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0018,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.1903,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.1850,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0018,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.1657,1,7,0.25,11,0.25    *rods.9
12,1,1.1227,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.1181,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.1514,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0975,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.1115,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0714,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0660,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0961,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0625,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0015,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0016,1,16,0.25,22,0.25    *rods.9
23,1,1.0160,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0069,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0016,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.9425,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.8276,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.6617,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.8466,1,22,0.25,29,0.25    *rods.9
30,1,0.8128,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.8033,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.8089,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.7119,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.3095,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.0885,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.9280,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.3070,1,29,0.25,37,0.25    *rods.9
38,3,1.2926,1,29,0.25,30,0.25,37,0.5    *rods.9
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39,3,1.2793,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.2557,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.1631,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.0095,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.9189,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.8711,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.8564,1,36,0.125,38,0.375    *rods.9
46,4,0.91261,1,37,38.31439394    *rods.9
47,4,0.91261,1,38,38.45123106    *rods.9
48,4,0.91261,1,39,72.25    *rods.9
49,4,0.91261,1,40,144.5    *rods.9
50,4,1.230,1,41,144.5    *rods.9
51,4,1.120,1,42,289    *rods.9
52,4,1.080,1,43,144.5    *rods.9
53,4,0.990,1,44,2023    *rods.9
54,4,0.960,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026          *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,2.0936,
620.6,0.0698,1.7806,710.6,0.0707,1.7200,
800.6,0.0715,1.6665,890.6,0.0722,1.6202,
980.6,0.0729,1.5807,1070.6,0.0735,1.5471,
1160.6,0.0740,1.5180,1250.6,0.0745,1.4918,
1340.6,0.0750,1.4670,1430.6,0.0754,1.4424,
1520.6,0.0758,1.4171,1610.6,0.0762,1.3911,
1700.6,0.0767,1.3645,1790.6,0.0771,1.3374,
1880.6,0.0775,1.3104,1970.6,0.0779,1.2839,
2060.6,0.0783,1.2582,2150.6,0.0788,1.2337,
2240.6,0.0793,1.2107,2330.6,0.0799,1.1895,
2420.6,0.0805,1.1702,2510.6,0.0813,1.1531,
2600.6,0.0821,1.1384,2690.6,0.0830,1.1261,
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2780.6,0.0840,1.1164,2870.6,0.0851,1.1093,
2960.6,0.0864,1.1050,3050.6,0.0879,1.1034,
3140.6,0.0895,1.1047,3230.6,0.0914,1.1087,
3320.6,0.0934,1.1156,3410.6,0.0956,1.1252,
3500.6,0.0980,1.1376,3590.6,0.1006,1.1528,
3680.6,0.1035,1.1705,3770.6,0.1066,1.1909,
3860.6,0.1099,1.2138,3950.6,0.1134,1.2391,
4040.6,0.1172,1.2667,4130.6,0.1212,1.2965,
4220.6,0.1254,1.3285,4310.6,0.1299,1.3625,
4400.6,0.1346,1.3984,4490.6,0.1395,1.4360,
4580.6,0.1446,1.4753,4670.6,0.1499,1.5162,
4760.6,0.1555,1.5585,4850.6,0.1612,1.6022,
4940.6,0.1671,1.6470,5030.6,0.1732,1.6930,
5120.6,0.1794,1.7399,5210.6,0.1858,1.7877,
5300.6,0.1924,1.8363,5390.6,0.1990,1.8855,
5480.6,0.2059,1.9353,5570.6,0.2128,1.9856,
5660.6,0.2199,2.0362,5750.6,0.2270,2.0872,
13940.,0.6954,4.3664,
2,61,359.929,IMF *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,

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4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.0724,
620.6,0.0925,2.3130,710.6,0.0937,2.1909,
800.6,0.0948,2.0888,890.6,0.0957,2.0040,
980.6,0.0966,1.9339,1070.6,0.0974,1.8758,
1160.6,0.0981,1.8272,1250.6,0.0987,1.7854,
1340.6,0.0993,1.7484,1430.6,0.0999,1.7143,
1520.6,0.1004,1.6818,1610.6,0.1009,1.6503,
1700.6,0.1015,1.6196,1790.6,0.1020,1.5893,
1880.6,0.1025,1.5597,1970.6,0.1030,1.5310,
2060.6,0.1034,1.5035,2150.6,0.1040,1.4773,
2240.6,0.1045,1.4529,2330.6,0.1051,1.4304,
2420.6,0.1057,1.4102,2510.6,0.1065,1.3925,
2600.6,0.1072,1.3775,2690.6,0.1080,1.3655,
2780.6,0.1089,1.3565,2870.6,0.1098,1.3508,
2960.6,0.1109,1.3483,3050.6,0.1121,1.3491,
3140.6,0.1134,1.3533,3230.6,0.1148,1.3605,
3320.6,0.1164,1.3710,3410.6,0.1181,1.3843,
3500.6,0.1199,1.4003,3590.6,0.1219,1.4189,
3680.6,0.1241,1.4396,3770.6,0.1264,1.4624,
3860.6,0.1289,1.4869,3950.6,0.1314,1.5126,
4040.6,0.1343,1.5394,4130.6,0.1372,1.5670,
4220.6,0.1403,1.5953,4310.6,0.1436,1.6239,
4400.6,0.1471,1.6527,4490.6,0.1507,1.6817,
4580.6,0.1544,1.7110,4670.6,0.1583,1.7408,
4760.6,0.1624,1.7713,4850.6,0.1666,1.8031,
4940.6,0.1709,1.8367,5030.6,0.1754,1.8732,
5120.6,0.1799,1.9134,5210.6,0.1846,1.9588,
5300.6,0.1894,2.0111,5390.6,0.1942,2.0721,
5480.6,0.1993,2.1442,5570.6,0.2043,2.2300,
5660.6,0.2096,2.3326,5750.6,0.2148,2.4554,
13940.0,0.5882,4919.2044,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
24,0,0,-1,0    *vipre.1
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Burnup [MWd/t] at 3.532937E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0019,1,1,0.125    *rods.9
2,1,1.1964,1,1,0.25,2,0.25    *rods.9
3,1,1.1525,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.1903,1,2,0.25,4,0.25    *rods.9
5,1,1.1468,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.1415,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0019,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.1767,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.1717,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0018,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.1529,1,7,0.25,11,0.25    *rods.9
12,1,1.1103,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.1061,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.1397,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0871,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.1002,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0604,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0554,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0860,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0536,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0015,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0016,1,16,0.25,22,0.25    *rods.9
23,1,1.0070,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.9982,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0016,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.9358,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.8227,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.6586,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.8403,1,22,0.25,29,0.25    *rods.9
30,1,0.8068,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.7976,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.8038,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
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33,1,0.7081,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.3095,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.0906,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.9316,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.3062,1,29,0.25,37,0.25    *rods.9
38,3,1.2918,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.2789,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.2561,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.1645,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.0125,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.9226,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.8752,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.8608,1,36,0.125,38,0.375    *rods.9
46,4,0.90711,1,37,38.31439394    *rods.9
47,4,0.90711,1,38,38.45123106    *rods.9
48,4,0.90711,1,39,72.25    *rods.9
49,4,0.90711,1,40,144.5    *rods.9
50,4,1.230,1,41,144.5    *rods.9
51,4,1.120,1,42,289    *rods.9
52,4,1.080,1,43,144.5    *rods.9
53,4,0.990,1,44,2023    *rods.9
54,4,0.960,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.9911,
620.6,0.0698,1.7062,710.6,0.0707,1.6509,
800.6,0.0715,1.6022,890.6,0.0722,1.5602,
980.6,0.0729,1.5247,1070.6,0.0735,1.4949,
1160.6,0.0740,1.4695,1250.6,0.0745,1.4467,
1340.6,0.0750,1.4252,1430.6,0.0754,1.4036,
1520.6,0.0758,1.3812,1610.6,0.0762,1.3578,
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1700.6,0.0767,1.3335,1790.6,0.0771,1.3086,
1880.6,0.0775,1.2835,1970.6,0.0779,1.2587,
2060.6,0.0783,1.2346,2150.6,0.0788,1.2115,
2240.6,0.0793,1.1898,2330.6,0.0799,1.1697,
2420.6,0.0805,1.1515,2510.6,0.0813,1.1354,
2600.6,0.0821,1.1216,2690.6,0.0830,1.1101,
2780.6,0.0840,1.1012,2870.6,0.0851,1.0948,
2960.6,0.0864,1.0911,3050.6,0.0879,1.0902,
3140.6,0.0895,1.0920,3230.6,0.0914,1.0966,
3320.6,0.0934,1.1039,3410.6,0.0956,1.1140,
3500.6,0.0980,1.1269,3590.6,0.1006,1.1424,
3680.6,0.1035,1.1606,3770.6,0.1066,1.1813,
3860.6,0.1099,1.2045,3950.6,0.1134,1.2302,
4040.6,0.1172,1.2581,4130.6,0.1212,1.2882,
4220.6,0.1254,1.3205,4310.6,0.1299,1.3547,
4400.6,0.1346,1.3908,4490.6,0.1395,1.4287,
4580.6,0.1446,1.4683,4670.6,0.1499,1.5094,
4760.6,0.1555,1.5519,4850.6,0.1612,1.5957,
4940.6,0.1671,1.6408,5030.6,0.1732,1.6869,
5120.6,0.1794,1.7340,5210.6,0.1858,1.7820,
5300.6,0.1924,1.8307,5390.6,0.1990,1.8801,
5480.6,0.2059,1.9300,5570.6,0.2128,1.9804,
5660.6,0.2199,2.0312,5750.6,0.2270,2.0823,
13940.,0.6954,4.3654,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
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3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,3.0025,
620.6,0.0925,2.2623,710.6,0.0937,2.1438,
800.6,0.0948,2.0449,890.6,0.0957,1.9631,
980.6,0.0966,1.8957,1070.6,0.0974,1.8403,
1160.6,0.0981,1.7941,1250.6,0.0987,1.7547,
1340.6,0.0993,1.7199,1430.6,0.0999,1.6879,
1520.6,0.1004,1.6573,1610.6,0.1009,1.6276,
1700.6,0.1015,1.5984,1790.6,0.1020,1.5696,
1880.6,0.1025,1.5414,1970.6,0.1030,1.5138,
2060.6,0.1034,1.4874,2150.6,0.1040,1.4622,
2240.6,0.1045,1.4386,2330.6,0.1051,1.4169,
2420.6,0.1057,1.3974,2510.6,0.1065,1.3804,
2600.6,0.1072,1.3661,2690.6,0.1080,1.3546,
2780.6,0.1089,1.3462,2870.6,0.1098,1.3409,
2960.6,0.1109,1.3388,3050.6,0.1121,1.3401,
3140.6,0.1134,1.3446,3230.6,0.1148,1.3523,
3320.6,0.1164,1.3630,3410.6,0.1181,1.3766,
3500.6,0.1199,1.3930,3590.6,0.1219,1.4118,
3680.6,0.1241,1.4329,3770.6,0.1264,1.4559,
3860.6,0.1289,1.4805,3950.6,0.1314,1.5066,
4040.6,0.1343,1.5336,4130.6,0.1372,1.5614,
4220.6,0.1403,1.5898,4310.6,0.1436,1.6186,
4400.6,0.1471,1.6475,4490.6,0.1507,1.6768,
4580.6,0.1544,1.7063,4670.6,0.1583,1.7362,
4760.6,0.1624,1.7668,4850.6,0.1666,1.7987,
4940.6,0.1709,1.8325,5030.6,0.1754,1.8690,
5120.6,0.1799,1.9093,5210.6,0.1846,1.9549,
5300.6,0.1894,2.0073,5390.6,0.1942,2.0684,
5480.6,0.1993,2.1406,5570.6,0.2043,2.2265,

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5660.6,0.2096,2.3291,5750.6,0.2148,2.4521,
13940.0,0.5882,4919.2037,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
25,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.940584E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0019,1,1,0.125    *rods.9
2,1,1.1823,1,1,0.25,2,0.25    *rods.9
3,1,1.1388,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.1766,1,2,0.25,4,0.25    *rods.9
5,1,1.1335,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.1286,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0019,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.1636,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.1590,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0018,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.1406,1,7,0.25,11,0.25    *rods.9
12,1,1.0984,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0946,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.1286,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0771,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0894,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0499,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0453,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0763,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0449,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0016,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0016,1,16,0.25,22,0.25    *rods.9
23,1,0.9981,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.9898,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0016,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.9292,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
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27,1,0.8177,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.6556,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.8343,1,22,0.25,29,0.25    *rods.9
30,1,0.8010,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.7921,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.7988,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.7042,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.3095,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,1.0927,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.9349,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.3055,1,29,0.25,37,0.25    *rods.9
38,3,1.2913,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.2787,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.2564,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,1.1658,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,1.0153,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.9261,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.8790,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.8647,1,36,0.125,38,0.375    *rods.9
46,4,0.90181,1,37,38.31439394    *rods.9
47,4,0.90181,1,38,38.45123106    *rods.9
48,4,0.90181,1,39,72.25    *rods.9
49,4,0.90181,1,40,144.5    *rods.9
50,4,1.230,1,41,144.5    *rods.9
51,4,1.120,1,42,289    *rods.9
52,4,1.080,1,43,144.5    *rods.9
53,4,0.990,1,44,2023    *rods.9
54,4,0.960,1,45,4046    *rods.9
0    *rods.9
*          Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002        *rods.65
* 0.05 0 0 0 0       *rods.66
* 0.0026         *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.9018,
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620.6,0.0698,1.6405,710.6,0.0707,1.5896,
800.6,0.0715,1.5449,890.6,0.0722,1.5066,
980.6,0.0729,1.4745,1070.6,0.0735,1.4479,
1160.6,0.0740,1.4255,1250.6,0.0745,1.4056,
1340.6,0.0750,1.3868,1430.6,0.0754,1.3678,
1520.6,0.0758,1.3479,1610.6,0.0762,1.3267,
1700.6,0.0767,1.3045,1790.6,0.0771,1.2815,
1880.6,0.0775,1.2581,1970.6,0.0779,1.2349,
2060.6,0.0783,1.2122,2150.6,0.0788,1.1904,
2240.6,0.0793,1.1698,2330.6,0.0799,1.1508,
2420.6,0.0805,1.1336,2510.6,0.0813,1.1184,
2600.6,0.0821,1.1054,2690.6,0.0830,1.0947,
2780.6,0.0840,1.0865,2870.6,0.0851,1.0808,
2960.6,0.0864,1.0777,3050.6,0.0879,1.0773,
3140.6,0.0895,1.0797,3230.6,0.0914,1.0848,
3320.6,0.0934,1.0926,3410.6,0.0956,1.1032,
3500.6,0.0980,1.1164,3590.6,0.1006,1.1324,
3680.6,0.1035,1.1509,3770.6,0.1066,1.1720,
3860.6,0.1099,1.1955,3950.6,0.1134,1.2215,
4040.6,0.1172,1.2497,4130.6,0.1212,1.2801,
4220.6,0.1254,1.3126,4310.6,0.1299,1.3471,
4400.6,0.1346,1.3835,4490.6,0.1395,1.4216,
4580.6,0.1446,1.4614,4670.6,0.1499,1.5027,
4760.6,0.1555,1.5454,4850.6,0.1612,1.5894,
4940.6,0.1671,1.6347,5030.6,0.1732,1.6810,
5120.6,0.1794,1.7282,5210.6,0.1858,1.7763,
5300.6,0.1924,1.8252,5390.6,0.1990,1.8747,
5480.6,0.2059,1.9248,5570.6,0.2128,1.9754,
5660.6,0.2199,2.0263,5750.6,0.2270,2.0775,
13940.,0.6954,4.3644,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
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2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX   *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.9416,
620.6,0.0925,2.2175,710.6,0.0937,2.1020,
800.6,0.0948,2.0059,890.6,0.0957,1.9265,
980.6,0.0966,1.8615,1070.6,0.0974,1.8082,
1160.6,0.0981,1.7641,1250.6,0.0987,1.7267,
1340.6,0.0993,1.6937,1430.6,0.0999,1.6635,
1520.6,0.1004,1.6346,1610.6,0.1009,1.6064,
1700.6,0.1015,1.5786,1790.6,0.1020,1.5512,
1880.6,0.1025,1.5240,1970.6,0.1030,1.4976,
2060.6,0.1034,1.4721,2150.6,0.1040,1.4478,
2240.6,0.1045,1.4250,2330.6,0.1051,1.4040,
2420.6,0.1057,1.3852,2510.6,0.1065,1.3688,
2600.6,0.1072,1.3550,2690.6,0.1080,1.3441,
2780.6,0.1089,1.3361,2870.6,0.1098,1.3313,
2960.6,0.1109,1.3297,3050.6,0.1121,1.3313,
3140.6,0.1134,1.3362,3230.6,0.1148,1.3442,
3320.6,0.1164,1.3553,3410.6,0.1181,1.3693,
3500.6,0.1199,1.3859,3590.6,0.1219,1.4050,
3680.6,0.1241,1.4263,3770.6,0.1264,1.4495,
3860.6,0.1289,1.4744,3950.6,0.1314,1.5006,
4040.6,0.1343,1.5279,4130.6,0.1372,1.5559,
4220.6,0.1403,1.5845,4310.6,0.1436,1.6134,
4400.6,0.1471,1.6426,4490.6,0.1507,1.6719,

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4580.6,0.1544,1.7016,4670.6,0.1583,1.7316,
4760.6,0.1624,1.7624,4850.6,0.1666,1.7944,
4940.6,0.1709,1.8283,5030.6,0.1754,1.8650,
5120.6,0.1799,1.9054,5210.6,0.1846,1.9510,
5300.6,0.1894,2.0035,5390.6,0.1942,2.0648,
5480.6,0.1993,2.1370,5570.6,0.2043,2.2231,
5660.6,0.2096,2.3258,5750.6,0.2148,2.4488,
13940.0,0.5882,4919.2030,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
26,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.348231E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0016,1,1,0.125    *rods.9
2,1,0.9673,1,1,0.25,2,0.25    *rods.9
3,1,0.9318,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,0.9628,1,2,0.25,4,0.25    *rods.9
5,1,0.9276,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,0.9238,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0015,1,4,0.25,7,0.25,0,0    *rods.9
8,1,0.9526,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,0.9491,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0015,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,0.9341,1,7,0.25,11,0.25    *rods.9
12,1,0.8997,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,0.8968,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,0.9250,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,0.8834,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,0.8929,1,11,0.25,16,0.25,0,0    *rods.9
17,1,0.8606,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,0.8570,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,0.8830,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,0.8578,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
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21,2,0.0013,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0013,1,16,0.25,22,0.25    *rods.9
23,1,0.8190,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.8125,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0013,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.7636,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.6727,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.5401,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.6855,1,22,0.25,29,0.25    *rods.9
30,1,0.6582,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.6511,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.6570,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.5797,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.0838,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,0.9059,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.7763,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.0799,1,29,0.25,37,0.25    *rods.9
38,3,1.0682,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.0581,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.0401,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,0.9659,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,0.8425,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.7691,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.7303,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.7186,1,36,0.125,38,0.375    *rods.9
46,4,0.74211,1,37,38.31439394    *rods.9
47,4,0.74211,1,38,38.45123106    *rods.9
48,4,0.74211,1,39,72.25    *rods.9
49,4,0.74211,1,40,144.5    *rods.9
50,4,1.070,1,41,144.5    *rods.9
51,4,1.030,1,42,289    *rods.9
52,4,1.010,1,43,144.5    *rods.9
53,4,1.000,1,44,2023    *rods.9
54,4,0.989,1,45,4046    *rods.9
0    *rods.9
*          Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
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```
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0       *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.8232,
620.6,0.0698,1.5819,710.6,0.0707,1.5347,
800.6,0.0715,1.4935,890.6,0.0722,1.4583,
980.6,0.0729,1.4291,1070.6,0.0735,1.4052,
1160.6,0.0740,1.3854,1250.6,0.0745,1.3680,
1340.6,0.0750,1.3515,1430.6,0.0754,1.3347,
1520.6,0.0758,1.3168,1610.6,0.0762,1.2976,
1700.6,0.0767,1.2772,1790.6,0.0771,1.2559,
1880.6,0.0775,1.2341,1970.6,0.0779,1.2122,
2060.6,0.0783,1.1908,2150.6,0.0788,1.1702,
2240.6,0.0793,1.1507,2330.6,0.0799,1.1327,
2420.6,0.0805,1.1164,2510.6,0.0813,1.1020,
2600.6,0.0821,1.0898,2690.6,0.0830,1.0798,
2780.6,0.0840,1.0723,2870.6,0.0851,1.0672,
2960.6,0.0864,1.0647,3050.6,0.0879,1.0649,
3140.6,0.0895,1.0677,3230.6,0.0914,1.0733,
3320.6,0.0934,1.0816,3410.6,0.0956,1.0926,
3500.6,0.0980,1.1062,3590.6,0.1006,1.1225,
3680.6,0.1035,1.1414,3770.6,0.1066,1.1629,
3860.6,0.1099,1.1867,3950.6,0.1134,1.2130,
4040.6,0.1172,1.2415,4130.6,0.1212,1.2722,
4220.6,0.1254,1.3049,4310.6,0.1299,1.3397,
4400.6,0.1346,1.3763,4490.6,0.1395,1.4146,
4580.6,0.1446,1.4546,4670.6,0.1499,1.4961,
4760.6,0.1555,1.5390,4850.6,0.1612,1.5833,
4940.6,0.1671,1.6286,5030.6,0.1732,1.6751,
5120.6,0.1794,1.7225,5210.6,0.1858,1.7708,
5300.6,0.1924,1.8198,5390.6,0.1990,1.8695,
5480.6,0.2059,1.9197,5570.6,0.2128,1.9704,
5660.6,0.2199,2.0215,5750.6,0.2270,2.0728,
13940.,0.6954,4.3634,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
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1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.8880,
620.6,0.0925,2.1776,710.6,0.0937,2.0646,
800.6,0.0948,1.9708,890.6,0.0957,1.8936,
980.6,0.0966,1.8305,1070.6,0.0974,1.7791,
1160.6,0.0981,1.7368,1250.6,0.0987,1.7010,
1340.6,0.0993,1.6696,1430.6,0.0999,1.6409,
1520.6,0.1004,1.6134,1610.6,0.1009,1.5866,
1700.6,0.1015,1.5600,1790.6,0.1020,1.5337,
1880.6,0.1025,1.5077,1970.6,0.1030,1.4821,
2060.6,0.1034,1.4575,2150.6,0.1040,1.4340,
2240.6,0.1045,1.4120,2330.6,0.1051,1.3917,
2420.6,0.1057,1.3735,2510.6,0.1065,1.3576,
2600.6,0.1072,1.3444,2690.6,0.1080,1.3339,
2780.6,0.1089,1.3265,2870.6,0.1098,1.3221,
2960.6,0.1109,1.3208,3050.6,0.1121,1.3228,
3140.6,0.1134,1.3280,3230.6,0.1148,1.3364,
3320.6,0.1164,1.3478,3410.6,0.1181,1.3620,
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3500.6,0.1199,1.3789,3590.6,0.1219,1.3983,
3680.6,0.1241,1.4198,3770.6,0.1264,1.4433,
3860.6,0.1289,1.4684,3950.6,0.1314,1.4948,
4040.6,0.1343,1.5223,4130.6,0.1372,1.5505,
4220.6,0.1403,1.5792,4310.6,0.1436,1.6083,
4400.6,0.1471,1.6377,4490.6,0.1507,1.6671,
4580.6,0.1544,1.6969,4670.6,0.1583,1.7271,
4760.6,0.1624,1.7580,4850.6,0.1666,1.7902,
4940.6,0.1709,1.8242,5030.6,0.1754,1.8609,
5120.6,0.1799,1.9015,5210.6,0.1846,1.9473,
5300.6,0.1894,1.9999,5390.6,0.1942,2.0612,
5480.6,0.1993,2.1335,5570.6,0.2043,2.2197,
5660.6,0.2096,2.3225,5750.6,0.2148,2.4456,
13940.0,0.5882,4919.2023,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
27,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.755878E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0016,1,1,0.125    *rods.9
2,1,0.9566,1,1,0.25,2,0.25    *rods.9
3,1,0.9215,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,0.9524,1,2,0.25,4,0.25    *rods.9
5,1,0.9176,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,0.9140,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0016,1,4,0.25,7,0.25,0,0    *rods.9
8,1,0.9427,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,0.9394,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0015,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,0.9247,1,7,0.25,11,0.25    *rods.9
12,1,0.8907,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,0.8880,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,0.9164,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
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15,1,0.8757,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,0.8846,1,11,0.25,16,0.25,0,0    *rods.9
17,1,0.8526,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,0.8493,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,0.8754,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,0.8510,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0013,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0014,1,16,0.25,22,0.25    *rods.9
23,1,0.8122,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.8059,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0013,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.7584,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.6688,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.5376,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.6808,1,22,0.25,29,0.25    *rods.9
30,1,0.6538,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.6468,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.6530,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.5767,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.0838,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,0.9073,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.7786,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.0794,1,29,0.25,37,0.25    *rods.9
38,3,1.0678,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.0579,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.0404,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,0.9668,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,0.8445,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.7716,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.7330,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.7213,1,36,0.125,38,0.375    *rods.9
46,4,0.73801,1,37,38.31439394    *rods.9
47,4,0.73801,1,38,38.45123106    *rods.9
48,4,0.73801,1,39,72.25    *rods.9
49,4,0.73801,1,40,144.5    *rods.9
50,4,1.070,1,41,144.5    *rods.9
51,4,1.030,1,42,289    *rods.9
52,4,1.010,1,43,144.5    *rods.9
53,4,1.000,1,44,2023    *rods.9
54,4,0.989,1,45,4046    *rods.9
0    *rods.9
*        Fuel Geometry Types
*
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1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.7533,
620.6,0.0698,1.5292,710.6,0.0707,1.4853,
800.6,0.0715,1.4470,890.6,0.0722,1.4145,
980.6,0.0729,1.3878,1070.6,0.0735,1.3662,
1160.6,0.0740,1.3485,1250.6,0.0745,1.3332,
1340.6,0.0750,1.3187,1430.6,0.0754,1.3038,
1520.6,0.0758,1.2878,1610.6,0.0762,1.2703,
1700.6,0.0767,1.2515,1790.6,0.0771,1.2316,
1880.6,0.0775,1.2112,1970.6,0.0779,1.1906,
2060.6,0.0783,1.1704,2150.6,0.0788,1.1508,
2240.6,0.0793,1.1323,2330.6,0.0799,1.1153,
2420.6,0.0805,1.0998,2510.6,0.0813,1.0862,
2600.6,0.0821,1.0747,2690.6,0.0830,1.0654,
2780.6,0.0840,1.0585,2870.6,0.0851,1.0540,
2960.6,0.0864,1.0521,3050.6,0.0879,1.0528,
3140.6,0.0895,1.0561,3230.6,0.0914,1.0622,
3320.6,0.0934,1.0709,3410.6,0.0956,1.0823,
3500.6,0.0980,1.0963,3590.6,0.1006,1.1130,
3680.6,0.1035,1.1322,3770.6,0.1066,1.1540,
3860.6,0.1099,1.1781,3950.6,0.1134,1.2046,
4040.6,0.1172,1.2334,4130.6,0.1212,1.2644,
4220.6,0.1254,1.2974,4310.6,0.1299,1.3324,
4400.6,0.1346,1.3692,4490.6,0.1395,1.4078,
4580.6,0.1446,1.4480,4670.6,0.1499,1.4897,
4760.6,0.1555,1.5328,4850.6,0.1612,1.5772,
4940.6,0.1671,1.6228,5030.6,0.1732,1.6694,
5120.6,0.1794,1.7170,5210.6,0.1858,1.7654,
5300.6,0.1924,1.8146,5390.6,0.1990,1.8644,
5480.6,0.2059,1.9147,5570.6,0.2128,1.9656,
5660.6,0.2199,2.0167,5750.6,0.2270,2.0682,
13940.,0.6954,4.3624,
2,61,359.929,IMF    *rods.70
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-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.8403,
620.6,0.0925,2.1416,710.6,0.0937,2.0309,
800.6,0.0948,1.9391,890.6,0.0957,1.8637,
980.6,0.0966,1.8024,1070.6,0.0974,1.7525,
1160.6,0.0981,1.7116,1250.6,0.0987,1.6773,
1340.6,0.0993,1.6473,1430.6,0.0999,1.6198,
1520.6,0.1004,1.5936,1610.6,0.1009,1.5680,
1700.6,0.1015,1.5425,1790.6,0.1020,1.5171,
1880.6,0.1025,1.4921,1970.6,0.1030,1.4674,
2060.6,0.1034,1.4436,2150.6,0.1040,1.4208,
2240.6,0.1045,1.3994,2330.6,0.1051,1.3798,
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2420.6,0.1057,1.3622,2510.6,0.1065,1.3469,
2600.6,0.1072,1.3341,2690.6,0.1080,1.3241,
2780.6,0.1089,1.3171,2870.6,0.1098,1.3131,
2960.6,0.1109,1.3122,3050.6,0.1121,1.3146,
3140.6,0.1134,1.3201,3230.6,0.1148,1.3288,
3320.6,0.1164,1.3405,3410.6,0.1181,1.3550,
3500.6,0.1199,1.3722,3590.6,0.1219,1.3918,
3680.6,0.1241,1.4135,3770.6,0.1264,1.4373,
3860.6,0.1289,1.4625,3950.6,0.1314,1.4891,
4040.6,0.1343,1.5167,4130.6,0.1372,1.5452,
4220.6,0.1403,1.5741,4310.6,0.1436,1.6034,
4400.6,0.1471,1.6328,4490.6,0.1507,1.6625,
4580.6,0.1544,1.6924,4670.6,0.1583,1.7227,
4760.6,0.1624,1.7538,4850.6,0.1666,1.7861,
4940.6,0.1709,1.8202,5030.6,0.1754,1.8571,
5120.6,0.1799,1.8978,5210.6,0.1846,1.9436,
5300.6,0.1894,1.9963,5390.6,0.1942,2.0577,
5480.6,0.1993,2.1301,5570.6,0.2043,2.2164,
5660.6,0.2096,2.3193,5750.6,0.2148,2.4424,
13940.0,0.5882,4919.2016,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
28,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 5.163525E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*          Normal Rod input
1,2,0.0016,1,1,0.125    *rods.9
2,1,0.9464,1,1,0.25,2,0.25    *rods.9
3,1,0.9117,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,0.9425,1,2,0.25,4,0.25    *rods.9
5,1,0.9081,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,0.9047,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0016,1,4,0.25,7,0.25,0,0    *rods.9
8,1,0.9332,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
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9,1,0.9302,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0015,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,0.9158,1,7,0.25,11,0.25    *rods.9
12,1,0.8821,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,0.8797,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,0.9082,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,0.8683,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,0.8766,1,11,0.25,16,0.25,0,0    *rods.9
17,1,0.8450,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,0.8419,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,0.8682,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,0.8446,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0013,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0014,1,16,0.25,22,0.25    *rods.9
23,1,0.8057,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.7997,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0013,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.7533,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.6651,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.5354,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.6763,1,22,0.25,29,0.25    *rods.9
30,1,0.6495,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.6428,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.6492,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.5739,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.0837,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,0.9086,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.7808,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.0790,1,29,0.25,37,0.25    *rods.9
38,3,1.0674,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.0578,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.0406,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,0.9677,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,0.8464,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.7739,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.7354,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.7239,1,36,0.125,38,0.375    *rods.9
46,4,0.73411,1,37,38.31439394    *rods.9
47,4,0.73411,1,38,38.45123106    *rods.9
48,4,0.73411,1,39,72.25    *rods.9
49,4,0.73411,1,40,144.5    *rods.9
50,4,1.070,1,41,144.5    *rods.9
51,4,1.030,1,42,289    *rods.9
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52,4,1.010,1,43,144.5    *rods.9
53,4,1.000,1,44,2023    *rods.9
54,4,0.989,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.6907,
620.6,0.0698,1.4816,710.6,0.0707,1.4405,
800.6,0.0715,1.4048,890.6,0.0722,1.3746,
980.6,0.0729,1.3501,1070.6,0.0735,1.3304,
1160.6,0.0740,1.3146,1250.6,0.0745,1.3011,
1340.6,0.0750,1.2883,1430.6,0.0754,1.2750,
1520.6,0.0758,1.2606,1610.6,0.0762,1.2446,
1700.6,0.0767,1.2272,1790.6,0.0771,1.2086,
1880.6,0.0775,1.1894,1970.6,0.0779,1.1700,
2060.6,0.0783,1.1508,2150.6,0.0788,1.1323,
2240.6,0.0793,1.1147,2330.6,0.0799,1.0985,
2420.6,0.0805,1.0838,2510.6,0.0813,1.0710,
2600.6,0.0821,1.0602,2690.6,0.0830,1.0515,
2780.6,0.0840,1.0452,2870.6,0.0851,1.0413,
2960.6,0.0864,1.0399,3050.6,0.0879,1.0411,
3140.6,0.0895,1.0449,3230.6,0.0914,1.0513,
3320.6,0.0934,1.0604,3410.6,0.0956,1.0722,
3500.6,0.0980,1.0866,3590.6,0.1006,1.1036,
3680.6,0.1035,1.1232,3770.6,0.1066,1.1453,
3860.6,0.1099,1.1697,3950.6,0.1134,1.1965,
4040.6,0.1172,1.2256,4130.6,0.1212,1.2568,
4220.6,0.1254,1.2900,4310.6,0.1299,1.3253,
4400.6,0.1346,1.3623,4490.6,0.1395,1.4011,
4580.6,0.1446,1.4415,4670.6,0.1499,1.4834,
4760.6,0.1555,1.5267,4850.6,0.1612,1.5712,
4940.6,0.1671,1.6170,5030.6,0.1732,1.6638,
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5120.6,0.1794,1.7115,5210.6,0.1858,1.7601,
5300.6,0.1924,1.8094,5390.6,0.1990,1.8593,
5480.6,0.2059,1.9098,5570.6,0.2128,1.9608,
5660.6,0.2199,2.0121,5750.6,0.2270,2.0636,
13940.,0.6954,4.3614,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.7977,
620.6,0.0925,2.1092,710.6,0.0937,2.0003,
800.6,0.0948,1.9103,890.6,0.0957,1.8365,
980.6,0.0966,1.7767,1070.6,0.0974,1.7281,
1160.6,0.0981,1.6885,1250.6,0.0987,1.6554,
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1340.6,0.0993,1.6266,1430.6,0.0999,1.6002,
1520.6,0.1004,1.5751,1610.6,0.1009,1.5504,
1700.6,0.1015,1.5259,1790.6,0.1020,1.5015,
1880.6,0.1025,1.4772,1970.6,0.1030,1.4534,
2060.6,0.1034,1.4303,2150.6,0.1040,1.4082,
2240.6,0.1045,1.3874,2330.6,0.1051,1.3684,
2420.6,0.1057,1.3513,2510.6,0.1065,1.3365,
2600.6,0.1072,1.3242,2690.6,0.1080,1.3146,
2780.6,0.1089,1.3080,2870.6,0.1098,1.3044,
2960.6,0.1109,1.3039,3050.6,0.1121,1.3066,
3140.6,0.1134,1.3125,3230.6,0.1148,1.3214,
3320.6,0.1164,1.3333,3410.6,0.1181,1.3481,
3500.6,0.1199,1.3655,3590.6,0.1219,1.3854,
3680.6,0.1241,1.4074,3770.6,0.1264,1.4313,
3860.6,0.1289,1.4568,3950.6,0.1314,1.4836,
4040.6,0.1343,1.5114,4130.6,0.1372,1.5400,
4220.6,0.1403,1.5690,4310.6,0.1436,1.5985,
4400.6,0.1471,1.6281,4490.6,0.1507,1.6579,
4580.6,0.1544,1.6880,4670.6,0.1583,1.7184,
4760.6,0.1624,1.7496,4850.6,0.1666,1.7820,
4940.6,0.1709,1.8163,5030.6,0.1754,1.8532,
5120.6,0.1799,1.8940,5210.6,0.1846,1.9400,
5300.6,0.1894,1.9928,5390.6,0.1942,2.0542,
5480.6,0.1993,2.1268,5570.6,0.2043,2.2131,
5660.6,0.2096,2.3161,5750.6,0.2148,2.4393,
13940.0,0.5882,4919.2010,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
29,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 5.571172E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0016,1,1,0.125    *rods.9
2,1,0.9368,1,1,0.25,2,0.25    *rods.9
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3,1,0.9026,1,1,0.125,2,0.25,3,0.125   *rods.9
4,1,0.9331,1,2,0.25,4,0.25   *rods.9
5,1,0.8992,1,2,0.25,3,0.25,4,0.25,5,0.25   *rods.9
6,1,0.8960,1,3,0.125,5,0.25,6,0.125   *rods.9
7,2,0.0016,1,4,0.25,7,0.25,0,0   *rods.9
8,1,0.9243,1,4,0.25,5,0.25,7,0.25,8,0.25   *rods.9
9,1,0.9216,1,5,0.25,6,0.25,8,0.25,9,0.25   *rods.9
10,2,0.0016,1,6,0.125,9,0.25,10,0.125   *rods.9
11,1,0.9074,1,7,0.25,11,0.25   *rods.9
12,1,0.8741,1,7,0.25,8,0.25,11,0.25,12,0.25   *rods.9
13,1,0.8720,1,8,0.25,9,0.25,12,0.25,13,0.25   *rods.9
14,1,0.9005,1,9,0.25,10,0.25,13,0.25,14,0.25   *rods.9
15,1,0.8615,1,10,0.125,14,0.25,15,0.125   *rods.9
16,1,0.8692,1,11,0.25,16,0.25,0,0   *rods.9
17,1,0.8379,1,11,0.25,12,0.25,16,0.25,17,0.25   *rods.9
18,1,0.8350,1,12,0.25,13,0.25,17,0.25,18,0.25   *rods.9
19,1,0.8615,1,13,0.25,14,0.25,18,0.25,19,0.25   *rods.9
20,1,0.8385,1,14,0.25,15,0.25,19,0.25,20,0.25   *rods.9
21,2,0.0013,1,15,0.125,20,0.25,21,0.125   *rods.9
22,2,0.0014,1,16,0.25,22,0.25   *rods.9
23,1,0.7997,1,16,0.25,17,0.25,22,0.25,23,0.25   *rods.9
24,1,0.7939,1,17,0.25,18,0.25,23,0.25,24,0.25   *rods.9
25,2,0.0014,1,18,0.25,19,0.25,24,0.25,25,0.25   *rods.9
26,1,0.7487,1,19,0.25,20,0.25,25,0.25,26,0.25   *rods.9
27,1,0.6616,1,20,0.25,21,0.25,26,0.25,27,0.25   *rods.9
28,1,0.5334,1,21,0.125,27,0.25,28,0.125   *rods.9
29,1,0.6722,1,22,0.25,29,0.25   *rods.9
30,1,0.6456,1,22,0.25,23,0.25,29,0.25,30,0.25   *rods.9
31,1,0.6391,1,23,0.25,24,0.25,30,0.25,31,0.25   *rods.9
32,1,0.6458,1,24,0.25,25,0.25,31,0.25,32,0.25   *rods.9
33,1,0.5714,1,25,0.25,26,0.25,32,0.25,33,0.25   *rods.9
34,3,1.0837,1,26,0.25,27,0.25,33,0.25,34,0.25   *rods.9
35,3,0.9100,1,27,0.25,28,0.25,34,0.25,35,0.25   *rods.9
36,3,0.7830,1,28,0.125,35,0.25,36,0.125   *rods.9
37,3,1.0786,1,29,0.25,37,0.25   *rods.9
38,3,1.0672,1,29,0.25,30,0.25,37,0.5   *rods.9
39,3,1.0578,1,30,0.25,31,0.25,37,0.5   *rods.9
40,3,1.0410,1,31,0.25,32,0.25,37,0.5   *rods.9
41,3,0.9687,1,32,0.25,33,0.25,37,0.25,38,0.25   *rods.9
42,3,0.8483,1,33,0.25,34,0.25,38,0.5   *rods.9
43,3,0.7762,1,34,0.25,35,0.25,38,0.5   *rods.9
44,3,0.7379,1,35,0.25,36,0.25,38,0.5   *rods.9
45,3,0.7264,1,36,0.125,38,0.375   *rods.9

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46,4,0.73051,1,37,38.31439394    *rods.9
47,4,0.73051,1,38,38.45123106    *rods.9
48,4,0.73051,1,39,72.25    *rods.9
49,4,0.73051,1,40,144.5    *rods.9
50,4,1.070,1,41,144.5    *rods.9
51,4,1.030,1,42,289    *rods.9
52,4,1.010,1,43,144.5    *rods.9
53,4,1.000,1,44,2023    *rods.9
54,4,0.989,1,45,4046    *rods.9
0    *rods.9
*          Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.6342,
620.6,0.0698,1.4381,710.6,0.0707,1.3996,
800.6,0.0715,1.3661,890.6,0.0722,1.3380,
980.6,0.0729,1.3153,1070.6,0.0735,1.2974,
1160.6,0.0740,1.2831,1250.6,0.0745,1.2711,
1340.6,0.0750,1.2598,1430.6,0.0754,1.2480,
1520.6,0.0758,1.2349,1610.6,0.0762,1.2202,
1700.6,0.0767,1.2041,1790.6,0.0771,1.1867,
1880.6,0.0775,1.1687,1970.6,0.0779,1.1503,
2060.6,0.0783,1.1321,2150.6,0.0788,1.1144,
2240.6,0.0793,1.0977,2330.6,0.0799,1.0823,
2420.6,0.0805,1.0684,2510.6,0.0813,1.0563,
2600.6,0.0821,1.0461,2690.6,0.0830,1.0380,
2780.6,0.0840,1.0323,2870.6,0.0851,1.0289,
2960.6,0.0864,1.0280,3050.6,0.0879,1.0296,
3140.6,0.0895,1.0339,3230.6,0.0914,1.0408,
3320.6,0.0934,1.0503,3410.6,0.0956,1.0624,
3500.6,0.0980,1.0772,3590.6,0.1006,1.0945,
3680.6,0.1035,1.1144,3770.6,0.1066,1.1368,
3860.6,0.1099,1.1615,3950.6,0.1134,1.1886,
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4040.6,0.1172,1.2179,4130.6,0.1212,1.2494,
4220.6,0.1254,1.2828,4310.6,0.1299,1.3183,
4400.6,0.1346,1.3555,4490.6,0.1395,1.3945,
4580.6,0.1446,1.4351,4670.6,0.1499,1.4772,
4760.6,0.1555,1.5207,4850.6,0.1612,1.5654,
4940.6,0.1671,1.6113,5030.6,0.1732,1.6582,
5120.6,0.1794,1.7061,5210.6,0.1858,1.7548,
5300.6,0.1924,1.8043,5390.6,0.1990,1.8544,
5480.6,0.2059,1.9050,5570.6,0.2128,1.9561,
5660.6,0.2199,2.0075,5750.6,0.2270,2.0592,
13940.,0.6954,4.3604,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
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3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.7591,
620.6,0.0925,2.0795,710.6,0.0937,1.9725,
800.6,0.0948,1.8839,890.6,0.0957,1.8116,
980.6,0.0966,1.7529,1070.6,0.0974,1.7056,
1160.6,0.0981,1.6671,1250.6,0.0987,1.6350,
1340.6,0.0993,1.6071,1430.6,0.0999,1.5818,
1520.6,0.1004,1.5576,1610.6,0.1009,1.5338,
1700.6,0.1015,1.5102,1790.6,0.1020,1.4865,
1880.6,0.1025,1.4631,1970.6,0.1030,1.4399,
2060.6,0.1034,1.4175,2150.6,0.1040,1.3960,
2240.6,0.1045,1.3758,2330.6,0.1051,1.3573,
2420.6,0.1057,1.3408,2510.6,0.1065,1.3265,
2600.6,0.1072,1.3146,2690.6,0.1080,1.3054,
2780.6,0.1089,1.2992,2870.6,0.1098,1.2959,
2960.6,0.1109,1.2958,3050.6,0.1121,1.2988,
3140.6,0.1134,1.3050,3230.6,0.1148,1.3142,
3320.6,0.1164,1.3264,3410.6,0.1181,1.3414,
3500.6,0.1199,1.3591,3590.6,0.1219,1.3792,
3680.6,0.1241,1.4014,3770.6,0.1264,1.4255,
3860.6,0.1289,1.4512,3950.6,0.1314,1.4782,
4040.6,0.1343,1.5062,4130.6,0.1372,1.5349,
4220.6,0.1403,1.5641,4310.6,0.1436,1.5938,
4400.6,0.1471,1.6235,4490.6,0.1507,1.6534,
4580.6,0.1544,1.6836,4670.6,0.1583,1.7142,
4760.6,0.1624,1.7455,4850.6,0.1666,1.7780,
4940.6,0.1709,1.8124,5030.6,0.1754,1.8494,
5120.6,0.1799,1.8903,5210.6,0.1846,1.9364,
5300.6,0.1894,1.9893,5390.6,0.1942,2.0509,
5480.6,0.1993,2.1235,5570.6,0.2043,2.2099,
5660.6,0.2096,2.3130,5750.6,0.2148,2.4363,
13940.0,0.5882,4919.2003,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
30,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 5.978819E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*          Nuclear Fuel Rod Power Profile
-1,3    *rods.3
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*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0016,1,1,0.125    *rods.9
2,1,0.9280,1,1,0.25,2,0.25    *rods.9
3,1,0.8941,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,0.9245,1,2,0.25,4,0.25    *rods.9
5,1,0.8909,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,0.8880,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0016,1,4,0.25,7,0.25,0,0    *rods.9
8,1,0.9161,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,0.9135,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0016,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,0.8996,1,7,0.25,11,0.25    *rods.9
12,1,0.8667,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,0.8648,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,0.8934,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,0.8551,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,0.8623,1,11,0.25,16,0.25,0,0    *rods.9
17,1,0.8313,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,0.8287,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,0.8553,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,0.8329,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0014,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0014,1,16,0.25,22,0.25    *rods.9
23,1,0.7941,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.7886,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0014,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.7444,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.6585,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.5317,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.6684,1,22,0.25,29,0.25    *rods.9
30,1,0.6421,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.6358,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.6427,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.5692,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.0838,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,0.9113,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.7852,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.0784,1,29,0.25,37,0.25    *rods.9
38,3,1.0671,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.0578,1,30,0.25,31,0.25,37,0.5    *rods.9
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40,3,1.0414,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,0.9696,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,0.8502,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.7784,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.7402,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.7288,1,36,0.125,38,0.375    *rods.9
46,4,0.72721,1,37,38.31439394    *rods.9
47,4,0.72721,1,38,38.45123106    *rods.9
48,4,0.72721,1,39,72.25    *rods.9
49,4,0.72721,1,40,144.5    *rods.9
50,4,1.070,1,41,144.5    *rods.9
51,4,1.030,1,42,289    *rods.9
52,4,1.010,1,43,144.5    *rods.9
53,4,1.000,1,44,2023    *rods.9
54,4,0.989,1,45,4046    *rods.9
0    *rods.9
*            Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002          *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026            *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.5828,
620.6,0.0698,1.3983,710.6,0.0707,1.3620,
800.6,0.0715,1.3305,890.6,0.0722,1.3042,
980.6,0.0729,1.2831,1070.6,0.0735,1.2667,
1160.6,0.0740,1.2538,1250.6,0.0745,1.2432,
1340.6,0.0750,1.2331,1430.6,0.0754,1.2225,
1520.6,0.0758,1.2107,1610.6,0.0762,1.1972,
1700.6,0.0767,1.1821,1790.6,0.0771,1.1659,
1880.6,0.0775,1.1488,1970.6,0.0779,1.1314,
2060.6,0.0783,1.1141,2150.6,0.0788,1.0973,
2240.6,0.0793,1.0814,2330.6,0.0799,1.0667,
2420.6,0.0805,1.0535,2510.6,0.0813,1.0420,
2600.6,0.0821,1.0324,2690.6,0.0830,1.0250,
2780.6,0.0840,1.0197,2870.6,0.0851,1.0169,
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2960.6,0.0864,1.0164,3050.6,0.0879,1.0185,
3140.6,0.0895,1.0232,3230.6,0.0914,1.0305,
3320.6,0.0934,1.0404,3410.6,0.0956,1.0529,
3500.6,0.0980,1.0680,3590.6,0.1006,1.0857,
3680.6,0.1035,1.1058,3770.6,0.1066,1.1285,
3860.6,0.1099,1.1535,3950.6,0.1134,1.1808,
4040.6,0.1172,1.2104,4130.6,0.1212,1.2421,
4220.6,0.1254,1.2758,4310.6,0.1299,1.3114,
4400.6,0.1346,1.3489,4490.6,0.1395,1.3881,
4580.6,0.1446,1.4289,4670.6,0.1499,1.4711,
4760.6,0.1555,1.5148,4850.6,0.1612,1.5597,
4940.6,0.1671,1.6057,5030.6,0.1732,1.6528,
5120.6,0.1794,1.7008,5210.6,0.1858,1.7497,
5300.6,0.1924,1.7993,5390.6,0.1990,1.8495,
5480.6,0.2059,1.9002,5570.6,0.2128,1.9514,
5660.6,0.2199,2.0030,5750.6,0.2270,2.0548,
13940.,0.6954,4.3594,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
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4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.7241,
620.6,0.0925,2.0524,710.6,0.0937,1.9468,
800.6,0.0948,1.8597,890.6,0.0957,1.7885,
980.6,0.0966,1.7310,1070.6,0.0974,1.6847,
1160.6,0.0981,1.6471,1250.6,0.0987,1.6159,
1340.6,0.0993,1.5889,1430.6,0.0999,1.5644,
1520.6,0.1004,1.5411,1610.6,0.1009,1.5181,
1700.6,0.1015,1.4952,1790.6,0.1020,1.4723,
1880.6,0.1025,1.4495,1970.6,0.1030,1.4271,
2060.6,0.1034,1.4052,2150.6,0.1040,1.3843,
2240.6,0.1045,1.3647,2330.6,0.1051,1.3467,
2420.6,0.1057,1.3306,2510.6,0.1065,1.3167,
2600.6,0.1072,1.3053,2690.6,0.1080,1.2965,
2780.6,0.1089,1.2906,2870.6,0.1098,1.2878,
2960.6,0.1109,1.2879,3050.6,0.1121,1.2912,
3140.6,0.1134,1.2977,3230.6,0.1148,1.3072,
3320.6,0.1164,1.3197,3410.6,0.1181,1.3350,
3500.6,0.1199,1.3529,3590.6,0.1219,1.3732,
3680.6,0.1241,1.3955,3770.6,0.1264,1.4199,
3860.6,0.1289,1.4457,3950.6,0.1314,1.4729,
4040.6,0.1343,1.5011,4130.6,0.1372,1.5300,
4220.6,0.1403,1.5594,4310.6,0.1436,1.5890,
4400.6,0.1471,1.6190,4490.6,0.1507,1.6491,
4580.6,0.1544,1.6794,4670.6,0.1583,1.7101,
4760.6,0.1624,1.7415,4850.6,0.1666,1.7741,
4940.6,0.1709,1.8086,5030.6,0.1754,1.8457,
5120.6,0.1799,1.8867,5210.6,0.1846,1.9329,
5300.6,0.1894,1.9859,5390.6,0.1942,2.0476,
5480.6,0.1993,2.1203,5570.6,0.2043,2.2067,
5660.6,0.2096,2.3099,5750.6,0.2148,2.4333,
13940.0,0.5882,4919.1996,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
31,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 6.386466E+04
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rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*           Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*           Normal Rod input
1,2,0.0016,1,1,0.125    *rods.9
2,1,0.9196,1,1,0.25,2,0.25    *rods.9
3,1,0.8861,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,0.9163,1,2,0.25,4,0.25    *rods.9
5,1,0.8831,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,0.8804,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0016,1,4,0.25,7,0.25,0,0    *rods.9
8,1,0.9083,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,0.9060,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0016,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,0.8923,1,7,0.25,11,0.25    *rods.9
12,1,0.8598,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,0.8580,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,0.8866,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,0.8491,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,0.8559,1,11,0.25,16,0.25,0,0    *rods.9
17,1,0.8251,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,0.8227,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,0.8494,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,0.8277,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0014,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0014,1,16,0.25,22,0.25    *rods.9
23,1,0.7889,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.7836,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0014,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.7404,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.6557,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.5302,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.6650,1,22,0.25,29,0.25    *rods.9
30,1,0.6389,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.6328,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.6398,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.5672,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
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34,3,1.0837,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,0.9125,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.7871,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.0781,1,29,0.25,37,0.25    *rods.9
38,3,1.0668,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.0578,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.0417,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,0.9705,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,0.8520,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.7806,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.7424,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.7311,1,36,0.125,38,0.375    *rods.9
46,4,0.72411,1,37,38.31439394    *rods.9
47,4,0.72411,1,38,38.45123106    *rods.9
48,4,0.72411,1,39,72.25    *rods.9
49,4,0.72411,1,40,144.5    *rods.9
50,4,1.070,1,41,144.5    *rods.9
51,4,1.030,1,42,289    *rods.9
52,4,1.010,1,43,144.5    *rods.9
53,4,1.000,1,44,2023    *rods.9
54,4,0.989,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0       *rods.66
* 0.0026           *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.5358,
620.6,0.0698,1.3616,710.6,0.0707,1.3273,
800.6,0.0715,1.2975,890.6,0.0722,1.2728,
980.6,0.0729,1.2532,1070.6,0.0735,1.2381,
1160.6,0.0740,1.2265,1250.6,0.0745,1.2169,
1340.6,0.0750,1.2080,1430.6,0.0754,1.1985,
1520.6,0.0758,1.1877,1610.6,0.0762,1.1752,
1700.6,0.0767,1.1612,1790.6,0.0771,1.1459,
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2240.6,0.0793,1.0656,2330.6,0.0799,1.0516,
2420.6,0.0805,1.0391,2510.6,0.0813,1.0282,
2600.6,0.0821,1.0192,2690.6,0.0830,1.0123,
2780.6,0.0840,1.0076,2870.6,0.0851,1.0052,
2960.6,0.0864,1.0052,3050.6,0.0879,1.0077,
3140.6,0.0895,1.0128,3230.6,0.0914,1.0205,
3320.6,0.0934,1.0307,3410.6,0.0956,1.0436,
3500.6,0.0980,1.0590,3590.6,0.1006,1.0770,
3680.6,0.1035,1.0974,3770.6,0.1066,1.1204,
3860.6,0.1099,1.1456,3950.6,0.1134,1.1732,
4040.6,0.1172,1.2030,4130.6,0.1212,1.2349,
4220.6,0.1254,1.2689,4310.6,0.1299,1.3047,
4400.6,0.1346,1.3424,4490.6,0.1395,1.3818,
4580.6,0.1446,1.4227,4670.6,0.1499,1.4652,
4760.6,0.1555,1.5090,4850.6,0.1612,1.5540,
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5120.6,0.1794,1.6957,5210.6,0.1858,1.7446,
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5480.6,0.2059,1.8956,5570.6,0.2128,1.9469,
5660.6,0.2199,1.9985,5750.6,0.2270,2.0504,
13940.,0.6954,4.3584,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
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800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
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3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.6920,
620.6,0.0925,2.0274,710.6,0.0937,1.9232,
800.6,0.0948,1.8372,890.6,0.0957,1.7671,
980.6,0.0966,1.7106,1070.6,0.0974,1.6652,
1160.6,0.0981,1.6285,1250.6,0.0987,1.5980,
1340.6,0.0993,1.5718,1430.6,0.0999,1.5480,
1520.6,0.1004,1.5254,1610.6,0.1009,1.5031,
1700.6,0.1015,1.4809,1790.6,0.1020,1.4587,
1880.6,0.1025,1.4366,1970.6,0.1030,1.4146,
2060.6,0.1034,1.3934,2150.6,0.1040,1.3731,
2240.6,0.1045,1.3539,2330.6,0.1051,1.3364,
2420.6,0.1057,1.3208,2510.6,0.1065,1.3073,
2600.6,0.1072,1.2963,2690.6,0.1080,1.2879,
2780.6,0.1089,1.2823,2870.6,0.1098,1.2798,
2960.6,0.1109,1.2803,3050.6,0.1121,1.2838,
3140.6,0.1134,1.2906,3230.6,0.1148,1.3004,
3320.6,0.1164,1.3131,3410.6,0.1181,1.3286,
3500.6,0.1199,1.3467,3590.6,0.1219,1.3672,
3680.6,0.1241,1.3898,3770.6,0.1264,1.4144,
3860.6,0.1289,1.4404,3950.6,0.1314,1.4677,
4040.6,0.1343,1.4960,4130.6,0.1372,1.5250,
4220.6,0.1403,1.5547,4310.6,0.1436,1.5845,
4400.6,0.1471,1.6145,4490.6,0.1507,1.6448,
4580.6,0.1544,1.6752,4670.6,0.1583,1.7060,
4760.6,0.1624,1.7375,4850.6,0.1666,1.7702,
4940.6,0.1709,1.8048,5030.6,0.1754,1.8421,
5120.6,0.1799,1.8832,5210.6,0.1846,1.9294,
5300.6,0.1894,1.9825,5390.6,0.1942,2.0443,
5480.6,0.1993,2.1171,5570.6,0.2043,2.2036,
5660.6,0.2096,2.3068,5750.6,0.2148,2.4303,
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13940.0,0.5882,4919.1989,
endd
*
* 17x17 Westinghouse 4-loop PWR (Comanche Peak) - DUPLEX IMF-UOX
32,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 6.794112E+04
rods,1,54,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*            Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*            Normal Rod input
1,2,0.0016,1,1,0.125    *rods.9
2,1,0.9121,1,1,0.25,2,0.25    *rods.9
3,1,0.8791,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,0.9090,1,2,0.25,4,0.25    *rods.9
5,1,0.8762,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,0.8736,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0.0016,1,4,0.25,7,0.25,0,0    *rods.9
8,1,0.9014,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,0.8993,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0.0016,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,0.8858,1,7,0.25,11,0.25    *rods.9
12,1,0.8536,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,0.8521,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,0.8807,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,0.8439,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,0.8502,1,11,0.25,16,0.25,0,0    *rods.9
17,1,0.8197,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,0.8175,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,0.8443,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,0.8231,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0.0014,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0.0014,1,16,0.25,22,0.25    *rods.9
23,1,0.7844,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,0.7793,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0.0014,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,0.7370,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,0.6534,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
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28,1,0.5292,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,0.6622,1,22,0.25,29,0.25    *rods.9
30,1,0.6363,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,0.6304,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,0.6376,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,0.5658,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,3,1.0838,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,3,0.9139,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,3,0.7893,1,28,0.125,35,0.25,36,0.125    *rods.9
37,3,1.0781,1,29,0.25,37,0.25    *rods.9
38,3,1.0669,1,29,0.25,30,0.25,37,0.5    *rods.9
39,3,1.0581,1,30,0.25,31,0.25,37,0.5    *rods.9
40,3,1.0422,1,31,0.25,32,0.25,37,0.5    *rods.9
41,3,0.9716,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,3,0.8541,1,33,0.25,34,0.25,38,0.5    *rods.9
43,3,0.7829,1,34,0.25,35,0.25,38,0.5    *rods.9
44,3,0.7448,1,35,0.25,36,0.25,38,0.5    *rods.9
45,3,0.7334,1,36,0.125,38,0.375    *rods.9
46,4,0.72151,1,37,38.31439394    *rods.9
47,4,0.72151,1,38,38.45123106    *rods.9
48,4,0.72151,1,39,72.25    *rods.9
49,4,0.72151,1,40,144.5    *rods.9
50,4,1.070,1,41,144.5    *rods.9
51,4,1.030,1,42,289    *rods.9
52,4,1.010,1,43,144.5    *rods.9
53,4,1.000,1,44,2023    *rods.9
54,4,0.989,1,45,4046    *rods.9
0    *rods.9
*           Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.95,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
* 0.4 0.00004 0.00002         *rods.65
* 0.05 0 0 0 0        *rods.66
* 0.0026          *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,1.4925,
620.6,0.0698,1.3276,710.6,0.0707,1.2950,
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1700.6,0.0767,1.1412,1790.6,0.0771,1.1268,
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2780.6,0.0840,0.9957,2870.6,0.0851,0.9938,
2960.6,0.0864,0.9943,3050.6,0.0879,0.9972,
3140.6,0.0895,1.0027,3230.6,0.0914,1.0107,
3320.6,0.0934,1.0213,3410.6,0.0956,1.0345,
3500.6,0.0980,1.0502,3590.6,0.1006,1.0685,
3680.6,0.1035,1.0892,3770.6,0.1066,1.1124,
3860.6,0.1099,1.1380,3950.6,0.1134,1.1658,
4040.6,0.1172,1.1958,4130.6,0.1212,1.2280,
4220.6,0.1254,1.2621,4310.6,0.1299,1.2982,
4400.6,0.1346,1.3360,4490.6,0.1395,1.3756,
4580.6,0.1446,1.4167,4670.6,0.1499,1.4593,
4760.6,0.1555,1.5033,4850.6,0.1612,1.5485,
4940.6,0.1671,1.5949,5030.6,0.1732,1.6422,
5120.6,0.1794,1.6906,5210.6,0.1858,1.7397,
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5480.6,0.2059,1.8910,5570.6,0.2128,1.9424,
5660.6,0.2199,1.9941,5750.6,0.2270,2.0461,
13940.,0.6954,4.3575,
2,61,359.929,IMF   *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
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1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,

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2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
-457.6,0.0787,4.4122,260.6,0.0840,2.6625,
620.6,0.0925,2.0042,710.6,0.0937,1.9011,
800.6,0.0948,1.8163,890.6,0.0957,1.7472,
980.6,0.0966,1.6916,1070.6,0.0974,1.6469,
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1340.6,0.0993,1.5557,1430.6,0.0999,1.5325,
1520.6,0.1004,1.5105,1610.6,0.1009,1.4889,
1700.6,0.1015,1.4673,1790.6,0.1020,1.4457,
1880.6,0.1025,1.4241,1970.6,0.1030,1.4028,
2060.6,0.1034,1.3821,2150.6,0.1040,1.3622,
2240.6,0.1045,1.3436,2330.6,0.1051,1.3264,
2420.6,0.1057,1.3112,2510.6,0.1065,1.2982,
2600.6,0.1072,1.2875,2690.6,0.1080,1.2794,
2780.6,0.1089,1.2742,2870.6,0.1098,1.2720,
2960.6,0.1109,1.2728,3050.6,0.1121,1.2767,
3140.6,0.1134,1.2837,3230.6,0.1148,1.2937,
3320.6,0.1164,1.3067,3410.6,0.1181,1.3224,
3500.6,0.1199,1.3407,3590.6,0.1219,1.3615,
3680.6,0.1241,1.3842,3770.6,0.1264,1.4089,
3860.6,0.1289,1.4352,3950.6,0.1314,1.4627,
4040.6,0.1343,1.4911,4130.6,0.1372,1.5203,
4220.6,0.1403,1.5500,4310.6,0.1436,1.5800,
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5120.6,0.1799,1.8798,5210.6,0.1846,1.9261,
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5480.6,0.1993,2.1140,5570.6,0.2043,2.2006,
5660.6,0.2096,2.3038,5750.6,0.2148,2.4274,
13940.0,0.5882,4919.1983,
endd
0
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C.2. PLOFA Transient Analysis

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*  TRANSIENT TYPE: PLOFA -  Power Multiplier:   1.12
*  SBU input deck for 17x17 Westinghouse 4-loop PWR (Comanche Peak)
*   Burnup at 19,024 [MWd/tHM]
1,0,0,-1,0    *vipre.1
1/8 17x17 DUPLEX Assembly Hot Bundle Analysis - CLOFA (ME1)        *vipre.2
*
*    channel geometry -   292  channels  ,  31  equally spaced axial nodes
*  Fuel Rod length is 152 inches, heated length is 144 inches
geom,292,292,31,0,0,0    *geom.1
152,0,0.5 * core height = 152 inches sl ratio = 0.5 *geom.2
*       channel dimensions
1,113.8943,1114.2770,995.9764,3,2,0.780,15.41,3,1.559,11.442,4,1.559,11.442
*geom.4
2,36.4462,356.5686,318.7124,3,3,1.559,6.482,6,1.559,6.482,10,0.780,12.434    *geom.4
3,36.4462,356.5686,318.7124,2,4,1.559,8.466,6,1.559,8.466    *geom.4
4,36.4462,356.5686,318.7124,2,5,1.559,6.978,7,1.559,8.466    *geom.4
5,18.2231,178.2843,159.3562,1,8,1.559,6.482    *geom.4
6,36.4462,356.5686,318.7124,2,7,1.559,8.466,11,1.559,8.466    *geom.4
7,36.4462,356.5686,318.7124,2,8,1.559,8.466,12,1.559,8.466    *geom.4
8,36.4462,356.5686,318.7124,5,9,1.559,6.978,13,0.390,8.466,14,0.390,8.466    *geom.4
15,0.3899,8.4660,16,0.390,8.466    *geom.4a
9,18.2231,178.2843,159.3562,1,17,1.559,6.978    *geom.4
10,18.2231,178.2843,159.3562,2,11,1.559,6.482,19,0.780,8.466    *geom.4
11,36.4462,356.5686,318.7124,2,12,1.559,8.466,20,1.559,8.466    *geom.4
12,36.4462,356.5686,318.7124,2,13,1.559,5.49,21,1.559,5.49    *geom.4
13,9.3875,91.7746,82.3105,5,14,1.559,1.984,25,0.090,4.746,26,0.090,4.746    *geom.4
27,0.0897,4.7460,28,0.090,4.746    *geom.4a
14,9.3875,91.7746,82.3105,5,15,1.559,1.984,29,0.090,4.746,30,0.090,4.746    *geom.4
31,0.0897,4.7460,32,0.090,4.746    *geom.4a
15,9.3875,91.7746,82.3105,5,16,1.559,1.984,33,0.090,4.746,34,0.090,4.746    *geom.4
35,0.0897,4.7460,36,0.090,4.746    *geom.4a
16,9.3875,91.7746,82.3105,5,17,1.559,5.49,37,0.090,4.746,38,0.090,4.746    *geom.4
39,0.0897,4.7460,40,0.090,4.746    *geom.4a
17,36.4462,356.5686,318.7124,2,18,1.559,6.978,281,1.559,5.49    *geom.4
18,18.2231,178.2843,159.3562,1,285,1.559,6.978    *geom.4
19,18.2231,178.2843,159.3562,2,20,1.559,6.482,286,0.780,8.466    *geom.4
20,36.4462,356.5686,318.7124,5,21,0.390,8.466,22,0.390,8.466,23,0.390,8.466
*geom.4
24,0.3899,8.4660,287,1.559,8.466    *geom.4a
21,9.3875,91.7746,82.3105,5,22,1.559,1.984,25,0.090,4.746,41,0.090,4.746    *geom.4
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57,0.0897,4.7460,73,0.090,4.746    *geom.4a
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121,0.0897,4.7460,137,0.090,4.746    *geom.4a
23,9.3875,91.7746,82.3105,5,24,1.559,1.984,153,0.090,4.746,169,0.090,4.746
*geom.4
185,0.0897,4.7460,201,0.090,4.746    *geom.4a
24,9.3875,91.7746,82.3105,5,217,0.090,4.746,233,0.090,4.746,249,0.090,4.746
*geom.4
265,0.0897,4.7460,288,1.559,5.49    *geom.4a
25,0.1164,1.2763,1.2763,2,26,0.090,0,41,0.090,0    *geom.4
26,0.1164,1.2763,1.2763,2,27,0.090,0,42,0.090,0    *geom.4
27,0.1164,1.2763,1.2763,2,28,0.090,0,43,0.090,0    *geom.4
28,0.1213,1.2510,1.2510,2,29,0.106,0,44,0.106,0    *geom.4
29,0.1263,1.2257,1.2257,2,30,0.106,0,45,0.122,0    *geom.4
30,0.1263,1.2257,1.2257,2,31,0.106,0,46,0.122,0    *geom.4
31,0.1263,1.2257,1.2257,2,32,0.106,0,47,0.122,0    *geom.4
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33,0.1263,1.2257,1.2257,2,34,0.106,0,49,0.122,0    *geom.4
34,0.1263,1.2257,1.2257,2,35,0.106,0,50,0.122,0    *geom.4
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36,0.1263,1.2257,1.2257,2,37,0.106,0,52,0.122,0    *geom.4
37,0.1213,1.2510,1.2510,2,38,0.090,0,53,0.106,0    *geom.4
38,0.1164,1.2763,1.2763,2,39,0.090,0,54,0.090,0    *geom.4
39,0.1164,1.2763,1.2763,2,40,0.090,0,55,0.090,0    *geom.4
40,0.1164,1.2763,1.2763,2,56,0.090,0,281,0.090,0    *geom.4
41,0.1164,1.2763,1.2763,2,42,0.090,0,57,0.090,0    *geom.4
42,0.1213,1.2510,1.2510,2,43,0.106,0,58,0.106,0    *geom.4
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44,0.1312,1.2003,1.2003,2,45,0.122,0,60,0.122,0    *geom.4
45,0.1180,1.2598,0.8813,2,46,0.068,0,61,0.068,0    *geom.4
46,0.1180,1.2598,0.8813,2,47,0.122,0,62,0.068,0    *geom.4
47,0.1361,1.1750,1.1750,2,48,0.122,0,63,0.122,0    *geom.4
48,0.1180,1.2598,0.8813,2,49,0.068,0,64,0.068,0    *geom.4
49,0.1180,1.2598,0.8813,2,50,0.122,0,65,0.068,0    *geom.4
50,0.1361,1.1750,1.1750,2,51,0.122,0,66,0.122,0    *geom.4
51,0.1180,1.2598,0.8813,2,52,0.068,0,67,0.068,0    *geom.4
52,0.1180,1.2598,0.8813,2,53,0.122,0,68,0.068,0    *geom.4
53,0.1312,1.2003,1.2003,2,54,0.106,0,69,0.122,0    *geom.4
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55,0.1213,1.2510,1.2510,2,56,0.090,0,71,0.106,0    *geom.4
56,0.1164,1.2763,1.2763,2,72,0.090,0,281,0.090,0    *geom.4
57,0.1164,1.2763,1.2763,2,58,0.090,0,73,0.090,0    *geom.4
58,0.1263,1.2257,1.2257,2,59,0.122,0,74,0.106,0    *geom.4
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61,0.1180,1.2598,0.8813,2,62,0.068,0,77,0.122,0    *geom.4
62,0.1180,1.2598,0.8813,2,63,0.122,0,78,0.122,0    *geom.4
63,0.1361,1.1750,1.1750,2,64,0.122,0,79,0.122,0    *geom.4
64,0.1180,1.2598,0.8813,2,65,0.068,0,80,0.122,0    *geom.4
65,0.1180,1.2598,0.8813,2,66,0.122,0,81,0.122,0    *geom.4
66,0.1361,1.1750,1.1750,2,67,0.122,0,82,0.122,0    *geom.4
67,0.1180,1.2598,0.8813,2,68,0.068,0,83,0.122,0    *geom.4
68,0.1180,1.2598,0.8813,2,69,0.122,0,84,0.122,0    *geom.4
69,0.1180,1.2598,0.8813,2,70,0.068,0,85,0.068,0    *geom.4
70,0.1180,1.2598,0.8813,2,71,0.122,0,86,0.068,0    *geom.4
71,0.1263,1.2257,1.2257,2,72,0.090,0,87,0.106,0    *geom.4
72,0.1164,1.2763,1.2763,2,88,0.090,0,281,0.090,0    *geom.4
73,0.1213,1.2510,1.2510,2,74,0.106,0,89,0.106,0    *geom.4
74,0.1312,1.2003,1.2003,2,75,0.122,0,90,0.122,0    *geom.4
75,0.1180,1.2598,0.8813,2,76,0.068,0,91,0.122,0    *geom.4
76,0.1180,1.2598,0.8813,2,77,0.122,0,92,0.122,0    *geom.4
77,0.1361,1.1750,1.1750,2,78,0.122,0,93,0.122,0    *geom.4
78,0.1361,1.1750,1.1750,2,79,0.122,0,94,0.122,0    *geom.4
79,0.1361,1.1750,1.1750,2,80,0.122,0,95,0.122,0    *geom.4
80,0.1361,1.1750,1.1750,2,81,0.122,0,96,0.122,0    *geom.4
81,0.1361,1.1750,1.1750,2,82,0.122,0,97,0.122,0    *geom.4
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84,0.1361,1.1750,1.1750,2,85,0.122,0,100,0.122,0    *geom.4
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88,0.1213,1.2510,1.2510,2,104,0.106,0,281,0.090,0    *geom.4
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91,0.1180,1.2598,0.8813,2,92,0.122,0,107,0.068,0    *geom.4
92,0.1361,1.1750,1.1750,2,93,0.122,0,108,0.122,0    *geom.4
93,0.1180,1.2598,0.8813,2,94,0.068,0,109,0.068,0    *geom.4
94,0.1180,1.2598,0.8813,2,95,0.122,0,110,0.068,0    *geom.4
95,0.1361,1.1750,1.1750,2,96,0.122,0,111,0.122,0    *geom.4
96,0.1180,1.2598,0.8813,2,97,0.068,0,112,0.068,0    *geom.4
97,0.1180,1.2598,0.8813,2,98,0.122,0,113,0.068,0    *geom.4
98,0.1361,1.1750,1.1750,2,99,0.122,0,114,0.122,0    *geom.4
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100,0.1180,1.2598,0.8813,2,101,0.122,0,116,0.068,0    *geom.4
101,0.1361,1.1750,1.1750,2,102,0.122,0,117,0.122,0    *geom.4
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102,0.1180,1.2598,0.8813,2,103,0.068,0,118,0.068,0    *geom.4
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104,0.1263,1.2257,1.2257,2,120,0.106,0,282,0.090,0    *geom.4
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107,0.1180,1.2598,0.8813,2,108,0.122,0,123,0.122,0    *geom.4
108,0.1361,1.1750,1.1750,2,109,0.122,0,124,0.122,0    *geom.4
109,0.1180,1.2598,0.8813,2,110,0.068,0,125,0.122,0    *geom.4
110,0.1180,1.2598,0.8813,2,111,0.122,0,126,0.122,0    *geom.4
111,0.1361,1.1750,1.1750,2,112,0.122,0,127,0.122,0    *geom.4
112,0.1180,1.2598,0.8813,2,113,0.068,0,128,0.122,0    *geom.4
113,0.1180,1.2598,0.8813,2,114,0.122,0,129,0.122,0    *geom.4
114,0.1361,1.1750,1.1750,2,115,0.122,0,130,0.122,0    *geom.4
115,0.1180,1.2598,0.8813,2,116,0.068,0,131,0.122,0    *geom.4
116,0.1180,1.2598,0.8813,2,117,0.122,0,132,0.122,0    *geom.4
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118,0.1180,1.2598,0.8813,2,119,0.068,0,134,0.122,0    *geom.4
119,0.1180,1.2598,0.8813,2,120,0.122,0,135,0.122,0    *geom.4
120,0.1263,1.2257,1.2257,2,136,0.106,0,282,0.090,0    *geom.4
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122,0.1361,1.1750,1.1750,2,123,0.122,0,138,0.122,0    *geom.4
123,0.1361,1.1750,1.1750,2,124,0.122,0,139,0.122,0    *geom.4
124,0.1361,1.1750,1.1750,2,125,0.122,0,140,0.122,0    *geom.4
125,0.1361,1.1750,1.1750,2,126,0.122,0,141,0.122,0    *geom.4
126,0.1361,1.1750,1.1750,2,127,0.122,0,142,0.122,0    *geom.4
127,0.1361,1.1750,1.1750,2,128,0.122,0,143,0.122,0    *geom.4
128,0.1361,1.1750,1.1750,2,129,0.122,0,144,0.122,0    *geom.4
129,0.1361,1.1750,1.1750,2,130,0.122,0,145,0.122,0    *geom.4
130,0.1361,1.1750,1.1750,2,131,0.122,0,146,0.122,0    *geom.4
131,0.1361,1.1750,1.1750,2,132,0.122,0,147,0.122,0    *geom.4
132,0.1361,1.1750,1.1750,2,133,0.122,0,148,0.122,0    *geom.4
133,0.1361,1.1750,1.1750,2,134,0.122,0,149,0.122,0    *geom.4
134,0.1361,1.1750,1.1750,2,135,0.122,0,150,0.122,0    *geom.4
135,0.1361,1.1750,1.1750,2,136,0.122,0,151,0.122,0    *geom.4
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203.32,729.1,1800.    *prop.3
*
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.18,-.2,0.,64.,-1.,0.,*,axial friction correlation    *drag.2
.5,.496,* pitch = 0.496, Kij = 0.5l/p    *drag.5
*
grid,0,1    *grid.1
.86,* seed-blanket drag factors    *grid.2
-1,8    *grid.4
6,1,26,1,46,1,66,1,86,1,106,1,126,1,146,1    *grid.6
*grid.6
0    *grid.4
*
corr,1,0,    *corr.1
epri,epri,epri,none,    *corr.2
0.2    *corr.3
ditb    *corr.6
w-3l    *corr.9
0.043,0.066,0.986    *corr.11
*
*       Operating Conditions
oper,1,1,0,0,0,1,0,0,0,0    *oper.1
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60.0960,0.0420    *oper.20
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cont    *cont.1
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15.0,1500,40,40,2,0,0,0,* cont.2 - time step and convergence    criteria
0.1,0.0001,0.001,0.05,0.01,0.8,1.5,0.9,* cont.3 - convergence    limits
* 0.001  *cont.4
* 0.,0.10,8.5,0.01,10,0.1  * cont.5 - time step tables
5,1,0,1,-1,0,1,1,0,0,0,1,0,0,0    *cont.6
30000,0,5,0,0,0    *cont.7
2,* 229 * cont.8 - Channel    number
*                        *cont.9
2,* 168,242,247,186, * cont.10 - Rod    number
* 2   * 229                      *cont.11 - Channel number for CHF
*                        *cont.12
summ,2    *summ.1
6,1,1    *summ.2
8,1,1    *summ.2
*
*            Rod Layout - mixed nuclear and control rods
*
rods,1,325,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*            Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*            Normal Rod input
1,4,0.9232,1,1,825    *rods.9
2,4,1.025,1,2,528    *rods.9
3,4,0.86,1,3,264    *rods.9
4,4,0.8,1,4,264    *rods.9
5,4,0.79,1,5,132    *rods.9
6,4,1.08,1,6,264    *rods.9
7,4,1.02,1,7,264    *rods.9
8,4,1.07,1,8,264    *rods.9
9,4,1.15,1,9,132    *rods.9
10,4,0.82,1,10,132    *rods.9
11,4,0.88,1,11,264    *rods.9
12,4,0.86,1,12,264    *rods.9
13,4,1.07,1,13,66    *rods.9
14,4,1.07,1,14,66    *rods.9
15,4,1.07,1,15,66    *rods.9
16,4,1.07,1,16,66    *rods.9
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17,4,0.95,1,17,264    *rods.9
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19,4,0.93,1,19,132    *rods.9
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23,4,0.92,1,23,66    *rods.9
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29,3,1.3798,1,13,0.25,14,0.25,28,0.25,29,0.25    *rods.9
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100,1,1.3857,1,79,0.25,80,0.25,95,0.25,96,0.25    *rods.9
101,1,1.4381,1,80,0.25,81,0.25,96,0.25,97,0.25    *rods.9
102,1,1.3857,1,81,0.25,82,0.25,97,0.25,98,0.25    *rods.9
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103,1,1.3785,1,82,0.25,83,0.25,98,0.25,99,0.25    *rods.9
104,1,1.4156,1,83,0.25,84,0.25,99,0.25,100,0.25    *rods.9
105,1,1.3463,1,84,0.25,85,0.25,100,0.25,101,0.25    *rods.9
106,1,1.2978,1,85,0.25,86,0.25,101,0.25,102,0.25    *rods.9
107,1,1.1462,1,86,0.25,87,0.25,102,0.25,103,0.25    *rods.9
108,1,0.8609,1,87,0.25,88,0.25,103,0.25,104,0.25    *rods.9
109,3,1.3798,1,88,0.25,104,0.25,281,0.25,282,0.25    *rods.9
110,3,1.4949,1,22,0.5,89,0.25,105,0.25    *rods.9
111,1,0.9809,1,89,0.25,90,0.25,105,0.25,106,0.25    *rods.9
112,2,0.0018,1,90,0.25,91,0.25,106,0.25,107,0.25    *rods.9
113,1,1.3429,1,91,0.25,92,0.25,107,0.25,108,0.25    *rods.9
114,1,1.4156,1,92,0.25,93,0.25,108,0.25,109,0.25    *rods.9
115,2,0.0022,1,93,0.25,94,0.25,109,0.25,110,0.25    *rods.9
116,1,1.4630,1,94,0.25,95,0.25,110,0.25,111,0.25    *rods.9
117,1,1.4711,1,95,0.25,96,0.25,111,0.25,112,0.25    *rods.9
118,2,0.0022,1,96,0.25,97,0.25,112,0.25,113,0.25    *rods.9
119,1,1.4711,1,97,0.25,98,0.25,113,0.25,114,0.25    *rods.9
120,1,1.4630,1,98,0.25,99,0.25,114,0.25,115,0.25    *rods.9
121,2,0.0022,1,99,0.25,100,0.25,115,0.25,116,0.25    *rods.9
122,1,1.4156,1,100,0.25,101,0.25,116,0.25,117,0.25    *rods.9
123,1,1.3429,1,101,0.25,102,0.25,117,0.25,118,0.25    *rods.9
124,2,0.0018,1,102,0.25,103,0.25,118,0.25,119,0.25    *rods.9
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127,3,1.5260,1,22,0.5,105,0.25,121,0.25    *rods.9
128,1,0.9769,1,105,0.25,106,0.25,121,0.25,122,0.25    *rods.9
129,1,1.2310,1,106,0.25,107,0.25,122,0.25,123,0.25    *rods.9
130,1,1.3100,1,107,0.25,108,0.25,123,0.25,124,0.25    *rods.9
131,1,1.3785,1,108,0.25,109,0.25,124,0.25,125,0.25    *rods.9
132,1,1.4630,1,109,0.25,110,0.25,125,0.25,126,0.25    *rods.9
133,1,1.4295,1,110,0.25,111,0.25,126,0.25,127,0.25    *rods.9
134,1,1.4379,1,111,0.25,112,0.25,127,0.25,128,0.25    *rods.9
135,1,1.4916,1,112,0.25,113,0.25,128,0.25,129,0.25    *rods.9
136,1,1.4379,1,113,0.25,114,0.25,129,0.25,130,0.25    *rods.9
137,1,1.4295,1,114,0.25,115,0.25,130,0.25,131,0.25    *rods.9
138,1,1.4630,1,115,0.25,116,0.25,131,0.25,132,0.25    *rods.9
139,1,1.3785,1,116,0.25,117,0.25,132,0.25,133,0.25    *rods.9
140,1,1.3100,1,117,0.25,118,0.25,133,0.25,134,0.25    *rods.9
141,1,1.2310,1,118,0.25,119,0.25,134,0.25,135,0.25    *rods.9
142,1,0.9769,1,119,0.25,120,0.25,135,0.25,136,0.25    *rods.9
143,3,1.5260,1,120,0.25,136,0.25,282,0.5    *rods.9
144,3,1.5435,1,22,0.5,121,0.25,137,0.25    *rods.9
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146,1,1.2437,1,122,0.25,123,0.25,138,0.25,139,0.25    *rods.9
147,1,1.3183,1,123,0.25,124,0.25,139,0.25,140,0.25    *rods.9
148,1,1.3857,1,124,0.25,125,0.25,140,0.25,141,0.25    *rods.9
149,1,1.4711,1,125,0.25,126,0.25,141,0.25,142,0.25    *rods.9
150,1,1.4379,1,126,0.25,127,0.25,142,0.25,143,0.25    *rods.9
151,1,1.4467,1,127,0.25,128,0.25,143,0.25,144,0.25    *rods.9
152,1,1.5010,1,128,0.25,129,0.25,144,0.25,145,0.25    *rods.9
153,1,1.4467,1,129,0.25,130,0.25,145,0.25,146,0.25    *rods.9
154,1,1.4379,1,130,0.25,131,0.25,146,0.25,147,0.25    *rods.9
155,1,1.4711,1,131,0.25,132,0.25,147,0.25,148,0.25    *rods.9
156,1,1.3857,1,132,0.25,133,0.25,148,0.25,149,0.25    *rods.9
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159,1,0.9897,1,135,0.25,136,0.25,151,0.25,152,0.25    *rods.9
160,3,1.5435,1,136,0.25,152,0.25,282,0.5    *rods.9
161,3,1.5612,1,22,0.25,23,0.25,137,0.25,153,0.25    *rods.9
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164,1,1.3669,1,139,0.25,140,0.25,155,0.25,156,0.25    *rods.9
165,1,1.4381,1,140,0.25,141,0.25,156,0.25,157,0.25    *rods.9
166,2,0.0022,1,141,0.25,142,0.25,157,0.25,158,0.25    *rods.9
167,1,1.4916,1,142,0.25,143,0.25,158,0.25,159,0.25    *rods.9
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169,2,0.0022,1,144,0.25,145,0.25,160,0.25,161,0.25    *rods.9
170,1,1.5010,1,145,0.25,146,0.25,161,0.25,162,0.25    *rods.9
171,1,1.4916,1,146,0.25,147,0.25,162,0.25,163,0.25    *rods.9
172,2,0.0022,1,147,0.25,148,0.25,163,0.25,164,0.25    *rods.9
173,1,1.4381,1,148,0.25,149,0.25,164,0.25,165,0.25    *rods.9
174,1,1.3669,1,149,0.25,150,0.25,165,0.25,166,0.25    *rods.9
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176,1,1.0304,1,151,0.25,152,0.25,167,0.25,168,0.25    *rods.9
177,3,1.5612,1,152,0.25,168,0.25,282,0.25,283,0.25    *rods.9
178,3,1.5435,1,23,0.5,153,0.25,169,0.25    *rods.9
179,1,0.9897,1,153,0.25,154,0.25,169,0.25,170,0.25    *rods.9
180,1,1.2437,1,154,0.25,155,0.25,170,0.25,171,0.25    *rods.9
181,1,1.3183,1,155,0.25,156,0.25,171,0.25,172,0.25    *rods.9
182,1,1.3857,1,156,0.25,157,0.25,172,0.25,173,0.25    *rods.9
183,1,1.4711,1,157,0.25,158,0.25,173,0.25,174,0.25    *rods.9
184,1,1.4379,1,158,0.25,159,0.25,174,0.25,175,0.25    *rods.9
185,1,1.4467,1,159,0.25,160,0.25,175,0.25,176,0.25    *rods.9
186,1,1.5010,1,160,0.25,161,0.25,176,0.25,177,0.25    *rods.9
187,1,1.4467,1,161,0.25,162,0.25,177,0.25,178,0.25    *rods.9
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191,1,1.3183,1,165,0.25,166,0.25,181,0.25,182,0.25    *rods.9
192,1,1.2437,1,166,0.25,167,0.25,182,0.25,183,0.25    *rods.9
193,1,0.9897,1,167,0.25,168,0.25,183,0.25,184,0.25    *rods.9
194,3,1.5435,1,168,0.25,184,0.25,283,0.5    *rods.9
195,3,1.5260,1,23,0.5,169,0.25,185,0.25    *rods.9
196,1,0.9769,1,169,0.25,170,0.25,185,0.25,186,0.25    *rods.9
197,1,1.2310,1,170,0.25,171,0.25,186,0.25,187,0.25    *rods.9
198,1,1.3100,1,171,0.25,172,0.25,187,0.25,188,0.25    *rods.9
199,1,1.3785,1,172,0.25,173,0.25,188,0.25,189,0.25    *rods.9
200,1,1.4630,1,173,0.25,174,0.25,189,0.25,190,0.25    *rods.9
201,1,1.4295,1,174,0.25,175,0.25,190,0.25,191,0.25    *rods.9
202,1,1.4379,1,175,0.25,176,0.25,191,0.25,192,0.25    *rods.9
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207,1,1.3785,1,180,0.25,181,0.25,196,0.25,197,0.25    *rods.9
208,1,1.3100,1,181,0.25,182,0.25,197,0.25,198,0.25    *rods.9
209,1,1.2310,1,182,0.25,183,0.25,198,0.25,199,0.25    *rods.9
210,1,0.9769,1,183,0.25,184,0.25,199,0.25,200,0.25    *rods.9
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213,1,0.9809,1,185,0.25,186,0.25,201,0.25,202,0.25    *rods.9
214,2,0.0018,1,186,0.25,187,0.25,202,0.25,203,0.25    *rods.9
215,1,1.3429,1,187,0.25,188,0.25,203,0.25,204,0.25    *rods.9
216,1,1.4156,1,188,0.25,189,0.25,204,0.25,205,0.25    *rods.9
217,2,0.0022,1,189,0.25,190,0.25,205,0.25,206,0.25    *rods.9
218,1,1.4630,1,190,0.25,191,0.25,206,0.25,207,0.25    *rods.9
219,1,1.4711,1,191,0.25,192,0.25,207,0.25,208,0.25    *rods.9
220,2,0.0022,1,192,0.25,193,0.25,208,0.25,209,0.25    *rods.9
221,1,1.4711,1,193,0.25,194,0.25,209,0.25,210,0.25    *rods.9
222,1,1.4630,1,194,0.25,195,0.25,210,0.25,211,0.25    *rods.9
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240,1,1.4156,1,211,0.25,212,0.25,227,0.25,228,0.25    *rods.9
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246,3,1.1892,1,24,0.5,217,0.25,233,0.25    *rods.9
247,3,1.5606,1,217,0.25,218,0.25,233,0.25,234,0.25    *rods.9
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254,1,1.3669,1,224,0.25,225,0.25,240,0.25,241,0.25    *rods.9
255,1,1.3183,1,225,0.25,226,0.25,241,0.25,242,0.25    *rods.9
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263,3,1.0778,1,24,0.5,233,0.25,249,0.25    *rods.9
264,3,1.2871,1,233,0.25,234,0.25,249,0.25,250,0.25    *rods.9
265,1,0.7978,1,234,0.25,235,0.25,250,0.25,251,0.25    *rods.9
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269,1,1.2310,1,238,0.25,239,0.25,254,0.25,255,0.25    *rods.9
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281,3,1.0892,1,249,0.25,250,0.25,265,0.25,266,0.25    *rods.9
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285,1,0.9809,1,253,0.25,254,0.25,269,0.25,270,0.25    *rods.9
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293,3,1.5606,1,261,0.25,262,0.25,277,0.25,278,0.25    *rods.9
294,3,1.2871,1,262,0.25,263,0.25,278,0.25,279,0.25    *rods.9
295,3,1.0892,1,263,0.25,264,0.25,279,0.25,280,0.25    *rods.9
296,3,1.0191,1,264,0.25,280,0.25,284,0.5    *rods.9
297,3,1.0006,1,24,0.375,265,0.25,289,0.375    *rods.9
298,3,1.0191,1,265,0.25,266,0.25,289,0.5    *rods.9
299,3,1.0778,1,266,0.25,267,0.25,289,0.5    *rods.9
300,3,1.1892,1,267,0.25,268,0.25,289,0.5    *rods.9
301,3,1.3798,1,268,0.25,269,0.25,289,0.25,290,0.25    *rods.9
302,3,1.4949,1,269,0.25,270,0.25,290,0.5    *rods.9
303,3,1.5260,1,270,0.25,271,0.25,290,0.5    *rods.9
304,3,1.5435,1,271,0.25,272,0.25,290,0.5    *rods.9
305,3,1.5612,1,272,0.25,273,0.25,290,0.25,291,0.25    *rods.9
306,3,1.5435,1,273,0.25,274,0.25,291,0.5    *rods.9
307,3,1.5260,1,274,0.25,275,0.25,291,0.5    *rods.9
308,3,1.4949,1,275,0.25,276,0.25,291,0.5    *rods.9
309,3,1.3798,1,276,0.25,277,0.25,291,0.25,292,0.25    *rods.9
310,3,1.1892,1,277,0.25,278,0.25,292,0.5    *rods.9
311,3,1.0778,1,278,0.25,279,0.25,292,0.5    *rods.9
312,3,1.0191,1,279,0.25,280,0.25,292,0.5    *rods.9
313,3,1.0006,1,280,0.25,284,0.375,292,0.375    *rods.9
314,4,1.1,1,281,66    *rods.9
315,4,1.1,1,282,66    *rods.9
316,4,1.1,1,283,66    *rods.9
317,4,1.1,1,284,66    *rods.9
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318,4,0.82,1,285,264    *rods.9
319,4,1.12,1,286,132    *rods.9
320,4,1.16,1,287,264    *rods.9
321,4,1.03,1,288,264    *rods.9
322,4,0.83,1,289,66    *rods.9
323,4,0.83,1,290,66    *rods.9
324,4,0.83,1,291,66    *rods.9
325,4,0.83,1,292,66    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.9,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
*  0.4  0.00004  0.00002                  *rods.65
*  0.05  0  0  0  0               *rods.66
*  0.0026                     *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
-457.6,0.0597,4.0445,260.6,0.0634,2.5185,
620.6,0.0698,2.0773,710.6,0.0707,1.9934,
800.6,0.0715,1.9188,890.6,0.0722,1.8531,
980.6,0.0729,1.7955,1070.6,0.0735,1.7449,
1160.6,0.0740,1.6997,1250.6,0.0745,1.6583,
1340.6,0.0750,1.6193,1430.6,0.0754,1.5816,
1520.6,0.0758,1.5445,1610.6,0.0762,1.5079,
1700.6,0.0767,1.4717,1790.6,0.0771,1.4362,
1880.6,0.0775,1.4018,1970.6,0.0779,1.3687,
2060.6,0.0783,1.3371,2150.6,0.0788,1.3074,
2240.6,0.0793,1.2798,2330.6,0.0799,1.2543,
2420.6,0.0805,1.2313,2510.6,0.0813,1.2108,
2600.6,0.0821,1.1929,2690.6,0.0830,1.1778,
2780.6,0.0840,1.1655,2870.6,0.0851,1.1560,
2960.6,0.0864,1.1495,3050.6,0.0879,1.1459,
3140.6,0.0895,1.1452,3230.6,0.0914,1.1475,
3320.6,0.0934,1.1527,3410.6,0.0956,1.1608,
3500.6,0.0980,1.1718,3590.6,0.1006,1.1856,
3680.6,0.1035,1.2021,3770.6,0.1066,1.2212,
3860.6,0.1099,1.2430,3950.6,0.1134,1.2672,
4040.6,0.1172,1.2938,4130.6,0.1212,1.3227,
```

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4220.6,0.1254,1.3538,4310.6,0.1299,1.3869,
4400.6,0.1346,1.4220,4490.6,0.1395,1.4589,
4580.6,0.1446,1.4975,4670.6,0.1499,1.5377,
4760.6,0.1555,1.5793,4850.6,0.1612,1.6223,
4940.6,0.1671,1.6666,5030.6,0.1732,1.7119,
5120.6,0.1794,1.7583,5210.6,0.1858,1.8056,
5300.6,0.1924,1.8536,5390.6,0.1990,1.9024,
5480.6,0.2059,1.9517,5570.6,0.2128,2.0015,
5660.6,0.2199,2.0518,5750.6,0.2270,2.1023,
13940.,0.6954,4.3696,
2,61,359.929,IMF    *rods.70
-457.6,0.1194,5.2001,260.6,0.1281,5.1697,
620.6,0.1412,3.4540,710.6,0.1431,3.2000,
800.6,0.1447,2.9936,890.6,0.1462,2.8264,
980.6,0.1474,2.6907,1070.6,0.1486,2.5803,
1160.6,0.1496,2.4898,1250.6,0.1506,2.4147,
1340.6,0.1515,2.3514,1430.6,0.1523,2.2970,
1520.6,0.1531,2.2490,1610.6,0.1539,2.2058,
1700.6,0.1546,2.1661,1790.6,0.1553,2.1290,
1880.6,0.1560,2.0939,1970.6,0.1567,2.0606,
2060.6,0.1573,2.0291,2150.6,0.1580,1.9994,
2240.6,0.1586,1.9718,2330.6,0.1592,1.9467,
2420.6,0.1598,1.9244,2510.6,0.1604,1.9054,
2600.6,0.1610,1.8900,2690.6,0.1616,1.8784,
2780.6,0.1621,1.8711,2870.6,0.1627,1.8682,
2960.6,0.1633,1.8697,3050.6,0.1639,1.8756,
3140.6,0.1645,1.8859,3230.6,0.1651,1.9002,
3320.6,0.1657,1.9182,3410.6,0.1663,1.9394,
3500.6,0.1669,1.9633,3590.6,0.1675,1.9892,
3680.6,0.1681,2.0164,3770.6,0.1688,2.0443,
3860.6,0.1695,2.0720,3950.6,0.1701,2.0988,
4040.6,0.1708,2.1239,4130.6,0.1716,2.1468,
4220.6,0.1723,2.1670,4310.6,0.1730,2.1840,
4400.6,0.1738,2.1977,4490.6,0.1746,2.2083,
4580.6,0.1755,2.2162,4670.6,0.1763,2.2221,
4760.6,0.1772,2.2273,4850.6,0.1781,2.2336,
4940.6,0.1790,2.2433,5030.6,0.1800,2.2592,
5120.6,0.1809,2.2851,5210.6,0.1819,2.3255,
5300.6,0.1830,2.3857,5390.6,0.1840,2.4720,
5480.6,0.1851,2.5918,5570.6,0.1862,2.7538,
5660.6,0.1874,2.9676,5750.6,0.1885,3.2444,
13940.,0.3584,15451.,
3,61,359.929,MIX    *rods.70
```

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-457.6,0.0787,4.4122,260.6,0.0840,3.3621,
620.6,0.0925,2.5153,710.6,0.0937,2.3773,
800.6,0.0948,2.2608,890.6,0.0957,2.1628,
980.6,0.0966,2.0803,1070.6,0.0974,2.0107,
1160.6,0.0981,1.9511,1250.6,0.0987,1.8990,
1340.6,0.0993,1.8522,1430.6,0.0999,1.8092,
1520.6,0.1004,1.7687,1610.6,0.1009,1.7300,
1700.6,0.1015,1.6926,1790.6,0.1020,1.6566,
1880.6,0.1025,1.6220,1970.6,0.1030,1.5888,
2060.6,0.1034,1.5573,2150.6,0.1040,1.5276,
2240.6,0.1045,1.5000,2330.6,0.1051,1.4746,
2420.6,0.1057,1.4518,2510.6,0.1065,1.4318,
2600.6,0.1072,1.4147,2690.6,0.1080,1.4007,
2780.6,0.1089,1.3900,2870.6,0.1098,1.3826,
2960.6,0.1109,1.3787,3050.6,0.1121,1.3781,
3140.6,0.1134,1.3809,3230.6,0.1148,1.3870,
3320.6,0.1164,1.3963,3410.6,0.1181,1.4085,
3500.6,0.1199,1.4236,3590.6,0.1219,1.4413,
3680.6,0.1241,1.4612,3770.6,0.1264,1.4831,
3860.6,0.1289,1.5068,3950.6,0.1314,1.5318,
4040.6,0.1343,1.5579,4130.6,0.1372,1.5849,
4220.6,0.1403,1.6125,4310.6,0.1436,1.6405,
4400.6,0.1471,1.6688,4490.6,0.1507,1.6973,
4580.6,0.1544,1.7262,4670.6,0.1583,1.7555,
4760.6,0.1624,1.7855,4850.6,0.1666,1.8168,
4940.6,0.1709,1.8501,5030.6,0.1754,1.8860,
5120.6,0.1799,1.9259,5210.6,0.1846,1.9710,
5300.6,0.1894,2.0229,5390.6,0.1942,2.0836,
5480.6,0.1993,2.1554,5570.6,0.2043,2.2409,
5660.6,0.2096,2.3432,5750.6,0.2148,2.4657,
13940.0,0.5882,4919.2065,
endd
0
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C.3. CLOFA Transient Analysis

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*  TRANSIENT TYPE: CLOFA - Power Multiplier:   1.12
*  SBU input deck for 17x17 Westinghouse 4-loop PWR (Comanche Peak)
*   Burnup at 19,024 [MWd/tHM]
1,0,0,-1,0    *vipre.1
1/8 17x17 DUPLEX Assembly Hot Bundle Analysis - CLOFA (ME1)        *vipre.2
*
*    channel geometry -   292  channels  ,  31  equally spaced axial nodes
*  Fuel Rod length is 152 inches, heated length is 144 inches
geom,292,292,31,0,0,0    *geom.1
152,0,0.5 * core height = 152 inches sl ratio = 0.5 *geom.2
*      channel dimensions
1,113.8943,1114.2770,995.9764,3,2,0.780,15.41,3,1.559,11.442,4,1.559,11.442
*geom.4
2,36.4462,356.5686,318.7124,3,3,1.559,6.482,6,1.559,6.482,10,0.780,12.434    *geom.4
3,36.4462,356.5686,318.7124,2,4,1.559,8.466,6,1.559,8.466    *geom.4
4,36.4462,356.5686,318.7124,2,5,1.559,6.978,7,1.559,8.466    *geom.4
5,18.2231,178.2843,159.3562,1,8,1.559,6.482    *geom.4
6,36.4462,356.5686,318.7124,2,7,1.559,8.466,11,1.559,8.466    *geom.4
7,36.4462,356.5686,318.7124,2,8,1.559,8.466,12,1.559,8.466    *geom.4
8,36.4462,356.5686,318.7124,5,9,1.559,6.978,13,0.390,8.466,14,0.390,8.466    *geom.4
15,0.3899,8.4660,16,0.390,8.466    *geom.4a
9,18.2231,178.2843,159.3562,1,17,1.559,6.978    *geom.4
10,18.2231,178.2843,159.3562,2,11,1.559,6.482,19,0.780,8.466    *geom.4
11,36.4462,356.5686,318.7124,2,12,1.559,8.466,20,1.559,8.466    *geom.4
12,36.4462,356.5686,318.7124,2,13,1.559,5.49,21,1.559,5.49    *geom.4
13,9.3875,91.7746,82.3105,5,14,1.559,1.984,25,0.090,4.746,26,0.090,4.746    *geom.4
27,0.0897,4.7460,28,0.090,4.746    *geom.4a
14,9.3875,91.7746,82.3105,5,15,1.559,1.984,29,0.090,4.746,30,0.090,4.746    *geom.4
31,0.0897,4.7460,32,0.090,4.746    *geom.4a
15,9.3875,91.7746,82.3105,5,16,1.559,1.984,33,0.090,4.746,34,0.090,4.746    *geom.4
35,0.0897,4.7460,36,0.090,4.746    *geom.4a
16,9.3875,91.7746,82.3105,5,17,1.559,5.49,37,0.090,4.746,38,0.090,4.746    *geom.4
39,0.0897,4.7460,40,0.090,4.746    *geom.4a
17,36.4462,356.5686,318.7124,2,18,1.559,6.978,281,1.559,5.49    *geom.4
18,18.2231,178.2843,159.3562,1,285,1.559,6.978    *geom.4
19,18.2231,178.2843,159.3562,2,20,1.559,6.482,286,0.780,8.466    *geom.4
20,36.4462,356.5686,318.7124,5,21,0.390,8.466,22,0.390,8.466,23,0.390,8.466
*geom.4
24,0.3899,8.4660,287,1.559,8.466    *geom.4a
21,9.3875,91.7746,82.3105,5,22,1.559,1.984,25,0.090,4.746,41,0.090,4.746    *geom.4
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57,0.0897,4.7460,73,0.090,4.746 *geom.4a
22,9.3875,91.7746,82.3105,5,23,1.559,1.984,89,0.090,4.746,105,0.090,4.746 *geom.4
121,0.0897,4.7460,137,0.090,4.746 *geom.4a
23,9.3875,91.7746,82.3105,5,24,1.559,1.984,153,0.090,4.746,169,0.090,4.746
*geom.4
185,0.0897,4.7460,201,0.090,4.746 *geom.4a
24,9.3875,91.7746,82.3105,5,217,0.090,4.746,233,0.090,4.746,249,0.090,4.746
*geom.4
265,0.0897,4.7460,288,1.559,5.49 *geom.4a
25,0.1164,1.2763,1.2763,2,26,0.090,0,41,0.090,0 *geom.4
26,0.1164,1.2763,1.2763,2,27,0.090,0,42,0.090,0 *geom.4
27,0.1164,1.2763,1.2763,2,28,0.090,0,43,0.090,0 *geom.4
28,0.1213,1.2510,1.2510,2,29,0.106,0,44,0.106,0 *geom.4
29,0.1263,1.2257,1.2257,2,30,0.106,0,45,0.122,0 *geom.4
30,0.1263,1.2257,1.2257,2,31,0.106,0,46,0.122,0 *geom.4
31,0.1263,1.2257,1.2257,2,32,0.106,0,47,0.122,0 *geom.4
32,0.1263,1.2257,1.2257,2,33,0.106,0,48,0.122,0 *geom.4
33,0.1263,1.2257,1.2257,2,34,0.106,0,49,0.122,0 *geom.4
34,0.1263,1.2257,1.2257,2,35,0.106,0,50,0.122,0 *geom.4
35,0.1263,1.2257,1.2257,2,36,0.106,0,51,0.122,0 *geom.4
36,0.1263,1.2257,1.2257,2,37,0.106,0,52,0.122,0 *geom.4
37,0.1213,1.2510,1.2510,2,38,0.090,0,53,0.106,0 *geom.4
38,0.1164,1.2763,1.2763,2,39,0.090,0,54,0.090,0 *geom.4
39,0.1164,1.2763,1.2763,2,40,0.090,0,55,0.090,0 *geom.4
40,0.1164,1.2763,1.2763,2,56,0.090,0,281,0.090,0 *geom.4
41,0.1164,1.2763,1.2763,2,42,0.090,0,57,0.090,0 *geom.4
42,0.1213,1.2510,1.2510,2,43,0.106,0,58,0.106,0 *geom.4
43,0.1263,1.2257,1.2257,2,44,0.106,0,59,0.122,0 *geom.4
44,0.1312,1.2003,1.2003,2,45,0.122,0,60,0.122,0 *geom.4
45,0.1180,1.2598,0.8813,2,46,0.068,0,61,0.068,0 *geom.4
46,0.1180,1.2598,0.8813,2,47,0.122,0,62,0.068,0 *geom.4
47,0.1361,1.1750,1.1750,2,48,0.122,0,63,0.122,0 *geom.4
48,0.1180,1.2598,0.8813,2,49,0.068,0,64,0.068,0 *geom.4
49,0.1180,1.2598,0.8813,2,50,0.122,0,65,0.068,0 *geom.4
50,0.1361,1.1750,1.1750,2,51,0.122,0,66,0.122,0 *geom.4
51,0.1180,1.2598,0.8813,2,52,0.068,0,67,0.068,0 *geom.4
52,0.1180,1.2598,0.8813,2,53,0.122,0,68,0.068,0 *geom.4
53,0.1312,1.2003,1.2003,2,54,0.106,0,69,0.122,0 *geom.4
54,0.1263,1.2257,1.2257,2,55,0.106,0,70,0.122,0 *geom.4
55,0.1213,1.2510,1.2510,2,56,0.090,0,71,0.106,0 *geom.4
56,0.1164,1.2763,1.2763,2,72,0.090,0,281,0.090,0 *geom.4
57,0.1164,1.2763,1.2763,2,58,0.090,0,73,0.090,0 *geom.4
58,0.1263,1.2257,1.2257,2,59,0.122,0,74,0.106,0 *geom.4

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59,0.1180,1.2598,0.8813,2,60,0.068,0,75,0.068,0    *geom.4
60,0.1180,1.2598,0.8813,2,61,0.122,0,76,0.068,0    *geom.4
61,0.1180,1.2598,0.8813,2,62,0.068,0,77,0.122,0    *geom.4
62,0.1180,1.2598,0.8813,2,63,0.122,0,78,0.122,0    *geom.4
63,0.1361,1.1750,1.1750,2,64,0.122,0,79,0.122,0    *geom.4
64,0.1180,1.2598,0.8813,2,65,0.068,0,80,0.122,0    *geom.4
65,0.1180,1.2598,0.8813,2,66,0.122,0,81,0.122,0    *geom.4
66,0.1361,1.1750,1.1750,2,67,0.122,0,82,0.122,0    *geom.4
67,0.1180,1.2598,0.8813,2,68,0.068,0,83,0.122,0    *geom.4
68,0.1180,1.2598,0.8813,2,69,0.122,0,84,0.122,0    *geom.4
69,0.1180,1.2598,0.8813,2,70,0.068,0,85,0.068,0    *geom.4
70,0.1180,1.2598,0.8813,2,71,0.122,0,86,0.068,0    *geom.4
71,0.1263,1.2257,1.2257,2,72,0.090,0,87,0.106,0    *geom.4
72,0.1164,1.2763,1.2763,2,88,0.090,0,281,0.090,0    *geom.4
73,0.1213,1.2510,1.2510,2,74,0.106,0,89,0.106,0    *geom.4
74,0.1312,1.2003,1.2003,2,75,0.122,0,90,0.122,0    *geom.4
75,0.1180,1.2598,0.8813,2,76,0.068,0,91,0.122,0    *geom.4
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drag,1,0,1    *drag.1
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grid,0,1    *grid.1
.86,* seed-blanket drag factors    *grid.2
-1,8    *grid.4
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*grid.6
0    *grid.4
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epri,epri,epri,none,    *corr.2
0.2    *corr.3
ditb    *corr.6
w-3l    *corr.9
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60.1823,0.0419    *oper.20
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* 0.001  *cont.4
* 0.,0.10,8.5,0.01,10,0.1  * cont.5 - time step tables
5,1,0,1,-1,0,1,1,0,0,0,1,0,0,0    *cont.6
30000,0,5,0,0,0    *cont.7
2,* 229 * cont.8 - Channel    number
*                        *cont.9
2,* 168,242,247,186, * cont.10 - Rod    number
* 2   * 229                        *cont.11 - Channel number for CHF
*                        *cont.12
summ,2    *summ.1
6,1,1    *summ.2
8,1,1    *summ.2
*
*            Rod Layout - mixed nuclear and control rods
*
rods,1,325,1,4,3,0,0,0,0,0,0,0    *rods.1
*
144,4,0,0,0.0    *rods.2
*
*            Nuclear Fuel Rod Power Profile
-1,3    *rods.3
*
1.55    *rods.5
*
*            Normal Rod input
1,4,0.9232,1,1,825    *rods.9
2,4,1.025,1,2,528    *rods.9
3,4,0.86,1,3,264    *rods.9
4,4,0.8,1,4,264    *rods.9
5,4,0.79,1,5,132    *rods.9
6,4,1.08,1,6,264    *rods.9
7,4,1.02,1,7,264    *rods.9
8,4,1.07,1,8,264    *rods.9
9,4,1.15,1,9,132    *rods.9
10,4,0.82,1,10,132    *rods.9
11,4,0.88,1,11,264    *rods.9
12,4,0.86,1,12,264    *rods.9
13,4,1.07,1,13,66    *rods.9
14,4,1.07,1,14,66    *rods.9
15,4,1.07,1,15,66    *rods.9
16,4,1.07,1,16,66    *rods.9
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20,4,1.36,1,20,264    *rods.9
21,4,0.92,1,21,66    *rods.9
22,4,0.92,1,22,66    *rods.9
23,4,0.92,1,23,66    *rods.9
24,4,0.92,1,24,66    *rods.9
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26,3,1.0191,1,13,0.5,25,0.25,26,0.25    *rods.9
27,3,1.0778,1,13,0.5,26,0.25,27,0.25    *rods.9
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38,3,1.1892,1,16,0.5,37,0.25,38,0.25    *rods.9
39,3,1.0778,1,16,0.5,38,0.25,39,0.25    *rods.9
40,3,1.0191,1,16,0.5,39,0.25,40,0.25    *rods.9
41,3,1.0006,1,16,0.375,40,0.25,281,0.375    *rods.9
42,3,1.0191,1,21,0.5,25,0.25,41,0.25    *rods.9
43,3,1.0892,1,25,0.25,26,0.25,41,0.25,42,0.25    *rods.9
44,3,1.2871,1,26,0.25,27,0.25,42,0.25,43,0.25    *rods.9
45,3,1.5606,1,27,0.25,28,0.25,43,0.25,44,0.25    *rods.9
46,1,0.8609,1,28,0.25,29,0.25,44,0.25,45,0.25    *rods.9
47,1,0.9809,1,29,0.25,30,0.25,45,0.25,46,0.25    *rods.9
48,1,0.9769,1,30,0.25,31,0.25,46,0.25,47,0.25    *rods.9
49,1,0.9897,1,31,0.25,32,0.25,47,0.25,48,0.25    *rods.9
50,1,1.0304,1,32,0.25,33,0.25,48,0.25,49,0.25    *rods.9
51,1,0.9897,1,33,0.25,34,0.25,49,0.25,50,0.25    *rods.9
52,1,0.9769,1,34,0.25,35,0.25,50,0.25,51,0.25    *rods.9
53,1,0.9809,1,35,0.25,36,0.25,51,0.25,52,0.25    *rods.9
54,1,0.8609,1,36,0.25,37,0.25,52,0.25,53,0.25    *rods.9
55,3,1.5606,1,37,0.25,38,0.25,53,0.25,54,0.25    *rods.9
56,3,1.2871,1,38,0.25,39,0.25,54,0.25,55,0.25    *rods.9
57,3,1.0892,1,39,0.25,40,0.25,55,0.25,56,0.25    *rods.9
58,3,1.0191,1,40,0.25,56,0.25,281,0.5    *rods.9
59,3,1.0778,1,21,0.5,41,0.25,57,0.25    *rods.9
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62,1,1.0023,1,43,0.25,44,0.25,59,0.25,60,0.25    *rods.9
63,1,1.1462,1,44,0.25,45,0.25,60,0.25,61,0.25    *rods.9
64,2,0.0018,1,45,0.25,46,0.25,61,0.25,62,0.25    *rods.9
65,1,1.2310,1,46,0.25,47,0.25,62,0.25,63,0.25    *rods.9
66,1,1.2437,1,47,0.25,48,0.25,63,0.25,64,0.25    *rods.9
67,2,0.0019,1,48,0.25,49,0.25,64,0.25,65,0.25    *rods.9
68,1,1.2437,1,49,0.25,50,0.25,65,0.25,66,0.25    *rods.9
69,1,1.2310,1,50,0.25,51,0.25,66,0.25,67,0.25    *rods.9
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71,1,1.1462,1,52,0.25,53,0.25,68,0.25,69,0.25    *rods.9
72,1,1.0023,1,53,0.25,54,0.25,69,0.25,70,0.25    *rods.9
73,1,0.7978,1,54,0.25,55,0.25,70,0.25,71,0.25    *rods.9
74,3,1.2871,1,55,0.25,56,0.25,71,0.25,72,0.25    *rods.9
75,3,1.0778,1,56,0.25,72,0.25,281,0.5    *rods.9
76,3,1.1892,1,21,0.5,57,0.25,73,0.25    *rods.9
77,3,1.5606,1,57,0.25,58,0.25,73,0.25,74,0.25    *rods.9
78,1,1.0023,1,58,0.25,59,0.25,74,0.25,75,0.25    *rods.9
79,2,0.0018,1,59,0.25,60,0.25,75,0.25,76,0.25    *rods.9
80,1,1.2978,1,60,0.25,61,0.25,76,0.25,77,0.25    *rods.9
81,1,1.3429,1,61,0.25,62,0.25,77,0.25,78,0.25    *rods.9
82,1,1.3100,1,62,0.25,63,0.25,78,0.25,79,0.25    *rods.9
83,1,1.3183,1,63,0.25,64,0.25,79,0.25,80,0.25    *rods.9
84,1,1.3669,1,64,0.25,65,0.25,80,0.25,81,0.25    *rods.9
85,1,1.3183,1,65,0.25,66,0.25,81,0.25,82,0.25    *rods.9
86,1,1.3100,1,66,0.25,67,0.25,82,0.25,83,0.25    *rods.9
87,1,1.3429,1,67,0.25,68,0.25,83,0.25,84,0.25    *rods.9
88,1,1.2978,1,68,0.25,69,0.25,84,0.25,85,0.25    *rods.9
89,2,0.0018,1,69,0.25,70,0.25,85,0.25,86,0.25    *rods.9
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91,3,1.5606,1,71,0.25,72,0.25,87,0.25,88,0.25    *rods.9
92,3,1.1892,1,72,0.25,88,0.25,281,0.5    *rods.9
93,3,1.3798,1,21,0.25,22,0.25,73,0.25,89,0.25    *rods.9
94,1,0.8609,1,73,0.25,74,0.25,89,0.25,90,0.25    *rods.9
95,1,1.1462,1,74,0.25,75,0.25,90,0.25,91,0.25    *rods.9
96,1,1.2978,1,75,0.25,76,0.25,91,0.25,92,0.25    *rods.9
97,1,1.3463,1,76,0.25,77,0.25,92,0.25,93,0.25    *rods.9
98,1,1.4156,1,77,0.25,78,0.25,93,0.25,94,0.25    *rods.9
99,1,1.3785,1,78,0.25,79,0.25,94,0.25,95,0.25    *rods.9
100,1,1.3857,1,79,0.25,80,0.25,95,0.25,96,0.25    *rods.9
101,1,1.4381,1,80,0.25,81,0.25,96,0.25,97,0.25    *rods.9
102,1,1.3857,1,81,0.25,82,0.25,97,0.25,98,0.25    *rods.9
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103,1,1.3785,1,82,0.25,83,0.25,98,0.25,99,0.25   *rods.9
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106,1,1.2978,1,85,0.25,86,0.25,101,0.25,102,0.25   *rods.9
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115,2,0.0022,1,93,0.25,94,0.25,109,0.25,110,0.25   *rods.9
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118,2,0.0022,1,96,0.25,97,0.25,112,0.25,113,0.25   *rods.9
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127,3,1.5260,1,22,0.5,105,0.25,121,0.25   *rods.9
128,1,0.9769,1,105,0.25,106,0.25,121,0.25,122,0.25   *rods.9
129,1,1.2310,1,106,0.25,107,0.25,122,0.25,123,0.25   *rods.9
130,1,1.3100,1,107,0.25,108,0.25,123,0.25,124,0.25   *rods.9
131,1,1.3785,1,108,0.25,109,0.25,124,0.25,125,0.25   *rods.9
132,1,1.4630,1,109,0.25,110,0.25,125,0.25,126,0.25   *rods.9
133,1,1.4295,1,110,0.25,111,0.25,126,0.25,127,0.25   *rods.9
134,1,1.4379,1,111,0.25,112,0.25,127,0.25,128,0.25   *rods.9
135,1,1.4916,1,112,0.25,113,0.25,128,0.25,129,0.25   *rods.9
136,1,1.4379,1,113,0.25,114,0.25,129,0.25,130,0.25   *rods.9
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174,1,1.3669,1,149,0.25,150,0.25,165,0.25,166,0.25 *rods.9
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191,1,1.3183,1,165,0.25,166,0.25,181,0.25,182,0.25 *rods.9
192,1,1.2437,1,166,0.25,167,0.25,182,0.25,183,0.25 *rods.9
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194,3,1.5435,1,168,0.25,184,0.25,283,0.5 *rods.9
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199,1,1.3785,1,172,0.25,173,0.25,188,0.25,189,0.25 *rods.9
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201,1,1.4295,1,174,0.25,175,0.25,190,0.25,191,0.25 *rods.9
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212,3,1.4949,1,23,0.5,185,0.25,201,0.25 *rods.9
213,1,0.9809,1,185,0.25,186,0.25,201,0.25,202,0.25 *rods.9
214,2,0.0018,1,186,0.25,187,0.25,202,0.25,203,0.25 *rods.9
215,1,1.3429,1,187,0.25,188,0.25,203,0.25,204,0.25 *rods.9
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231,1,1.1462,1,202,0.25,203,0.25,218,0.25,219,0.25 *rods.9

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303,3,1.5260,1,270,0.25,271,0.25,290,0.5 *rods.9
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313,3,1.0006,1,280,0.25,284,0.375,292,0.375 *rods.9
314,4,1.1,1,281,66 *rods.9
315,4,1.1,1,282,66 *rods.9
316,4,1.1,1,283,66 *rods.9
317,4,1.1,1,284,66 *rods.9

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319,4,1.12,1,286,132    *rods.9
320,4,1.16,1,287,264    *rods.9
321,4,1.03,1,288,264    *rods.9
322,4,0.83,1,289,66    *rods.9
323,4,0.83,1,290,66    *rods.9
324,4,0.83,1,291,66    *rods.9
325,4,0.83,1,292,66    *rods.9
0    *rods.9
*            Fuel Geometry Types
*
1,nucl,0.374015748,0.322519685,6,0.0,0.022519685    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
3,nucl,0.406267717,0.354771654,6,0.0,0.022519685    *rods.62
0,2,0,0,0,2000,0.9,0    *rods.63
4,nucl,0.384277738,0.332781675,6,0.0,0.022519685    *rods.62
0,3,0,0,0,2000,0.95,0    *rods.63
*  0.4  0.00004  0.00002                  *rods.65
*  0.05  0  0  0  0               *rods.66
*  0.0026                    *rods.67
2,dumy,0.482,0,0    *rods.68
1,61,651.186,UO2    *rods.70
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