THERMAL-HYDRAULIC ANALYSIS OF ADVANCED MIXED-OXIDE FUEL ASSEMBLIES WITH VIPRE-01

A Thesis

by

ADAM ROSS BINGHAM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Nuclear Engineering

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Approved by:

Chair of Committee,	Karen Vierow
Committee Members,	Timothy Jacobs
	Jean Ragusa
Head of Department,	Raymond J. Juzaitis

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ABSTRACT

Thermal-Hydraulic Analysis of Advanced Mixed-Oxide Fuel Assemblies with VIPRE-01. (May 2009)

Adam Ross Bingham, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Karen Vierow

Two new fuel assembly designs for light water reactors using advanced mixed-oxide fuels have been proposed to reduce the radiotoxicity of used nuclear fuel discharged from nuclear power plants. The research efforts of this thesis are the first to consider the effects of burnup on advanced mixed-oxide fuel assembly performance and thermal safety margin over an assembly's expected operational burnup lifetime. In order to accomplish this, a new burnup-dependent thermal-hydraulic analysis methodology has been developed. The new methodology models many of the effects of burnup on an assembly design by including burnup-dependent variations in fuel pin relative power from neutronic calculations, assembly power reductions due to fissile content depletion and core reshuffling, and fuel material thermal-physical properties. Additionally, a text-based coupling method is developed to facilitate the exchange of information between the neutronic code DRAGON and thermal-hydraulic code VIPRE-01. The new methodology effectively covers the entire assembly burnup lifetime and evaluates the thermal-hydraulic performance against ANS Condition I, II, and III events with respect to the minimum departure from nucleate boiling ratio, peak cladding temperatures, and fuel centerline temperatures.

A comprehensive literature survey on the thermal conductivity of posed fuel materials with burnup-dependence has been carried out to model the advanced materials in the thermal-hydraulic code VIPRE-01. Where documented conductivity values are not available, a simplified method for estimating the thermal conductivity has been developed. The new thermal conductivity models are based on established FRAPCON-3 fuel property models used in the nuclear industry, with small adjustments having been made to account for actinide additions.

Steady-state and transient thermal-hydraulic analyses are performed with VIPRE-01 for a reference UO_2 assembly design, and two advanced mixed-oxide fuel assembly designs using the new burnup-dependent thermal-hydraulic analysis methodology. All three designs maintain a sufficiently large thermal margin with respect to the minimum departure from nucleate boiling ratio, and maximum cladding and fuel temperatures during partial and complete loss-of-flow accident scenarios. The presence of a thin $(Am,Zr)O_2$ outer layer on the fuel pellet in the two advanced mixed-oxide fuel assembly designs increases maximum fuel temperatures during transient conditions, but does not otherwise greatly compromise the thermal margin of the new designs.

TO MY WIFE

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I would like to thank all the members of the Laboratory for Nuclear Heat Transfer Systems for their advice and encouragement. I would also like to thank Professor Karen Vierow for being the best advisor any graduate student could ever have. The guidance and suggestions she provided have made this research possible.

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Finally, I would like to thank my family, including Gary & Cecelia Bingham, Samantha Bingham and, most importantly, my wife, Rachel Bingham. Their continued support, backing, and patience have been immensely influential in the completion of this work.

NOMENCLATURE

ABBREVIATIONS

ACF	actinide concentration-dependent factor
ADS	accelerator driven systems
AEC	Atomic Energy Commission
AECL	Atomic Energy of Canada Limited
AFCI	Advanced Fuel Cycle Initiative
Am	amercium
AMOX	advanced mixed-oxide
ANS	American Nuclear Society
AOO	Anticipated Operational Occurrence
APA	Advanced Plutonium Fuel Assembly
BOL	beginning-of-life
BWR	boiling water reactor
CHF	critical heat flux
CHFR	critical heat flux ratio
CLOFA	complete loss-of-flow accident
CONFU	Combined NonFertile and Uranium
CR	control rod
DBA	design basis accident
DNB	departure from nucleate boiling
DNBR	departure from nucleate boiling ratio
DOE	Department of Energy
EOL	end-of-life
FBR	fast burner reactors

FFF	fertile free fuels
Gen-IV	Generation-IV
GIS	gas-in-solid
GNEP	Global Nuclear Energy Partnership
GUI	graphic user interface
HEM	homogeneous equilibrium model
IMF	inert matrix fuel
LHGR	linear heat generation rate
LOCA	loss-of-coolant accident
LOFA	loss-of-flow accident
LWR	light water reactor
MA	minor actinides
MDNBR	miniumum departure from nucleate boiling ratio
MNFI	modified Nuclear Fuels Industries
MOX	mixed-oxide
NFI	Nuclear Fuels Industries
NRC	Nuclear Regulatory Commission
O	oxygen
O/M	oxygen-to-metal ratio
PCI	pellet cladding interaction
PCMI	pellet cladding mechanical interaction
PCT	peak cladding temperature
PLOFA	partial loss-of-flow accident
PRA	probabilistic risk assessment
Pu	plutonium
PWR	pressurized water reactor
RCS	Reactor Coolant System
SAR	Safety Analysis Report
SER	Safety Evaluation Report

TRU	transuranic elements
U	uranium
UNF	used nuclear fuel
Zr	zirconium

SYMBOLS

A	area
C_p	specific heat
d	diameter
f	friction factor
$\mathrm{F_Q}$	Heat Flux Hot Channel Factor
$\mathrm{F^E{}_Q}$	Engineering Heat Flux Hot Channel Factor
$\mathrm{F^N{}_Q}$	Nuclear Heat Flux Hot Channel Factor
$\mathrm{F^N{}_A}$	assembly relative power
$\mathrm{F^N{}_{HA}}$	hot assembly relative power
$\mathrm{F^N{}_{\Delta H}}$	Nuclear Enthalpy Rise Hot Channel Factor
$\mathrm{F^N{}_U}$	Nuclear Heat Flux Uncertainty Factor
$\mathrm{F^N{}_{XY}}$	Nuclear Heat Flux Radial Factor
$\mathrm{F^N{}_{XY,A}}$	maximum relative rod power in average assembly
$\mathrm{F^N{}_{XY,HA}}$	hot pin relative power in hot assembly
$\mathrm{F^N{}_Z}$	Nuclear Heat Flux Axial Factor
$\mathrm{F^V{}_{HA}}$	VIPRE hot assembly relative power
G	axial mass flux
h	enthalpy
h_g	gap gas thermal conductance
HP	channel heated perimeter
k	thermal conductivity
K	thermal conductance ($1/R$)
K_G	cross-flow resistance coefficient

M	mass
$PuCon$	plutonium-dioxide content
Re	Reynolds number (ud/ν)
r	radius
r_g	gap radius
r_{gi}	gap inner radius
r_{go}	gap outer radius
R	thermal resistance $(\Delta r/kA_s)$
Q	heat transfer
Q'''	volumetric heat generation rate
$q''(z)$	heat flux through a surface at axial position z
$q''_{\mathrm{CHF}}(z)$	critical heat flux through a surface at axial position z
S_p	fuel rod pin-to-pin pitch
t	time
T	temperature
T_{melt}	fuel melting temperature
u	axial velocity
v	lateral velocity
V	volume
WP	channel wetted perimeter
$\partial/\partial t$	partial derivative with respect to time
$\vec{\Psi}$	vector quantity
$\langle\Psi\rangle$	area averaged Ψ; $\frac{1}{A}\int_A \Psi dA$
$\langle\langle\Psi\rangle\rangle$	volume averaged Ψ; $\frac{1}{V}\int_V \Psi dV$

Greek symbols:

Γ	phonon diffusion cross-section
ϵ_t	eddy diffusivity
ν	kinematic viscosity

ρ	density

Subscripts:

g	gap
r	fuel rod
s	surface

VIPRE: Heat Transfer Model

Subscripts:

i	“from” heat node i
$i-1$	“to” heat node $i-1$
$i+1$	“to” heat node $i+1$

VIPRE: Flow-Field Model

A	channel flow area perpindicular to axial flow
F_{m}	total axial force on the cell due to turbulent mixing
FTM	turbulent momentum factor
$\overline{G}$	cell average axial mass flux ($\langle \rho u \rangle$)
Δh	enthalpy difference between cell, i, and adjacent cell, k
l	distance between centroids of adjacent cells
m	axial mass flow rate ($\langle \rho u \rangle A$)
Q_{m}	total turbulent mixing energy input to cell
s	gap width
S	gap area ($s\Delta X$)
s/l	gap-to-length ratio
u	axial flow velocity
$\overline{u}$	cell average axial flow velocity
Δu	axial velocity difference between cell, i, and adjacent cell, k
v	lateral flow velocity

w	lateral mass flow rate ($\langle \rho v \rangle S$)
w'	time-fluctuating cross-flow per unit length
ΔX	subchannel cell axial height

Greek symbols:

β	turbulent mixing coefficient

Subscripts:

As	assembly
cr	control rod
fr	fuel rod
i	“to” cell i
it	instrument tube
k	“from” adjacent cell k
$k \in i$	all lateral flow areas, k, connected to cell, i
sq	square channel
tr	triangular channel

Heat Conduction

A	phonon-lattice scattering representative factor
B	phonon-phonon scattering representative factor
C	electron hole pair formation representative factor

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1. INTRODUCTION

There is a growing demand for energy on a global scale. Worldwide energy consumption is expected to increase by 50% from 2005 to 2030 [1]. While high and volatile oil and natural gas prices are likely to retard to the growth of energy demand in the long-term, overall world energy consumption is projected to increase strongly as a result of stable economic growth and increasing population in the world's developing countries. Currently, the United States accounts for 22% of global energy consumption [1]. While this share is expected to diminish over the next 25 years, the nation's total energy requirements will continue to increase in all sectors.

The significance of greenhouse gases from carbon emissions and their negative effects on global climate have recently been realized, and great effort is being made to encourage reduction of carbon emissions from industrialized nations. Large sources of greenhouse gases in the United States are from electrical generation plants, with the largest emitters being coal, petroleum, and natural gas plants [1]. In order to meet growing energy demands and reduce the U.S. carbon footprint, many new and existing clean electricity generating technologies are being examined, including: solar, wind, and nuclear.

Nuclear energy is an attractive means of generating electricity because it can provide large amounts of reliable, inexpensive and uninterrupted power, the carbon footprint is minimal, the plants are based on proven technology, and the nuclear industry boasts a highly successful operational history over the past 30 years. However, while nuclear power plants do not generate large carbon emissions, they do produce radioactive waste. The 104 commercial operating nuclear power plants in the United States discharge over 2000 metric tons of used nuclear fuel (UNF) every year, with

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the total accumulated UNF inventory exceeding 54,000 metric tons as of 2004 [2].

The majority of UNF is stored onsite at nuclear power facilities throughout the country in used nuclear fuel pools or dry cask storage units. The used nuclear fuel pools and dry cask units were intended to store discharged fuel temporarily until a permanent repository was readied by the federal government. The U.S. Department of Energy (DOE) has proposed to build a permanent geological repository in the Yucca Mountains in Nevada, pending further evaluation from the U.S. Nuclear Regulatory Commission (NRC). If built, the Yucca Mountain repository will be the first of its kind in the U.S. and aid in alleviating the nuclear utility companies from a burdened waste retention infrastructure. However, concerns have already been raised by members of the nuclear engineering community regarding the need for a second UNF and radiological waste repository because the Yucca Mountain facility has a design capacity of 70,000 metric tons.

In order to avoid or delay the technical need for a second geological repository in the U.S., the feasibility of nuclear fuel reprocessing and closed fuel cycles are being investigated by the DOE as part of its Advanced Fuel Cycle Initiative (AFCI) and Generation-IV (Gen-IV) program. Currently, commercial U.S. power reactors operate on a once-through (‘open’) cycle, with the used nuclear fuel being stored onsite until a more permanent storage solution is available. However, even after discharge, UNF retains a great deal of usable material. The majority of the usable material consists of uranium and transuranic elements (TRUs) such as plutonium. Additional TRU elements found in discharged fuel are neptunium and minor actinides (MA), including americium and curium. These TRU constituents are the primary contributors to the long-term decay heat and radiotoxicity of the discharged UNF [3].

One of the goals of the Global Nuclear Energy Partnership (GNEP) is to reduce the total volume, radiotoxicity, and heat load of UNF by extracting TRUs from the fuel through reprocessing and destroying (‘burning’) them in fast burner reactors (FBRs). GNEP was announced by President Bush in his 2006 State of the Union address and has since attracted several international partner countries. The viability of reprocessing has been shown through successful programs implemented in Great Britain and France. To date, a number of reactor systems have been proposed for burning TRUs, such as subcritical accelerator driven systems (ADSs) and critical fast spectrum reactor systems like the FBRs [4]. While these technologies have proven capable of effectively destroying TRUs, the up-front capital cost and timescale for their implementation remain largely uncertain.

An alternative to fast burner reactors is the use of existing licensed light water reactors (LWR). The use of LWRs for the purpose of reducing the UNF inventory volume is appealing for several reasons: 1) less developmental and licensing work is required because the technology and infrastructure already exist, 2) a larger fleet of reactors are more capable of effectively reducing the TRU inventory, and 3) more economic incentives exist due to less up-front developmental costs and the ability to produce electricity while simultaneously burning the waste material.

The utilization of LWRs for this purpose creates new technical challenges that present an immediate need for the development of innovative fuel and core designs based on the thermal spectrum found in LWRs. The design and validation of such concepts will require the efforts and collaboration of multiple engineering disciplines and a variety of different types of analyses, including: neutronic, thermal-hydraulic, and mechanical. Additional technical challenges arise from the fact that documented data on thermal-physical and thermo-chemical properties necessary for analyzing these new fuel designs do not exist for many of the fuel materials conceptualized for transmuting minor actinides, including americium and curium.

The nuclear reactor core consists of tens-of-thousands of fuel rods. Each fuel rod contains hundreds of stacked cylindrical, ceramic fuel pellets in zircaloy tubes called cladding. In the U.S., the fuel material has historically been uranium dioxide, isotopically enriched to 2-5% ^{235}U. Mixed-oxide (MOX) fuels comprised of plutonium and uranium have also been used in commercial LWRs in France. Fuel rods are bundled together in square lattice structures called fuel assemblies. Fuel assembly structural components provide lateral and vertical fuel rod support, and the necessary rod geometry for reactor core criticality and sufficient core heat removal capacity.

It is generally agreed upon that the best approach for economically burning TRUs in LWRs is through the development of new fuel assembly designs that produce the necessary physics characteristics for TRU depletion while utilizing the existing reactor core infrastructure. This method is attractive because it reduces the need for new component implementation and reactor core retrofitting. A class of LWRs called pressurized water reactors (PWR) have been specifically targeted as the primary reactor type for TRU reduction since they represent the vast majority of the U.S. commercial reactor fleet. Using the thermal-hydraulic code VIPRE-01 [5,6], the current research efforts in this thesis seek to perform burnup-dependent thermal-hydraulic analyses of several advanced mixed-oxide (AMOX) fuel assembly designs which cause a reduction in plutonium inventory with net generation or minimized production of MAs.

1.1 Objectives

The main objectives of this thesis study are:

- To develop a methodology for analyzing advanced fuel designs which accounts for the effects of burnup on neutronic and thermal-hydraulic operational parameters
- To develop a simplified method for estimating thermal-physical properties of advanced fuel materials in order to model fuel performance and improve accuracy
- To enable the integration of neutronics data into thermal-hydraulic calculations through the coupling of the neutronic code DRAGON and VIPRE-01
- To perform steady-state and transient thermal-hydraulic analyses for two AMOX fuel assembly designs

The AMOX fuel assembly designs to be analyzed for this thesis are:

- Standard UO_2 fuel with an outer $(Zr,Am)O_2$ coating
- Standard MOX $(U,Pu)O_2$ fuel with an outer $(Zr,Am)O_2$ coating

Assembly designs are of the 17x17 pin variety, and are to be implemented in existing PWR cores with minimal need for additional components and control systems.

In order to accomplish the proposed objectives, thermal-hydraulic analyses of AMOX fuel assembly designs will be performed over the entire operational lifetime of the assembly, up to 62 GWd/tHM of burnup. The effects of burnup on fuel thermal-physical properties and assembly power distribution will be considered. Analyses will consist of steady-state and transient conditions that fall within the categories suggested by the NRC's Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800 [7]. If necessary, design optimization will be carried out in order to provide sufficient thermal margin against postulated adverse operating conditions.

The LWR severe accident code MELCOR [8] will be used as a systems code to model the entire primary side of the power plant during an induced transient and to generate the reactor core flow boundary conditions for VIPRE-01. VIPRE-01 will perform the actual core analysis during the transient and will produce both detailed core and assembly results. Results from the thermal-hydraulic analyses for the primary parameters of interest will be compared against results from a prototypic UO_2-loaded reference core and against design limits provided in the literature and in NUREG-0800.

The available thermal margin of a design will be investigated with respect to the following primary parameters of interest: minimum departure from nucleate boiling ratio (MDNBR), fuel centerline temperatures, and peak cladding temperatures. Fuel centerline and peak cladding temperature limits will be based on regulations found in NUREG-0800 and the available literature, with considerations for the deleterious effects of burnup on the fuel melting temperature.

The fuel composition, core power, and burnup-dependent radial and axial power profiles will be provided by calculations being performed by neutronic analysts. Data collected from neutronic calculations will be passed to VIPRE-01 via a text-based coupling method.

1.2 Thesis Organization

In order to accomplish the posed objectives, this thesis is structured in a way that addresses the problems in a comprehensive manner. A review of modern thermal-hydraulic codes and their modeling techniques is given in Section 2, along with a discussion of their use and merit in the current research. The development of the coupling method for integrated neutronic / thermal-hydraulic calculations is also presented in Section 2. Section 3 contains a literature review of current thermal-hydraulic analysis practices and previous work in advanced fuel assembly design. Based on this review, a new methodology for analyzing assembly designs loaded with advanced fuels and examining the thermal-hydraulic performance of the assembly over the entire operational lifetime is described in Section 3. A comparison of fuel thermal-physical property models is given in Section 4 and the developmental work for modeling the effects of actinide additions to the fuel is presented. The geometrical description and VIPRE-01 input deck formulation for a UO_2-loaded reference PWR core, and the MOX and AMOX assemblies under investigation are found in Section 5. Section 6 presents the thermal-hydraulic analysis of the proposed fuel assemblies. Investigations include steady-state and detailed loss-of-flow-accident (LOFA) analyses to insure sufficient safety margin exists for normal and anticipated transient operations. Finally, conclusions and recommendations for future work are made in Section 7.

2. THERMAL-HYDRAULIC TOOLS

With the increasing capabilities of modern computers, the primary method for analyzing the thermal-hydraulic performance of fuel assembly and core designs is the ‘subchannel’ approach using advanced thermal-hydraulic codes that evaluate phenomena within a portion of a fluid channel. Subchannel codes have advantages over system codes such as RELAP5 [9] and MELCOR, and older core analysis codes such as THINC-I [10], when analyzing fuel assembly designs due to their ability to model individual flow channels within an assembly while simultaneously analyzing the coupled effects and feedback from the entire reactor core [11].

2.1 Modeling Approach

System analysis codes like MELCOR group multiple fuel assemblies together, thereby producing results for the averaged behavior of lumped components [8]. This type of approach inherently neglects the localized fluid and thermal behavior around fuel pins within an assembly and is incapable of evaluating some of the key parameters of interest needed to quantify the thermal margin available in a particular assembly design.

Older core analysis codes such as COBRA-IV [12] and THINC-IV [13] offer improvements in modeling detail over system codes through the use of ‘chain procedures’ to create hot assembly boundary conditions by first analyzing the entire reactor core (first link of the chain) [14]. The flow solution from the entire core is then passed to a second code (second link in the chain) as boundary conditions for the subchannel analysis of the hottest assembly. The effects from interchange of mass, momentum, and energy from adjacent assemblies are considered independently and radial pressure gradients are neglected. Analyses performed using the chain procedure are able to determine primary core thermal-hydraulic parameters of interest, such as the identification and location of the hottest fuel pin and hottest channel within an assembly, as well as, localized fuel and cladding temperatures and the maximum heat flux within the hot assembly. However, these analyses do not fully reflect the coolant flow between assemblies and flow distribution occurring in the core, producing overly conservative results.

Modern subchannel codes, such as COBRA III C/MIT [15], CETOP [16], and VIPRE-01, can model subchannel regions that vary greatly in size. This capability allows the codes to examine the core-wide flow and enthalpy distribution using subchannels that are assembly size and larger while simultaneously considering the behavior of individual coolant channels between four adjacent rods [11]. It is therefore possible to conduct both a core-wide and detailed hot assembly analysis at the same time.

Industry codes utilizing the subchannel approach are widely used in the analysis and validation of core and fuel assembly designs. AREVA uses F-COBRA-TF for the analysis of all of its fuel assembly designs which are implemented in their reactors world-wide [17]. The Atomic Energy of Canada Limited (AECL) has used the subchannel thermal-hydraulics code ASSERT-PV in the analysis of a thorium-based advanced CANDU Reactor (TACR-1300) fuel channel [18]. VIPRE-01 is an NRC-approved subchannel thermal-hydraulic code that has been used extensively to model fuel assemblies by the U.S. nuclear industry, as well as numerous advanced fuel assembly designs, including those for the improvement of fuel performance and the burning of TRUs in LWRs. It is currently being used by Westinghouse Nuclear as the primary tool for analyzing the performance and thermal margin of new fuel assembly designs in their advanced AP1000 nuclear reactor [19].

2.2 VIPRE-01

For the purpose of performing detailed thermal-hydraulic analyses of the proposed fuel assembly designs contemporary subchannel codes were studied to assess their capabilities and applicability to the proposed fuel configurations. Several codes were considered, including VIPRE-01, COBRA-TF [20], and COBRA-IV PC. Of principal importance in the selection process was to identify a code that:

- features robust thermal-hydraulic models
- is capable of simulating 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)
- is able to calculate the selected primary thermal-hydraulic parameters of interest (peak cladding temperature, peak fuel temperature, and MDNBR)
- is well maintained, documented, and widely accepted in the nuclear industry
- is available for academic research

EPRI's VIPRE-01 code was selected based on its adoption by nuclear utilities, thorough documentation, ongoing maintenance, and recent application in evaluating the MDNBR for Westinghouse's AP1000 plant design.

VIPRE-01 MOD2.3 was developed on the strengths of the COBRA code series [5]. The COBRA-IIIC, COBRA-IV-I, and COBRA-WC codes were developed by Battelle under sponsorship of the Atomic Energy Commission (AEC), the NRC, and the DOE as part of reactor safety research efforts. COBRA-IIIC/MIT is based on the COBRA-IIIC code and was developed at MIT under EPRI sponsorship.

Numerous features from the COBRA codes have been included in VIPRE to make it reliable, efficient, and capable of meeting the needs of the nuclear utility industry. Features from COBRA-IIIC/MIT include the ability to split a given total coolant inlet flow for a uniform pressure drop across the core and the ability to specify several different rod axial power profiles in the same analysis. COBRA-IV-I contributed a spatially implicit energy equation and a problem dump/ restart capability. In VIPRE-01 MOD2, a modeling scheme was added from COBRA-WC that allows reverse and recirculating flow in both steady-state and transient calculations. While these features and models exist in individual COBRA codes, they are included in one package with VIPRE-01 MOD2.3 (referred to hereafter as VIPRE). VIPRE has a larger selection of critical heat flux correlations than the COBRA code series, as well as several additional flow-field models for subcooled quality, quality/ void and two-phase friction models [5]. Additionally, VIPRE contains a fuel rod heat conduction model and a dynamic gap conductance model that are not found in COBRA-IIIC and COBRA-IV-I codes.

VIPRE is capable of performing both steady-state and transient thermal-hydraulic analyses of nuclear reactor cores under normal and postulated abnormal operating conditions. Information and results from VIPRE calculations include fluid velocity and state, pressure drop, fuel rod surface and internal temperatures, heat transfer coefficient, heat flux, critical heat flux, and departure from nucleate boiling ratio (DNBR) for each cell at each axial level. The location of the MDNBR is also identified by channel and rod at each axial level.

2.2.1 Flow-Field Model

VIPRE's basic computational philosophy comes from COBRA-IIIC [5]. Using the subchannel approach, VIPRE applies conventional control volume-based modeling to small, user-specified volumes that represent the individual flow areas between adjacent rods in typical nuclear fuel assemblies. Figure 2.1 shows the relation of a standard subchannel control volume to a reactor core. Each nuclear fuel rod in a core is capable of being modeled and fluid control volumes ('cells') are made up of axially divided units of flow area between the fuel rods. The cells are coupled to the fuel rods through heat transfer models. A single cell in a given channel, represented by Figure 2.2, communicates axially with the cells above and below it, while additionally communicating laterally by cross-flow to other adjacent channels through gaps between rods. In this way, VIPRE can be considered a 3-D code, capable of modeling lateral changes in velocity and temperature profiles in a channel as a result of turbulent mixing, pressure gradients, and two-phase flow effects.

Conservation equations of mass, axial and lateral momentum, and energy are solved for the fluid enthalpy, axial flow rate, lateral flow per unit length, and momentum pressure drop. The fluid flow-field model in VIPRE uses the homogeneous

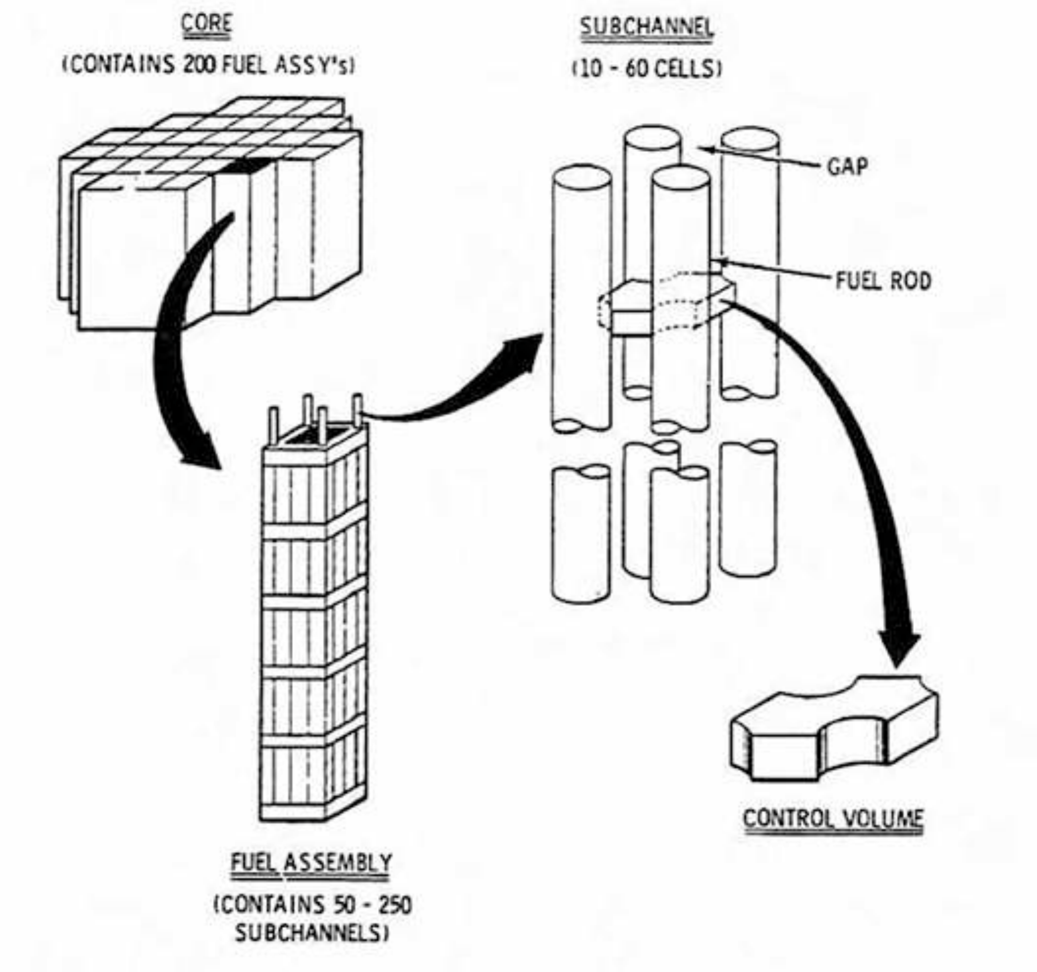

Figure 2.1. Relation of subchannel control volume to reactor core (from [5])

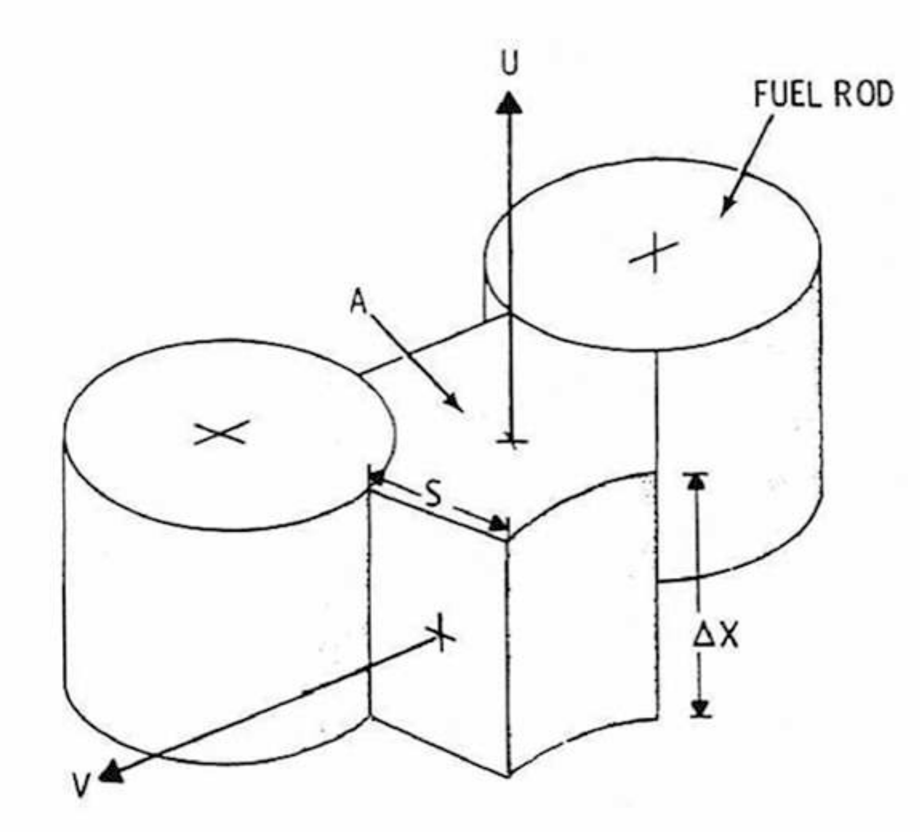

Figure 2.2. Single subchannel cell (from [5])

equilibrium model (HEM), where the vapor and liquid phases are assumed to be in both mechanical and thermal equilibrium. The main assumptions are [5]:

- The flow speed is sufficiently low such that kinetic and potential energies are small compared to the internal thermal energy of the fluid
- Work done by body forces and shear stresses in the energy equation are small compared to surface heat transfer and convective energy transport
- Heat conduction through a fluid surface (such as through a gap connection between two fluid control volumes) is small compared to convective energy transport and heat transfer from solid surfaces
- The fluid phases are in thermodynamic equilibrium

- Gravity is the only significant body force in the momentum equation
- Viscous shear stresses between fluid elements are assumed small compared to the drag force on solid surfaces
- The fluid is incompressible but thermally expandable

These assumptions allow the conservation equations to be written in simpler form and may be considered valid for the flow conditions found in a PWR, where the extreme system pressure suppresses boiling and the fluid flow is highly turbulent. While the flow-field is assumed to be incompressible and homogeneous, additional empirical models are added to reflect subcooled boiling and co-current liquid/vapor slip. The incompressible but thermally expandable flow assumption implies that the fluid properties are functions of the local enthalpy at a uniform system pressure; however, an option exists to add the effects of the local pressure drop.

VIPRE uses an implicit boundary value solution that propagates flow disturbances throughout the computation mesh by repeatedly sweeping the mesh [5]. This is different from conventional marching solutions that solve the flow-field a step at a time solely on the basis of upstream information. As a result, VIPRE is stable for any time step and cell size.

Mass, momentum, and energy are transported between neighboring channels by diversion cross-flow and turbulent mixing. A lateral connection, or ‘gap’, between channels is defined by its width and distance between the centroids of two adjoined channels, as shown in Figure 2.3. The flow-field models assume that the cross-flow loses its sense of direction upon crossing over to the adjacent channel. Therefore, there is no momentum coupling between cross-flows, and no discrete lateral coordinate directions or boundary conditions are needed [5]. A cross-flow is oriented and exists only between the two channels that it connects.

The VIPRE energy and momentum equations contain terms describing the lateral exchange of energy and momentum between adjacent channels due to turbulent mixing. The two items required for using the turbulent mixing model are the tur-

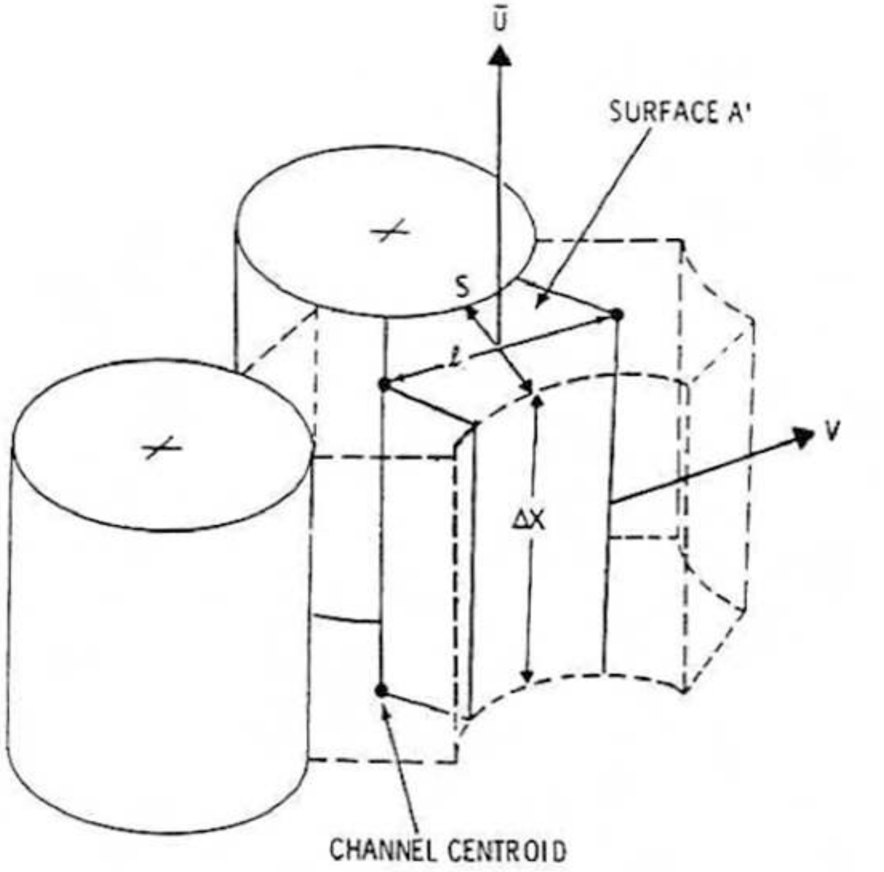

Figure 2.3. Subchannel cell for lateral momentum exchange (from [5])

bulent momentum factor, FTM, and the turbulent mixing coefficient, β. FTM is similar to the turbulent Prandtl number in that it relates how efficiently the turbulent cross-flow mixes momentum [6]. It can be applied on a scale from 0.0 to 1.0, where 0.0 indicates that turbulent cross-flow only mixes enthalpy, and 1.0 indicates that momentum is mixed with the same strength as the enthalpy. The turbulent mixing coefficient, β is a flow quality-dependent parameter that is multiplied against the single phase turbulent cross-flow in order to approximate the effects of two-phase flow on turbulent mixing.

The lateral turbulent energy exchange between channels is calculated using an empirical model that is not directly related to the integral balance equations. A time-fluctuating cross-flow per unit length, w', is computed as a fraction of the average axial flow, and performs an equal mass exchange between adjacent cells. The fluctuating cross-flow is related to the eddy diffusivity, ϵ_{t} by

$$w' = \epsilon_{\mathrm{t}}\rho\left(\frac{s}{l}\right) \tag{2.1}$$

VIPRE computes w' as a function of the turbulent mixing coefficient, β, such that

$$w' = \beta s\overline{G} \tag{2.2}$$

and

$$\beta = \frac{\epsilon_{\mathrm{t}}}{\overline{\overline{U}}} \tag{2.3}$$

The total turbulent mixing energy input to a cell that will be added as a source term, Q_{m}, in the energy balance is expressed as

$$Q_{\mathrm{m}} = -\Delta X \sum_{\mathrm{k}\in\mathrm{i}} w'\Delta h \tag{2.4}$$

Turbulent momentum mixing between channels is modeled in the same way as the thermal energy mixing term, and is included as a force in the momentum balance. The total axial force, F_{m}, on the cell due to turbulent mixing is computed as

$$F_{\mathrm{m}} = -\mathrm{FTM}\ \Delta X \sum_{\mathrm{k}\in\mathrm{i}} w'\Delta U \tag{2.5}$$

2.2.2 Heat Transfer Model

The heat transfer model in VIPRE is based on the control volume formulation of the conduction equation. It computes the heat source term for the fluid energy equation, as well as the internal temperature distribution for the fuel rod. The models governing fluid heat transfer calculate the heat transfer coefficient at the interface between the coolant and the heated surface. VIPRE assumes that axial and circumferential conduction are small in comparison to radial conduction inside the fuel rod, and therefore considers only radial conduction heat transfer [5]. This assumption requires that the heat transfer coefficient and fluid temperature distributions around the fuel rod are relatively uniform, but improves computational efficiency by keeping the number of conduction nodes down to a manageable size.

The conduction model is designed for `nuclear` fuel rods, `heater` rods, `tubes`, and `walls`. Figure 2.4 illustrates a `nuclear` rod type, which consist of a material region representative of the fuel pellet, a gap between the fuel pellet and the cladding inner surface, and a cladding region which connects the rod's internal materials to the outer fluid flowing over the rods. `Heater` rod types do not have a dedicated gap region and consist of concentric rings of different material regions, as shown in Figure 2.5. VIPRE assumes perfect contact between each material region, but contact resistance can be modeled by including a region one node wide with the material properties that result in the approximate thermal resistance [5]. The material properties for both geometrical types may be specified by user input or obtained from built-in property tables for uranium dioxide and zircaloy in the code.

VIPRE calculates heat conduction in solid materials using an implicit finite-

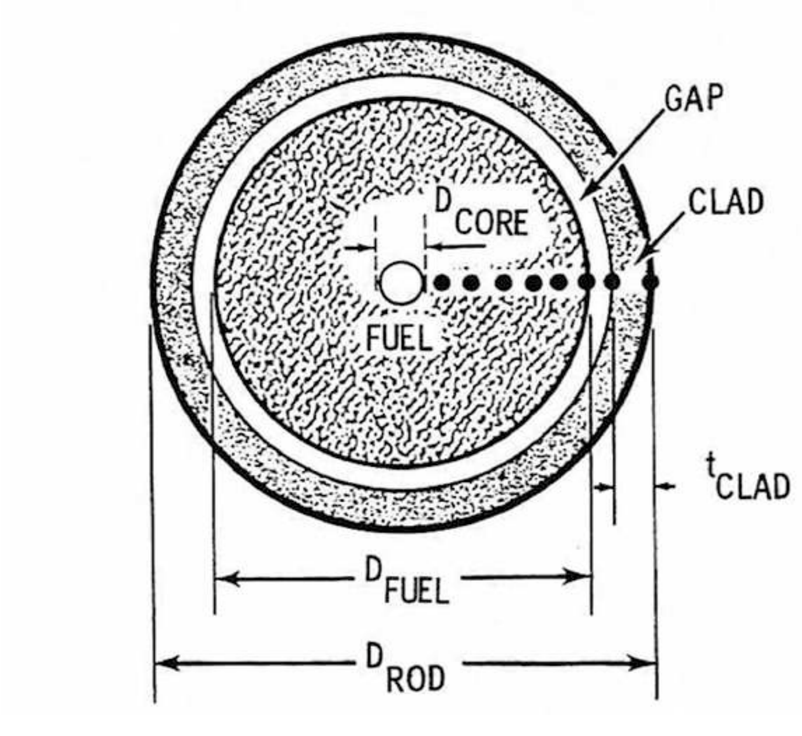

Figure 2.4. Nuclear rod type geometry (from [5])

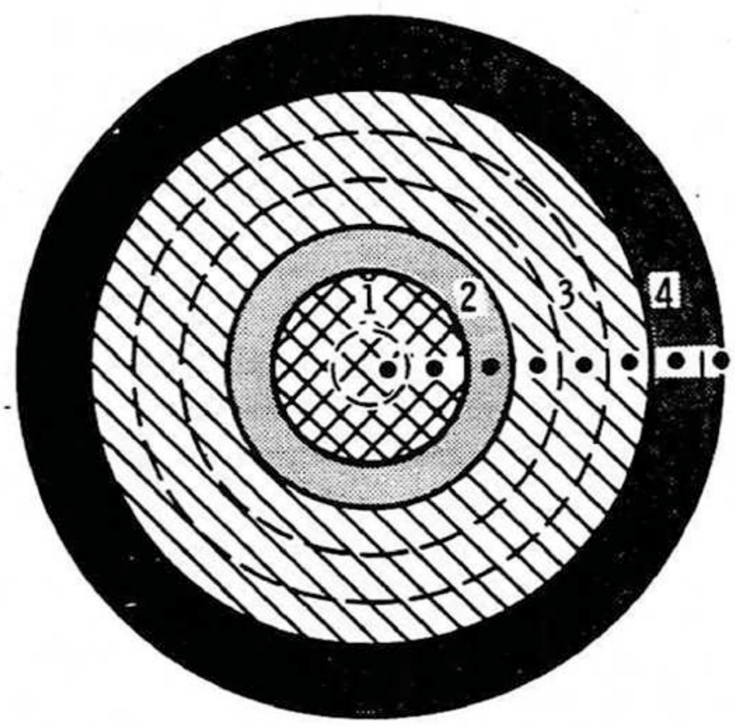

Figure 2.5. Heater rod type geometry (from [5])

difference representation of the conduction equation. The finite-difference nodes of the conduction equation are modeled as control volumes connected by thermal resistances. The set of linear equations formed by this method are solved for using Gaussian elimination and back-substitution. The conduction equation for a node can be derived from a simple energy balance, where for node i of Figure 2.6

$$(\rho C_p V)_i \frac{\partial T_i}{\partial t} = Q_{i-1,i} + Q_{i+1,i} + Q_i''' V_i \tag{2.6}$$

Each material region is divided into subregions of equal thickness and a conduction node is automatically positioned in the volume-average radius of each subregion [5]. In regions where one face of a node is a boundary surface, the conduction node is placed at the surface of the region, instead of the center of the node.

The radial positions of the conduction nodes do not change throughout the calculation. Therefore, the term $(\rho V)_i$ in Equation 2.6 is evaluated at the cold state density and dimensions to define the mass associated with node i, M_i, in order to

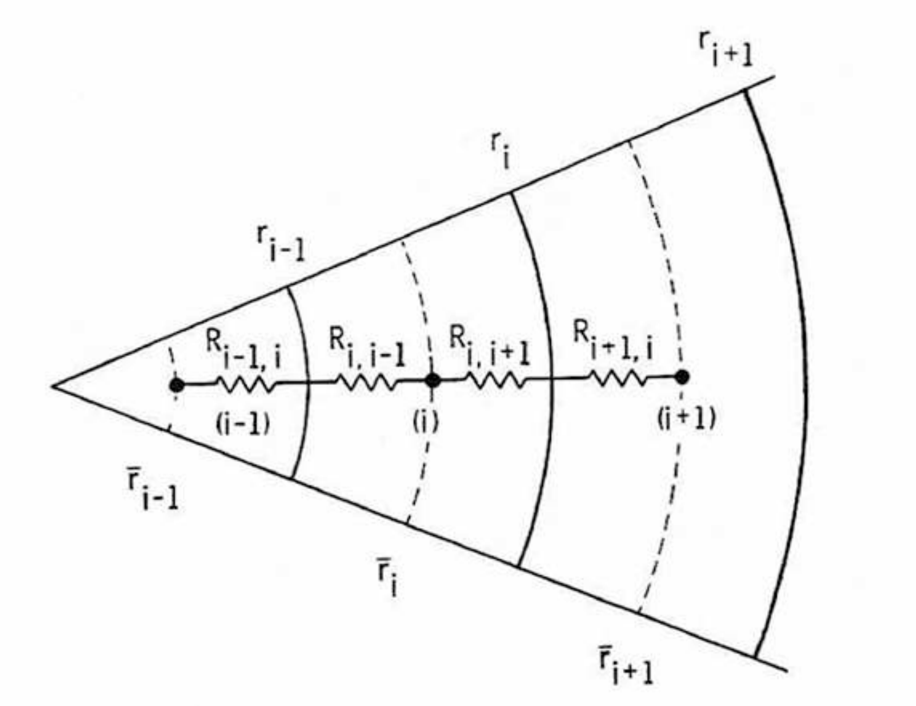

Figure 2.6. Heat balance control volume network (from [5])

prevent an apparent loss of mass from the conductor due to density changes with temperature. Equation 2.6 is rewritten as

$$(MC_p)_i \frac{\partial T_i}{\partial t} = Q_{i-1,i} + Q_{i+1,i} + Q_i'''V_i \tag{2.7}$$

Heat transfer through node i is computed from the conductance, K, of the region material and the temperature gradient across the node, such that

$$Q_{j,i} = K_{j,i}(T_j - T_i) \text{ for } j = \begin{cases} i-1 \\ i+1 \end{cases} \tag{2.8}$$

and

$$K_{i,j} = K_{j,i} \text{ for } j = \begin{cases} i-1 \\ i+1 \end{cases} \tag{2.9}$$

The conductance is simply the inverse of the thermal resistance, R, between a given set of nodes, as shown in Figure 2.6:

$$K_{i,i-1} = \frac{1}{R_{i,i-1} + R_{i-1,i}} \tag{2.10}$$

The thermal resistance for each node is calculated as a function of thermal conductivity, k, and geometry.

2.3 MELCOR

MELCOR is a severe accident code that was originally designed as a probabilistic risk assessment (PRA) tool, but through integration of numerous physics-based models and improved numerical schemes, it has become a best-estimate code. MELCOR uses a one-dimensional control volume solution method to model liquid water, water vapor, and non-condensable gas thermal-hydraulics [8]. Mass resides in the control volumes, and is passed to other control volumes via flow paths. The conservation equations of mass, momentum, and energy are integrated over all flow paths in the system.

MELCOR is capable of modeling the entire primary and secondary sides of a PWR power plant, and is currently used to analyze a wide range of severe accident phenomena in both boiling water reactors (BWR) and PWRs. The code is designed to model severe accident progression in a nuclear power plant from the onset of an accident through the transport of radionuclides to the environment [8]. MELCOR is often compared to other severe accident analysis codes, including MAAP [21] and SCDAP/RELAP5 [9]. Currently, these three codes are considered the leading severe accident analysis tools in the U.S. nuclear industry.

2.4 Neutronic / Thermal-Hydraulic Integration

A script-based interface was created to facilitate the exchange of information between the neutronics code DRAGON and thermal-hydraulic code VIPRE. The script-based interface is built on top of a standard file-based interface, where the output files of one code are used to create new input files for the other code. The interface is designed in such a way that the DRAGON and VIPRE codes become functional parts of high-level scripts that drive the fuel assembly analysis and carry-out pre-and-post processing tasks. The scripting language chosen is PERL [22]. PERL is a high-level, general purpose programming language that is used widely in the science and computer programming communities. PERL's strength lies in its text processing ability, which allows a script to easily analyze and manipulate text files.

Sophisticated spreadsheets in Microsoft Excel are used to automate the calculations necessary for creating the geometrical description of a given assembly design for a VIPRE input deck. Simple changes in an assembly's geometry can easily be propagated through the tens-to-hundreds of channels in an assembly model using this 'Excel-based' interface. The Excel-based method also acts as a rudimentary graphics user interface (GUI) through which the analyst can input other model parameters, including: average pin power, coolant inlet mass flow rate, coolant inlet temperature, system pressure, grid-spacer location, single and two-phase flow correlations, heat transfer and critical heat flux correlations, and a multitude of output options. The text files created using the Excel-based interface are called 'skeleton input files' as they contain important VIPRE input information for a particular design, but are not ready for VIPRE implementation.

A low-level PERL script reads-in the VIPRE input information from the skeleton input files and parses the text files into the required VIPRE input deck format. Another script interprets the burnup-dependent fuel rod radial power profiles from text files created through post-processing of neutronic output files. This same script translates the rod profiles from the neutronic analysis nodalization to the appropriate thermal-hydraulic rod location for VIPRE analysis. Multiplication factors are applied to the rod radial power profiles to create the same total power peaking for the hottest rod as in the reference Westinghouse PWR core (2.42 total, with respect to the average fuel rod).

Burnup information collected from neutronic analysis output files is used to drive the calculation of burnup-dependent fuel material thermal-physical properties. The burnup-dependent models used for estimating fuel thermal-physical properties, along with the applied modifications for actinide additions, are discussed in Section 4. The burnup-dependent rod power profiles and fuel material properties are implemented into the working input file. One VIPRE case contains all the information necessary to describe the geometrical configuration and rod power distribution for an assembly design at a set burnup level. A complete steady-state VIPRE analysis of an assembly design can consist of 30 to 50 cases, depending on the assembly lifetime and the refinement of the neutronic burnup computational mesh.

A high-level batch code file comprises the user interface through which the analyst interacts with the script-based method. Information passed to the high-level batch code upon execution includes: assembly model name, type of analysis, name and location of neutronic output file containing burnup information, fuel material, fuel constituents, number of axial cells in VIPRE analysis, and several post-processing commands. The batch code sends the user input to the appropriate low-level scripts, which then carryout their designated pre-processing function. A working input file is completed when all cases have been appended to constitute the entire burnup lifetime of the assembly. VIPRE is then called as an external executable that takes the completed input file as an argument. A schematic representation of the neutronic / thermal-hydraulic / script-based interface is provided in Figure 2.7.

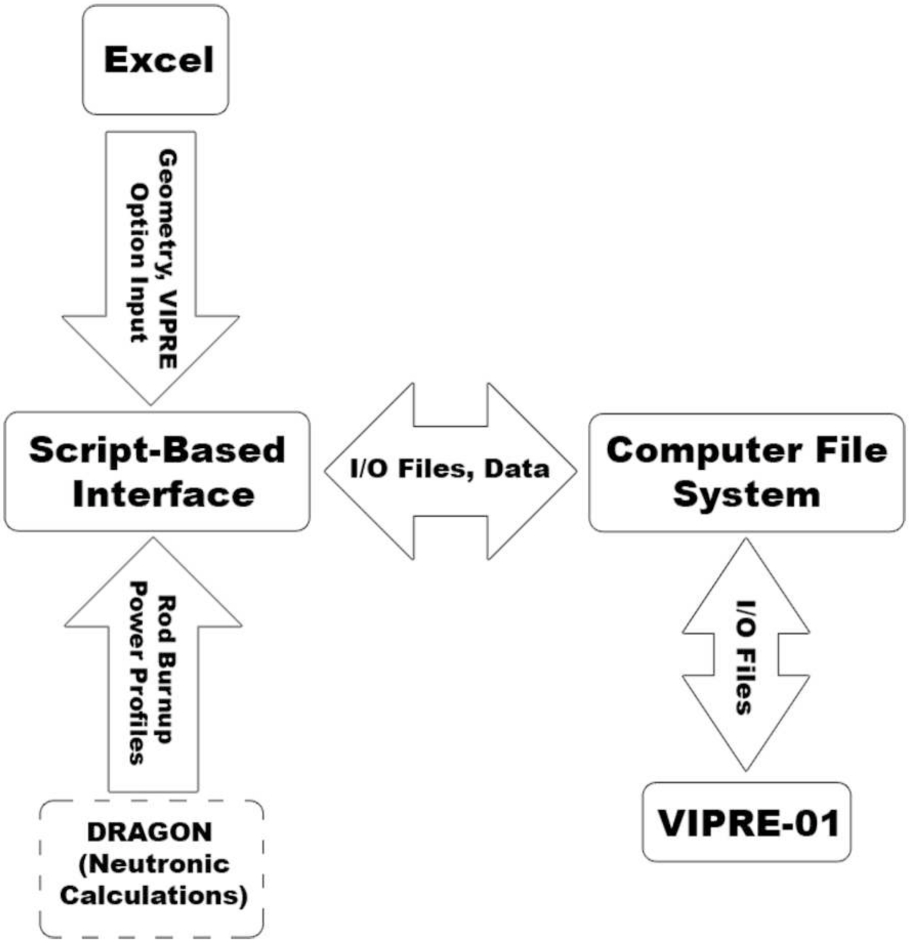

Figure 2.7. Neutronic / thermal-hydraulic interface diagram

3. THERMAL-HYDRAULIC METHODOLOGY

A burnup-dependent thermal-hydraulic analysis methodology has been developed as part of the research efforts of this thesis. Current thermal-hydraulic methodologies and analysis practices have been surveyed to incorporate techniques capable of evaluating the thermal performance of the posed fuel assembly designs over their entire operational lifetime. Surveyed literature includes federal regulatory guides for plant safety evaluation and licensing, previous work in thermal-hydraulic analysis of advanced TRU reducing assembly designs, and other work focusing on core and assembly analysis using subchannel codes. The culmination of selected techniques is a thermal-hydraulic methodology that is capable of analyzing the thermal performance of advanced assembly designs over their entire operational lifetime by including effects of burnup on neutronic power profiles, fuel thermal-physical properties, and accounting for the standard plant operating procedure of reshuffling the core. The new methodology includes steady-state and transient analyses to evaluate the assembly thermal margin during a number of postulated adverse operating conditions.

3.1 Thermal-Hydraulic Analysis in Practice

NUREG-0800 contains NRC guidance and evaluation criteria for assessing U.S. nuclear power plants. A Safety Analysis Report (SAR) is submitted by a utility company, or vendor, to the NRC for each proposed nuclear reactor facility, and must address and justify all design criteria required by NUREG-0800 in order to receive an operational license. Chapters 4 and 15 of NUREG-0800 outline the generic information and analyses necessary to validate a reactor core design during steady-state and transient operations.

With respect to fuel assembly design, Chapter 4 of NUREG-0800 states that the design basis for the thermal-hydraulic evaluation should include such items as: maximum fuel and cladding temperatures as function of burnup (at rated power, at design overpower, and during transients), departure from nucleate boiling ratio (at rated power, at design overpower, and during transients), flow velocities, and coolant and moderator voids [7]. As a focal point of the NRC's construction permit and operating license review process, Chapter 15 requires that a number of postulated transients, or Anticipated Operational Occurrences (AOO), and accidents be evaluated for any proposed core design. Initiating events that lead to an unstable operating state are assigned to 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 initiating events and plant conditions are divided into four categories by the American Nuclear Society (ANS) according to the anticipated frequency of occurrence and potential radiological consequences to the public [23]. The four categories are

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

Results from transient and accident analyses are to be discussed in terms of key parameters, namely: average and maximum heat flux, reactor coolant system pressure, minimum DNBR, core coolant flow rates, coolant conditions (inlet and average core temperatures, average and hot channel exit temperature, and steam volume fractions), and maximum temperatures for fuel and cladding [7].

Information and tools from both neutronic and thermal-hydraulic disciplines are required to perform many of the more comprehensive analyses required in NUREG-0800. For a given assembly design, the assembly average power, axial power distribution, and individual pin relative radial powers are determined from neutronic calculations as functions of fuel material loading, coolant density, and fuel temperatures. Power distributions in the core, and within an assembly, are discussed in terms of hot channel factors, which are defined as:

- $\mathrm{F_Q}$, Heat Flux Hot Channel Factor, the maximum local heat flux on the surface of a fuel rod divided by the average fuel rod heat flux, allowing for manufacturing tolerances on fuel pellets and rods.

- $\mathrm{F^N{}_Q}$, Nuclear Heat Flux Hot Channel Factor, the maximum local fuel rod linear power density divided by the average fuel rod linear power density, assuming nominal fuel pellet and rod parameters.

- $\mathrm{F^E{}_Q}$, Engineering Heat Flux Hot Channel Factor, the allowance on heat flux required for manufacturing tolerances. The engineering factor allows for local variations in enrichment, pellet density and diameter, surface area of the fuel rod, and eccentricity of the gap between pellet and clad. Combined statistically the net effect is a factor of 1.03 to be applied to fuel rod surface heat flux.

- $\mathrm{F^N{}_{\Delta H}}$, Nuclear Enthalpy Rise Hot Channel Factor, the ratio of the integral of linear power along the rod with the highest integrated power to the average rod power.

The subfactors of $\mathrm{F^N{}_Q}$ are:

- $F^N{}_Z$, Nuclear Heat Flux Axial Factor, the ratio of power per unit core height in the horizontal plane of peak local power to the average value of power per unit core height (peak-to-average axial power ratio).

- $F^N{}_{XY}$, Nuclear Heat Flux Radial Factor, the ratio of peak power density to average power density in the horizontal plane of peak local power (maximum relative rod power ratio within the core). $F^N{}_{XY}$ is the product of the relative power ratio of the hottest assembly, $F^N{}_{HA}$, and the relative power ratio of the hottest fuel pin within the hot assembly, $F^N{}_{XY,HA}$.

  $$F^N{}_{XY} = F^N{}_{HA} \times F^N{}_{XY,HA}$$

- $F^N{}_U$, Nuclear Heat Flux Uncertainty Factor, is a conservatism factor that accounts for uncertainties in core-wide power distribution (assumed to be 1.05).

$F^N{}_Q$ is defined mathematically in terms of its subfactors in Equation 3.1.

$$F^N{}_Q = F^N{}_{XY} \times F^N{}_Z \times F^N{}_U = F^N{}_{HA} \times F^N{}_{XY,HA} \times F^N{}_Z \times F^N{}_U \tag{3.1}$$

It is convenient for the purposes of discussion to define subfactors of $F^N{}_Q$, however, design limits are set in terms of the total peaking factor in the core, F_Q, which is represented mathematically by

$$F_Q = F^N{}_Q \times F^E{}_Q \tag{3.2}$$

The hot channel factors have a significant impact on the thermal-hydraulic performance of a fuel assembly, and many of them change over the lifetime of the assembly as fuel materials are burned and the assembly is relocated. Additionally, key neutronic parameters that affect the hot channel factors are susceptible to reactivity feedback effects from changes in thermal-hydraulic core characteristics, which are themselves dependent on neutronic performance - leading to a tightly coupled system.

The modeling restrictions imposed by the tightly coupled neutronic/thermal-hydraulic systems are lessened for steady-state and simplified transient conditions where neutronic feedback effects are small and can be neglected [24]. Under these conditions, a straightforward sequential coupling methodology is possible. Power profiles are determined via neutronic calculations which are then passed sequentially as boundary conditions to the thermal-hydraulics code. The thermal-hydraulics code yields results for the thermal margin of a particular design or fuel loading during steady-state operation, or its limiting conditions during a transient.

Limiting conditions for evaluating fuel assembly designs include: fuel temperatures above their melting point, cladding temperatures leading to deleterious fuel-cladding reactions, a MDNBR lower than the set point of the correlation used in its determination, maximum cladding strain range exceeding values at which failure can be expected, and excessive fuel pin internal gas pressure at end-of-life (EOL) conditions [11]. This is not an exhaustive list of the criteria used during fuel rod and assembly design, and all but the last two limits are capable of being evaluated using a subchannel code, such as VIPRE. A separate set of computational tools, called fuel rod (fuel element) design codes, are used for calculating the maximum cladding strain and strain range, pin internal gas pressure at EOL, maximum cladding stress, and total fission gas release of a particular fuel pin design. Examples of such codes include COMETHE [25], ESCORE [26], TACO3 [27], and FRAPCON [28].

Under typical operating conditions for a PWR, the fuel centerline temperature of an average rod with 96% theoretical density uranium dioxide fuel pellets is 1473K at a linear heat generation rate (LHGR) of 33 kW/m. For the hottest rod in the core with a maximum power peak of 2.82 to the core average power ($\mathrm{F_Q} = 2.82$), the LHGR is 50 kW/m and the maximum fuel centerline temperature is 2073K after the first rise to power [11]. The melting temperature of fresh, unirradiated $\mathrm{UO_2}$ is in the vicinity of 3113K, however the conservatively low value of 2873K is typically used in LWR design since the melting process starts at the solidus temperature and is completed at the higher liquidus temperature [29]. Therefore, the fuel temperature of the hottest rod in the core is not expected to approach its melting temperature during normal steady-state operation. However, the melting point of oxide fuel is adversely affected by deviations in the oxygen-to-metal ratio, plutonium or other heavy metal additions, and burnup effects. For a constant pin power, the thermal margin between the operating fuel temperature and the melting temperature is expected to decrease with increasing burnup.

Standard design practices include AOO and design basis accident (DBA) analyses at maximum overpower conditions (112% reactor power) in order to evaluate fuel assembly designs in terms of safety limits, such as fuel melting temperature and low MDNBR [29]. Fuel centerline temperatures must maintain margin below melting in order to prevent cladding failure due to excessive fuel pellet expansion, fuel stack instability, excessive release and migration of fission products, and contact of molten fuel with cladding [11]. While a small number of cladding failures are tolerable (up to 1% of all fuel elements), a larger number can release unacceptable amounts of fission products to the RCS and raise coolant activity. In current fuel assembly designs where the fuel material is UO_2, the requirement that center melting be avoided has generally not been the limiting factor for lower levels of burnup. Instead, those restrictions imposed by departure from nucleate boiling (DNB) and loss-of-coolant accident (LOCA) conditions have been predominantly limiting [30].

Cladding failures in PWRs can also result from large localized heat fluxes at the cladding surface. In the design and operation of a nuclear reactor, the heat fluxes of the fuel rods are controlled rather than the fuel rod temperatures and heat is removed via forced convection by the coolant. PWRs suppress bulk boiling of the coolant with high operating pressures, though the hottest coolant channels in the core may experience subcooled nucleate boiling to a limited extent. The heat flux which is sufficiently high enough to induce a departure from nucleate boiling heat transfer at the cladding heated surface is called the critical heat flux (CHF). During CHF conditions, the cladding heated surface, which is normally cooled by liquid via nucleate boiling, becomes vapor-blanketed, resulting in a cladding surface temperature excursion [29].

The high temperatures experienced by the cladding during CHF conditions can lead to immediate, or subsequent, fuel rod failure due to deleterious fuel-cladding interactions and increased cladding strain [11]. The CHF is a function of the operating system pressure, coolant flow rate, channel geometry, and local coolant thermodynamic quality. The ratio of the critical heat flux for a channel at a given axial location to the actual heat flux at the same location in Equation 3.3 is called the critical heat flux ratio (CHFR) or departure from nucleate boiling ratio (DNBR). Lower DNBR values indicate an approach to CHF conditions, and design limits are imposed on the minimum allowable DNBR value in order to insure sufficient safety margin exists for normal and anticipated transient operations.

$$\mathrm{DNBR} = \frac{q''_{\mathrm{CHF}}(z)}{q''(z)} \tag{3.3}$$

A standard DNBR design limit is 1.3 at 112% reactor core power [29]. The axial behavior of the CHF and DNBR with respect to an average coolant channel in a typical PWR is shown in Figure 3.1. As the enthalpy of the coolant rises with axial position, the CHF leading to a localized DNB condition decreases, leading to a reduction in the DNBR value. However, the DNBR value will increase for a decreasing channel heat flux, even though the coolant enthalpy continues to rise. The minimum DNBR value in the hottest assembly of the reactor core is the primary limiting factor in steady-state thermal-hydraulic design of fuel assemblies and reactor cores.

The inclusion of advanced fuel materials in the proposed fuel assembly designs will alter the prototypic behavior of the reactor core in comparison to UO_2-loaded fuel assemblies that have been exclusively used in the U.S. LWR fleet since its inception. While the current criteria used in LWR design is still valid for these assemblies, the design thermal margin may be reduced due to higher power peaking, lower fuel thermal conductivity, and lower fuel melting temperatures in rods loaded with plutonium and MAs. Efforts must be made during the design process to insure that the effects of these factors are minimized, and the same level of safety and reliability is provided.

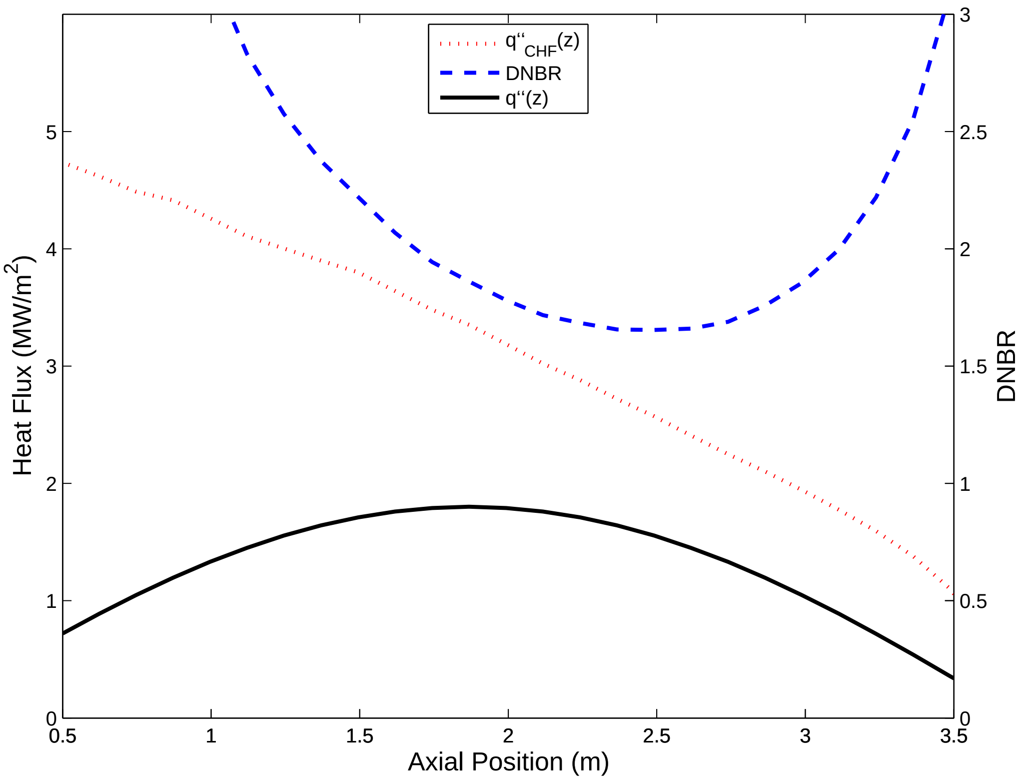

Figure 3.1. Channel heat flux, critical heat flux, and DNBR vs axial position in a PWR

3.2 Previous Work in Advanced Fuel Assembly Analysis

Thermal-hydraulic analysis with subchannel codes has been used widely for assessing the viability of new fuel assembly designs which incorporate advanced fuel materials for disposing of weapon and reactor grade plutonium and other TRUs. Puill and Bergeron [31] were some of the first to investigate the possibility of reducing the plutonium inventory while minimizing actinide production using LWRs. Their efforts lead to the Advanced Plutonium Fuel Assembly (APA).

The APA utilizes large annular fuel rods loaded entirely with PuO_2 in a ceramic matrix, known as an inert matrix fuel (IMF). The plutonium-loaded annular fuel rods do not contain any uranium, which is a fertile material for producing additional plutonium and minor actinides. Fuel materials with reduced or minimal amounts of fertile material are called fertile free fuels (FFF). The annular fuel in the APA takes the place of four standard PWR rods. The ideal assembly configuration for the APA is 36 thick annular rods and 120 standard UO_2 rods, with low-enriched uranium [31]. Neutronic analyses showed a significant reduction in the plutonium inventory (60% of the second generation plutonium is consumed), and a lower percentage of actinide production [31].

Thermal-hydraulic analysis of the APA was performed using the subchannel code FLICA 3M. The analysis was conducted for a 900-MWe PWR using $1/8^{\text{th}}$ core symmetry with power profiles generated during neutronic calculations. The radial channel description was carried out in detail in the vicinity of the most powered annular rod, with a decreasing level of detail for the rest of the fuel assembly and core. A description of the fuel assembly symmetry and subchannel nodalization is shown in Figure 3.2. Results from the thermal-hydraulic analysis indicated that the MDNBR reached the 1.3 design limit for 120% of rated reactor core power.

One of the drawbacks of the APA design is it cannot be combined with conventional 17 × 17, or 19 × 19, fuel assemblies in the same PWR core because of thermal-hydraulic design differences. Therefore, a significant amount of reactor core retrofitting is required in order to accommodate the APA assembly. Another design developed by Shwageraus et al. [4] builds on the fundamental principles of the APA design while restricting their design to conventional PWR assembly configurations. The Shwageraus design, or Combined NonFertile and Uranium (CONFU) design, modifies a standard 17 × 17 UO_2 PWR fuel assembly by replacing 20% of the fuel pins with FFF pins, which host the TRUs. The FFF rods share the same pin diameter with the UO_2 fuel rods, as shown in Figure 3.3.

The CONFU assembly design was shown to reduce the radiotoxicity and decay heat of UNF waste by three-orders-of-magnitude compared to that of the currently employed once-through UO_2 fuel cycle. Steady-state thermal-hydraulic analyses of various CONFU fuel loadings and fuel pin arrangements were performed using VIPRE. All steady-state calculations used conservative assumptions to account for

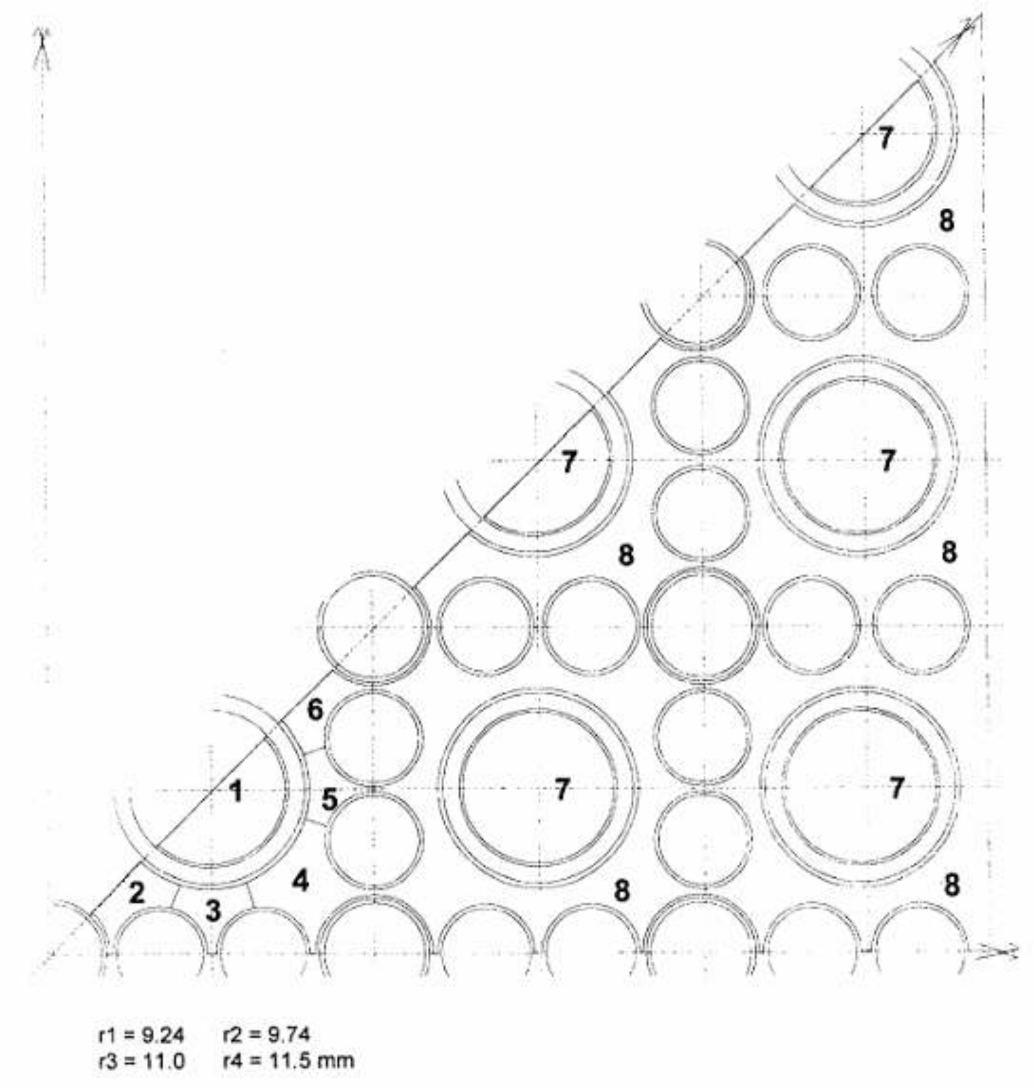

Figure 3.2. 1/8th Advanced Plutonium Fuel Assembly subchannel nodalization (from [31])

transient conditions, including: 118% reactor core power, increased inlet coolant temperature, and the relocation of the hottest fuel assembly to the center of the core. Results from the thermal-hydraulic analyses indicate a maximum reduction of 20% in the MDNBR thermal margin for the most limiting CONFU design when compared to the reference UO_2 case. The MDNBR value for the CONFU design is 1.43, which is greater than the established W-3L correlation limit of 1.3.

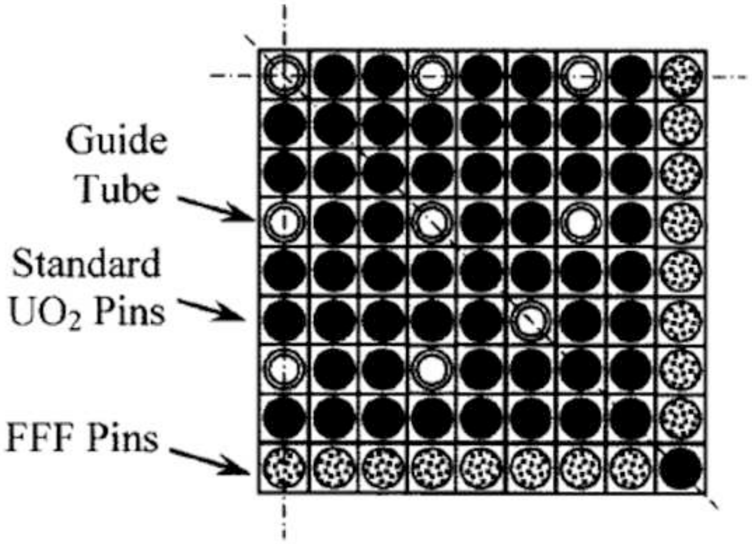

Figure 3.3. Quarter assembly geometry for CONFU design (from [4])

The feasibility of the CONFU assembly design was limited by the need for prolonged latency periods between discharge and reprocessing due to gradual buildup of small amounts of curium and californium during irradiation. These materials have high spontaneous fission rates, which lead to significant heat generation by some plutonium, americium, and curium isotopes.

Carmack et al. [3] proposed a core design which uses a heterogeneous mix of conventional UO_2 and fertile-free IMF assemblies, instead of a few fuel assemblies loaded with both UO_2 and IMF pins. The IMF assemblies consist of annular pins loaded with an Am-Pu-Np oxide dispersed within a MgO-ZrO_2 inert matrix. The IMF rods have the same pin diameter as the UO_2 rods in the adjacent assemblies. A diagram of four neighboring assemblies in the IMF-UO_2 mixed assembly configuration is shown in Figure 3.4.

The subchannel code COBRA-EN and systems code RELAP5-3D were used to model the thermal-hydraulic behavior of the assembly design during steady-state and transient conditions. Steady-state analyses using COBRA-EN investigated the assembly MDNBR at beginning-of-life (BOL) conditions with a maximum assembly

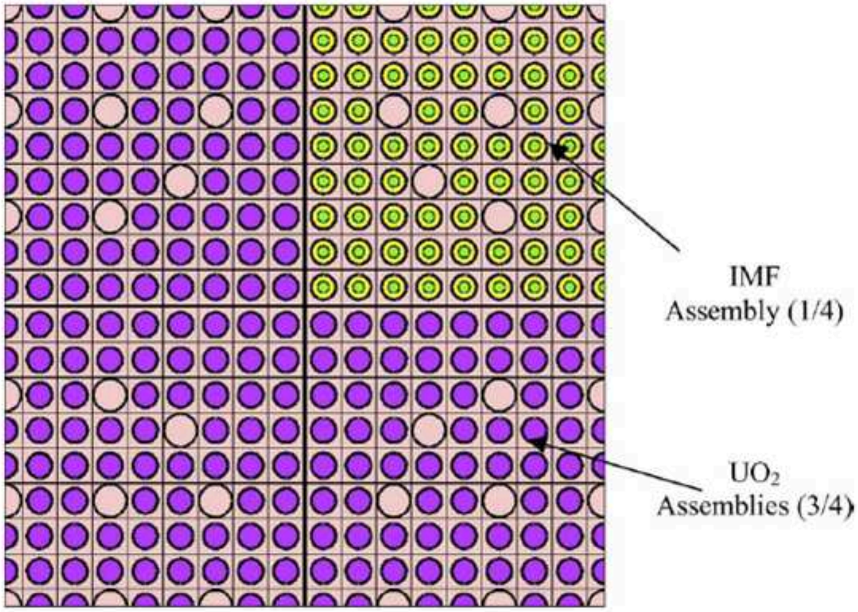

Figure 3.4. Quarter assembly geometry for 1-IMF assembly and 3-UO_2 assemblies (from [3])

radial peaking factor of $F^{N}{}_{HA} = 1.5678$. Evaluations of fuel temperatures were neglected. Results from the steady-state analyses suggest that the use of IMF fuels do not greatly affect the MDNBR performance of the assembly when compared to a standard MOX design [3].

Transient analyses with RELAP5-3D included LOCA, LOFA, and loss-of-power transient conditions [3]. The primary parameters of interest were the peak cladding temperature and the core average fuel temperature. The temperature dependence of the IMF fuel thermal conductivity was neglected, as well as the effects of TRU doping and burnup on the inert matrix. Transient results show similar performance for the IMF assemblies in comparison to standard UO_2 designs under the same conditions - with the IMF fuel occasionally having higher peak cladding temperatures. Average fuel temperatures are lower than those for UO_2 fuel under a loss-of-flow transient; however, this analysis is not prototypic since the IMF fuel thermal conductivity is assumed constant over the temperature range experienced by the fuel during the transient.

These analyses represent substantial work in the area of fuel assembly design for the purpose of TRU reduction, and are representative of all other work in this area. The first two investigations only assess the thermal-hydraulic steady-state performance of the fuel assembly to determine the available design thermal margin using the MDNBR as the parameter of interest. While the U.S. nuclear reactor fleet operates at a high capacity factor with limited interruptions, reactors are expected to undergo transients during any given cycle. Therefore, it is necessary to consider the thermal response and performance of a core design under expected operational transients, and not only steady-state conditions. Additionally, NUREG-0800 suggests that burnup-dependent peak fuel and cladding temperatures be used in addition to the MDNBR as parameters of interest in both steady-state and transient fuel assembly design evaluation. These considerations are addressed in the current research efforts by performing detailed steady-state and transient analyses for each fuel assembly design, and assessing an assembly's design merit with respect to the MDNBR, and peak cladding and fuel temperatures for both types of operational conditions.

A lack of results for fuel and cladding temperatures in previous work stems from limited fuel modeling capabilities due to insufficient thermal-physical property data for the investigated fuel materials. Until recently, many of the proposed fuel materials had not been fabricated, rendering it difficult to quantify property values for important parameters, including fuel thermal conductivity, melting temperature, and enthalpy. The modeling difficulty of advanced fuels is further increased by the complex dependencies of the thermal conductivity on temperature, compositional changes, and burnup. These technical challenges and the immediate need for advanced fuel property data have led to significant research efforts in material science and developmental work for fuel property models. While much work is still needed, great strides have been made and it is now possible to model the fuel performance of some advanced fuel types to a limited extent. This thesis attempts to model the thermal performance of the proposed fuel types using the most recent fuel material property models and data, and where fuel properties are not available, a simplified model has been developed for producing conservative estimates of the fuel thermal-physical properties. The development of this model is discussed in Section 4.

Previous work has been conducted solely at BOL conditions and, therefore, neglected the degenerative effects of irradiation on fuel performance properties, such as the reduction of fuel thermal conductivity. Since these assembly designs are intended for prolonged periods of irradiation (burnup) in order to successfully reduce or constrain TRU accumulation, the effects of burnup on overall fuel assembly performance cannot be overlooked. NUREG-0800 requires a more thorough thermal-hydraulic investigation for new assembly designs if they are to be licensed and implemented in the U.S. reactor fleet [7].

The current research efforts of this thesis seek to build upon the foundations laid by previous work in advanced fuel assembly design. To date, TRU reducing fuel assembly analysis has neglected the detrimental effects of burnup on fuel thermal-physical properties, and pin and assembly power distributions. New work for extending the typical steady-state thermal-hydraulic analysis by including more detailed transient analyses, as well as the effects of burnup on AMOX fuel assembly performance and thermal safety margin have been completed, as required by NUREG-0800.

3.3 Assessment of Burnup Effects on Fuel Assembly Thermal-Hydraulic Performance

One of the most important tasks in reactor core and assembly design is predicting how the properties of the core will change over its lifetime. Changes in a fuel assembly can be divided into three categories: neutronic, mechanical, and thermal-hydraulic. The properties of an assembly affect its performance, and how the properties change in time must be accounted for to ensure that the reactor will operate safely throughout the lifetime of the core. The standard terminology describing a fuel assembly's, or fuel pin's, utilization and subsequent 'age' is burnup.

Burnup represents the specific power extracted from the fuel material and is most commonly measured in megawatt-days per tonne of heavy metal (MWd/tHM) in the U.S. nuclear industry. Since the amount of energy released per fission of uranium and plutonium is known, the specific energy released from the fuel is an indicator of the amount of fissile atoms that have been converted, or depleted, from the fission process. In this way, burnup is a measurement of the amount of fuel expended, and part of the core design process is to make certain that enough fissile content is present at the beginning of a cycle to maintain criticality at the required power output for the desired discharge burnup.

The requirement that enough fissile content initially be present to sustain criticality has traditionally not been the principal factor in determining limits for discharge burnup. The maximum burnup for a fuel rod is primarily limited by mechanical limits set for the fuel's protective outer cladding, including: strain range, hydriding, and corrosion requirements [11]. Radiation induced damage in the cladding causes the cladding to become embrittled, which perpetuates with increasing burnup. Additionally, hydrogen uptake of the cladding occurs due to high cladding temperatures and contact with the surrounding cooling water. The effects of both of these phenomena become more pronounced with increasing exposure to the reactor core environment and lead to cladding embrittlement which can challenge the cladding's strain range limitations. Corrosion of the cladding occurs as a result of oxygen uptake, and tends to be autocatalytic since the oxide-zirconium interface temperature increases as the oxide layer thickens which causes the corrosion rate to increase [11]. These issues are analyzed in the nuclear industry by the fuel element design codes mentioned in Section 3.1.

As burnup increases, the amount of fissile content in the fuel decreases; however, it does not decrease uniformly throughout the core, or within an assembly. At a core level, once the reactor reaches steady-state at the desired power level, the neutron flux takes on a cosine shaped spatial distribution. The thermal flux is greatest in the center of the core and fuel is consumed and fission product poisons are produced more rapidly in this region than other parts of the core [32]. As a result, the flux in the center of the core is reduced over time relative to that on the outside periphery. Core design engineers attempt to minimize these effects by introducing burnable poisons in the core that absorb the excess criticality at the beginning of a cycle, as well as reshuffling fuel assemblies around during fuel reloading such that fresh, less expended fuel is located on the outer periphery of the core and those assemblies with higher burnup are located in the center regions [32]. The net result is a more flattened flux profile across the core with more uniform power profiles and depletion rates.

Within an assembly, as the fissile content of individual rods is depleted non-uniformly, the location and power level of the hottest rod changes over time. Therefore, the location of the channel experiencing the highest heat flux and the magnitude of that heat flux can change as burnup increases. The effects of burnup on thermal-hydraulic considerations include fluctuations in rod power profiles and the relocation of the hottest rod and channel within the assembly, as well as changes in state and thermal-physical properties of the fuel materials. The byproducts of fission are the release of tremendous amounts of energy, several fission neutrons, and two ionized elements called fission products that originate from the division of heavier elements. Solid fission products are dispersed within the fuel's ceramic matrix and cause a reduction in the thermal conductivity of the fuel, which is further reduced by radiation damage to the crystalline structure [33]. A complete discussion of the effects of burnup on oxide fuel thermal conductivity is presented in Section 4.

The generation of gaseous fission products causes the fuel pellet to expand and creates additional stress in the cladding due to pellet-cladding mechanical interactions (PCMI). The designed fuel pellet porosity is capable of absorbing the initial formation of fission gases and irradiation induced pellet densification for low levels of burnup. As fuel temperatures increase with burnup due to reductions in fuel thermal conductivity, it is possible for the fission gases that are trapped within the fuel to be released to the internal volume of the fuel pin. Fission product release becomes more rapid for higher fuel temperatures; and while special cavities inside the fuel rod are designed to accommodate the release of fission gases, excessive fission gas release can lead to significant increases in internal rod pressure [33]. High internal gas pressure can result in lift-off of the cladding from the fuel pellet [11]. Lift-off can lead to an increase in the size of the gap between the fuel pellet and cladding, which in turn increases fuel temperatures and enhances fission gas release. High internal gas pressure combined with increased fuel pellet swelling can induce high cladding stress and challenge the strain range limits of the cladding material. For this reason, effort is made to ensure that the majority of the fuel in the core is maintained at temperatures below 1673K during steady-state operation where fission gas release is less than 5% [33].

To better approximate the conditions a fuel assembly experiences over a full operational lifetime, the following thermal-hydraulic methodology attempts to model many of these burnup-dependent neutronic and thermal-hydraulic phenomena.

3.4 Technical Approach for Burnup-Dependent Thermal-Hydraulic Analysis of Advanced Fuel Assembly Designs

In order to assess the thermal performance of the proposed fuel assemblies in a conventional PWR, a reference Westinghouse PWR plant was selected. Luminant's Comanche Peak Steam Electric Station (formerly TXU Generation Company) Nuclear Unit 1 was selected as the reference PWR core because it is one of the most recently built PWR plants in the industry and plant data is readily available. Comanche Peak operating parameters and design characteristics are listed in Table 3.1.

Two analysis types are employed herein to evaluate the available thermal margin of proposed fuel assembly designs. The first is a steady-state analysis based on techniques from licensing calculations that are typically used in scoping studies. Feng et al. [35] and Shwageraus et al. [4] have applied similar analysis techniques to assess advanced assembly designs for PWRs. Conservative assumptions are made to allow for Condition I and II transients, and to account for uncertainties in the analysis. The

Table 3.1
Operating parameters and characteristics of reference Westinghouse PWR plant (from [34])

Property	Quantity
Reactor core power (MWt)	3458
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 flow rate (Mg/s)	18.91
Effective core flow rate for heat removal (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 (${F^N}_{\Delta H}$)	1.55
Nuclear conservatism factor (${F^N}_U$)	1.05
Number of fuel assemblies in core	193
Number of fuel rods per assembly	264
Number of instrument tubes per assembly	1
Number of control rods per assembly	24
Number of grid-spacers per assembly	8

second type of analysis simulates Condition II and III LOFA transients, and reduces some of the uncertainty and conservatism from the first analysis type. This form of transient analysis has been used by Blair [36] and the nuclear utility industry [19,34], is a required part of a power plant's Safety Evaluation Report (SER) and SAR used during the licensing process [7], and is capable of being modeled in VIPRE.

3.4.1 Assumptions

The amount of design data required to perform a rigorous thermal-hydraulic calculation is extensive. Much of this data is proprietary or unknown because the materials have not been fabricated or the components are untested. In order to perform even a simple thermal-hydraulic analysis of a conceptual design, many assumptions must be made. Some assumptions reduce the complexity of the analysis and thus reduce the time and computational power needed to perform the calculations, while others fill in gaps of knowledge for which the calculations are dependent. When assumptions are necessary, provision must be made to ensure that the analysis methodology produces conservative results with respect to the primary parameters of interest.

The thermal-hydraulic analysis methodology developed in this thesis employs the following assumptions for both types of analysis, and produces conservative results for the MDNBR, centerline fuel temperatures, and peak cladding temperatures:

1. Initial reactor core steady-state power, inlet coolant mass flow rate and temperature, and primary system pressure are equal to that of the reference core.

2. The gap between fuel pellets and cladding inner surface in nuclear fuel rods has a symmetrical conductance of 2000 $\mathrm{BTU/hr \cdot ft^2 \cdot {}^\circ F}$ ($11,346\ \mathrm{W/m^2 \cdot K}$). This gap conductance is higher than that documented at BOL conditions, but is more representative of fuel pins that have undergone one cycle of full power irradiation [29].

3. Coolant inlet temperature is raised 2K and total coolant mass flow rate is reduced by 5% to account for core bypass flow and uncertainties associated with core-wide flow and temperature distributions [4].

4. All fuel rods in the core use a uniform chopped cosine axial power profile with a peak-to-average ratio of $\mathrm{F^N}_\mathrm{Z} = 1.55$, which normally provides conservative results [4].

5. The maximum power peaking for the hottest rod in the core is the same as for the reference PWR ($\mathrm{F_Q} = 2.42$).

The following modeling assumptions are applied during VIPRE analysis, and are implemented as options in VIPRE input decks:

1. DNBR calculations are performed using the Westinghouse W-3L CHF correlation for PWR cores, with a MDNBR correlation limit of 1.3.

2. Assemblies employ 8 grid-spacers that are located at equal intervals over the assembly length [34]. The grid-spacer form loss coefficient is not available for the 17 × 17 assemblies, and has been adjusted to give the same core pressure drop as the reference core [35].

3. L-type mixing vanes are assumed for the W-3L CHF correlation with VIPRE default values for the grid mixing factor (0.042), grid factor leading coefficient (0.986), and a value for the grid-spacing factor (0.066) recommended by Feng et al. [35].

4. Fluid properties are evaluated at local pressure as VIPRE's solution scheme sweeps up the core. Fluid properties become a function of both the coolant temperature and the uniform core pressure at each axial level. Activating this option in VIPRE allows for local pressure effects to be modeled. While this is more representative of the actual phenomenon, pressure drops through the core are small compared to system pressure and VIPRE results are relatively insensitive to the way the fluid properties are computed under these conditions [5].

5. The gap-to-length ratio, s/l, and cross-flow resistance coefficient, K_G, are used in VIPRE to determine the channel area subjected to cross-flow and its magnitude. The gap-to-length ratio is set to the default value of 0.5. The default value for K_G is 0.5, but more exact values are determined from a Blasius-type relation [35]. For the cross-flow across a tube bundle with a square pitch, Idel'chik [37] gives the following relation for a pin-to-pin pitch S_p and a rod diameter d_r
$$K_G = 1.8 \left(\frac{S_p}{d_r} - 1 \right)^{-0.5} \mathrm{Re}^{-0.2} \tag{3.4}$$
Stewart et al. [5] have shown that the gap-to-length ratio and cross-flow resistance coefficient have insignificant effects on channel mass flux and DNBR in systems where the axial flow is dominant relative to the cross-flow.

6. The default option in VIPRE for coolant inlet flow distribution is selected for these analyses, which induces uniform inlet mass flux in all channels. The inlet flow distribution has a very small effect on VIPRE results in the upper half of the core where the MDNBR is typically located because the flow redistribution recovers the inlet flow maldistribution within the first few axial feet of flow in the core [5].

7. Axial friction factors, f, are determined from the Blasius relation with coefficients for standard smooth tubes.

8. Weisman [11] estimates that for rod bundles with small mixing vanes, a turbulent mixing coefficient, β, value of 0.076 is appropriate for Equation 2.2. However, the NRC has recommended using no turbulent mixing coefficient or a conservatively small one unless the value of β can be verified by experimental data [5]. Therefore, both the turbulent mixing coefficient and the turbulent momentum factor from Equation 2.5, FTM, are set equal to 0 based on recommendations from the NRC and Feng et al. [35]. These assumptions produce conservative results for the DNBR and hot channel flow conditions.

9. All two-phase flow and heat transfer correlations used in VIPRE are set to their defaults. The combination of default correlations gave the best agreement with external data when implemented in VIPRE [5].
10. The non-default CHF correlation used to define the peak of the boiling curve is the W-3L to be consistent with correlation selections for DNBR calculations.

3.4.2 Evaluation of Transient Conditions

Transient analyses are performed to validate steady-state scoping analysis results for Condition II transient events and to investigate the thermal-hydraulic performance of fuel assembly designs under a Condition III LOFA. Transient analysis is conducted at 112% power to allow for consistent overpower margin for any specific case of prescribed axial heat flux distribution and coolant channel conditions [29]. The core is modeled in VIPRE using $1/8^{\text{th}}$ symmetry so that the entire hot assembly can be analyzed while maintaining computational efficiency. Sensitivity studies have shown that as long as at least one full row of subchannels are placed completely around the hot channel, the details of the flow-field in the vicinity of the hot channel can be adequately resolved and the hot channel flow conditions are essentially insensitive to the core radial layout, or to the detail in which the rest of the hot bundle and core are modeled in VIPRE [5]. Each rod and channel in the entire hot assembly are modeled in VIPRE for transient analysis as illustrated in Figure 3.5, and the hot assembly is located in the outer rim of the core as is prototypic for PWRs.

A loss-of-flow accident describes a series of events that lead to a reduction in the coolant mass flow rate through the reactor core. LOFAs are most notably associated with a mechanical or electrical failure of a reactor coolant pump, or pumps, or from a fault in the pump power supply bus. A partial LOFA event is classified as an ANS Condition II incident (a fault of moderate frequency), and consists of failure of one or more pumps with at least one pump remaining intact to supply forced coolant circulation to the reactor core. A complete LOFA is classified as an ANS Condition

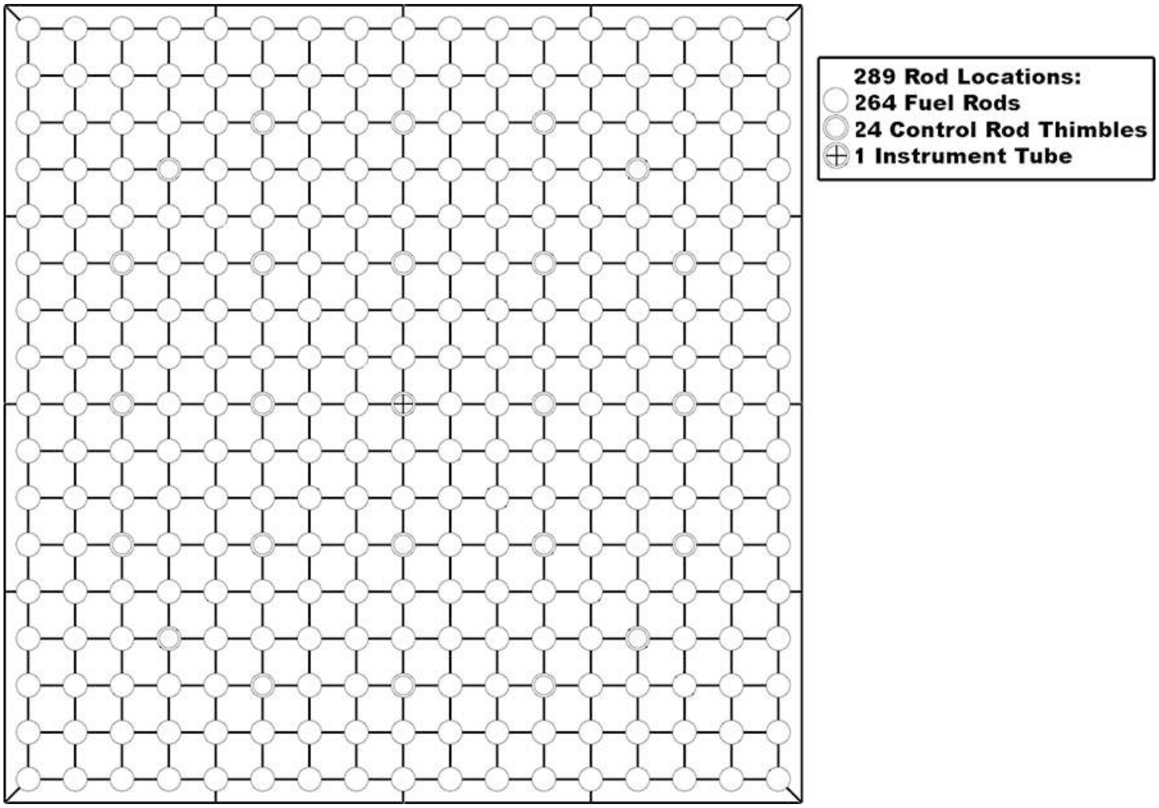

Figure 3.5. Full hot assembly nodalization for transient analysis

III incident (an infrequent fault), and consists of failure of all reactor coolant pumps. The action required following a LOFA is the immediate shutdown of the reactor, which is facilitated by the plant's safety system trip logic. The trip set points and their respective delay times for the reference plant are listed in Table 3.2.

MELCOR, a LWR severe accident code, is used as a systems code to model the entire primary side of the power plant during the induced LOFA transients, and to generate the reactor core flow boundary conditions for VIPRE. Reactor core results from MELCOR are passed as boundary conditions to VIPRE so that detailed assembly thermal performance may be analyzed. Specifically, the core flow rate, inlet coolant temperatures, core power, and primary system pressure are taken from MELCOR simulation results and applied as temporal forcing functions in VIPRE to induce

Table 3.2
Trip points and trip time delays for MELCOR transient analysis (from [34])

Trip function	Limiting trip point	Time delay (seconds)
Low reactor coolant flow	87% loop flow	1.0
Reactor coolant pump underfrequency trip	57.0Hz	0.6
Reactor coolant pump undervoltage trip	68% nominal	1.5

changes in reactor operating conditions with time. Successive VIPRE calculations provide detailed core results for the MDNBR, peak cladding and fuel temperatures, channel pressure drop, location of the hottest assembly and channel, and channel flow void fraction.

An existing MELCOR input deck [38] that models a Westinghouse 4-Loop PWR plant similar to the selected reference core design has been modified to induce complete and partial LOFAs. Modifications to the original MELCOR input deck include: removing control functions necessary for initiating a station blackout accident, changing the transient start time from 0.0 to 5.0 seconds, introducing new control functions for initiating the loss of one and four reactor coolant pumps, changing the maximum time step size in the first 15 seconds from 1 to 0.3 seconds to create a finer temporal discretization for VIPRE analysis, and modifying existing control functions for the safety system trip logic such that reactor shutdown after a LOFA event follows the trip points and delay times in Table 3.2 for a detected loss of loop coolant flow. The detectable loss of loop flow trip point is selected over the coolant pump undervoltage and underfrequency trip points because it creates more conservative results with a longer time period between transient initiation and reactor shutdown for full power operation to exist with decreasing coolant flow rate. Modified MELCOR input decks are included in the Appendices. The MELCOR transient results for complete and partial LOFAs are shown in Figures 3.6 to 3.13.

For both partial and complete LOFA events, the loss of one or more pumps occurs at 5 seconds, followed by a 87% loop flow signal at 8.18 and 8.06 seconds, respectively. The reactor shuts-down in Figures 3.6 and 3.7 at approximately 9.18 and 9.06 seconds due to a 87% loop flow signal, and only decay heat is generated in the core thereafter. Coolant mass flow rates drop quickly for both events in Figures 3.8 and 3.9 as the reactor coolant pumps coast down; however, the decrease in core inlet coolant mass flow rate for the complete LOFA case in Figure 3.9 is sharper and more drastic since all four reactor coolant pumps have been lost, as opposed to the loss of only one pump in Figure 3.8. Primary system pressure increases following the tran-

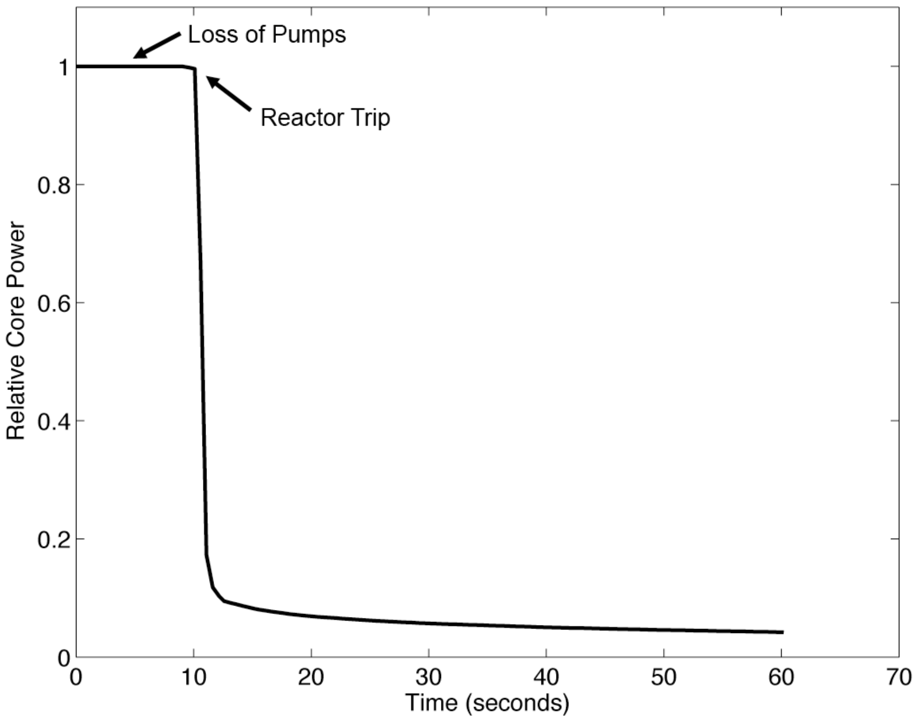

Figure 3.6. Normalized partial LOFA reactor core power

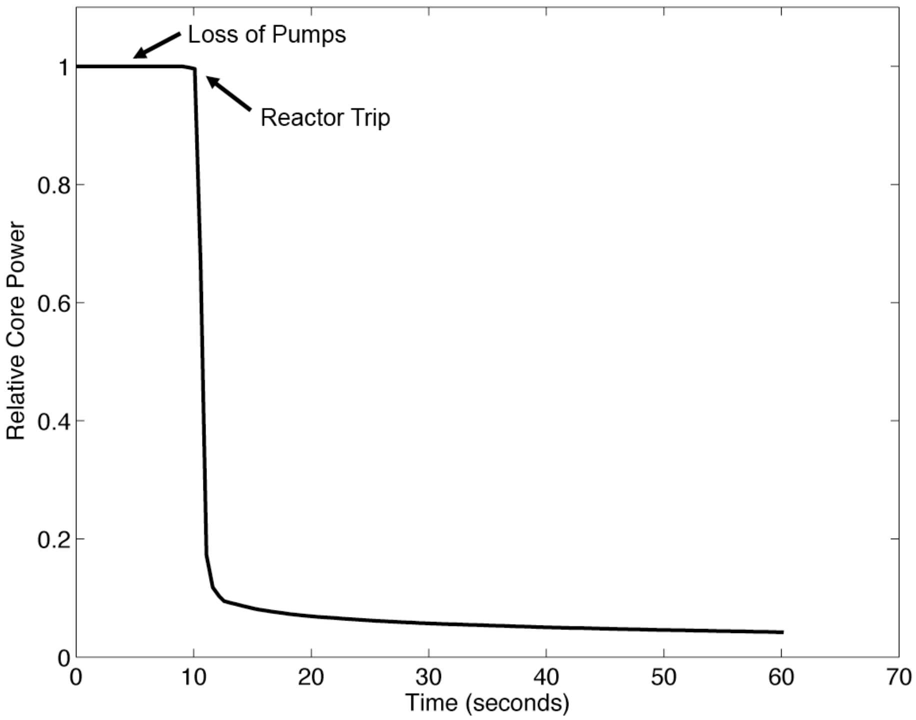

Figure 3.7. Normalized complete LOFA reactor core power

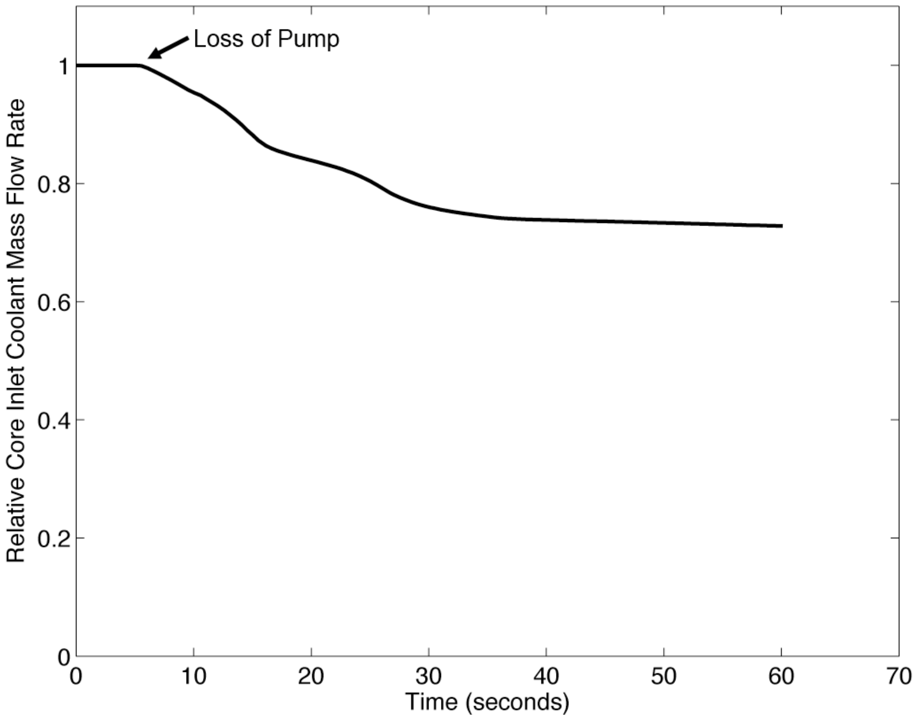

Figure 3.8. Normalized partial LOFA core coolant mass flow rate

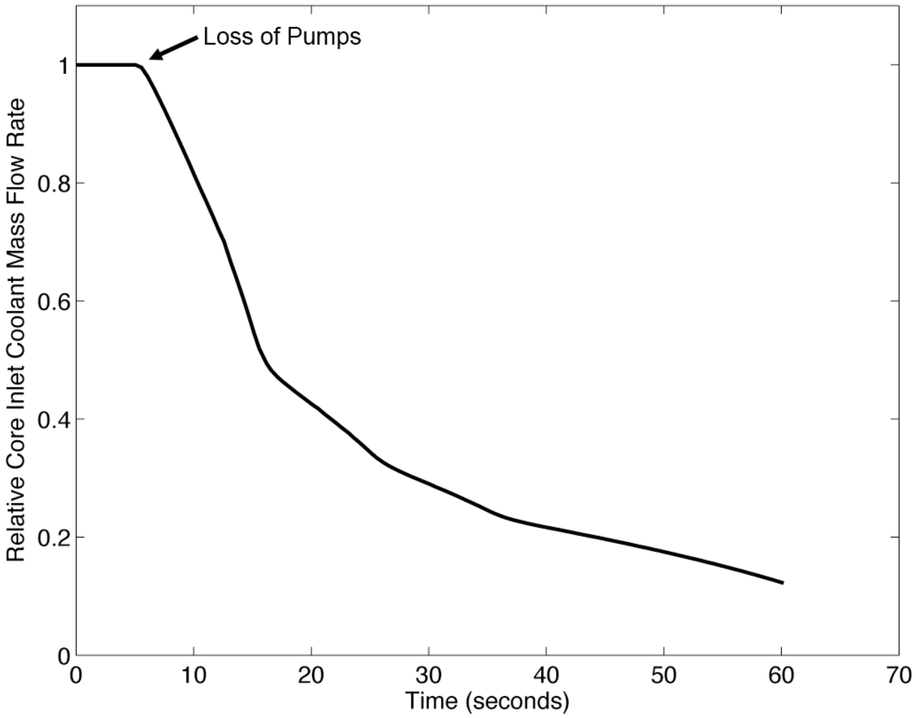

Figure 3.9. Normalized complete LOFA core coolant mass flow rate

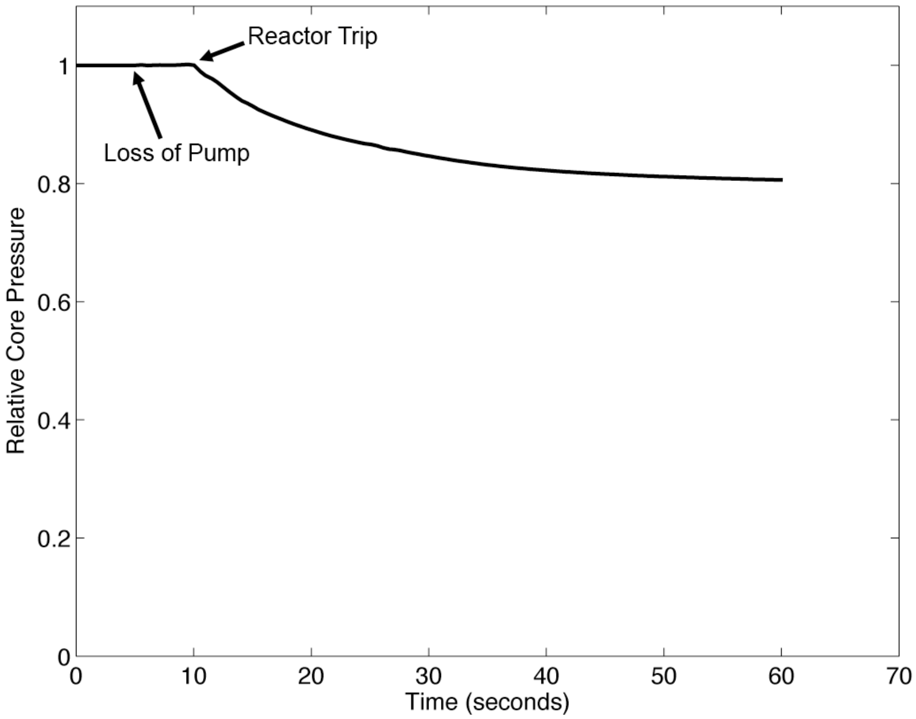

Figure 3.10. Normalized partial LOFA reactor core pressure

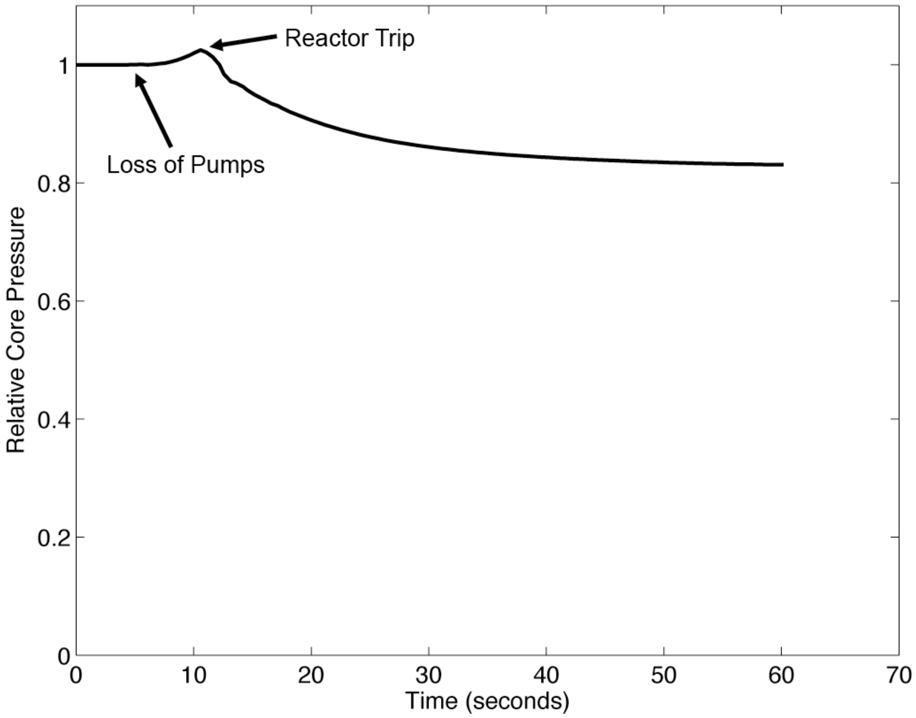

Figure 3.11. Normalized complete LOFA reactor core pressure

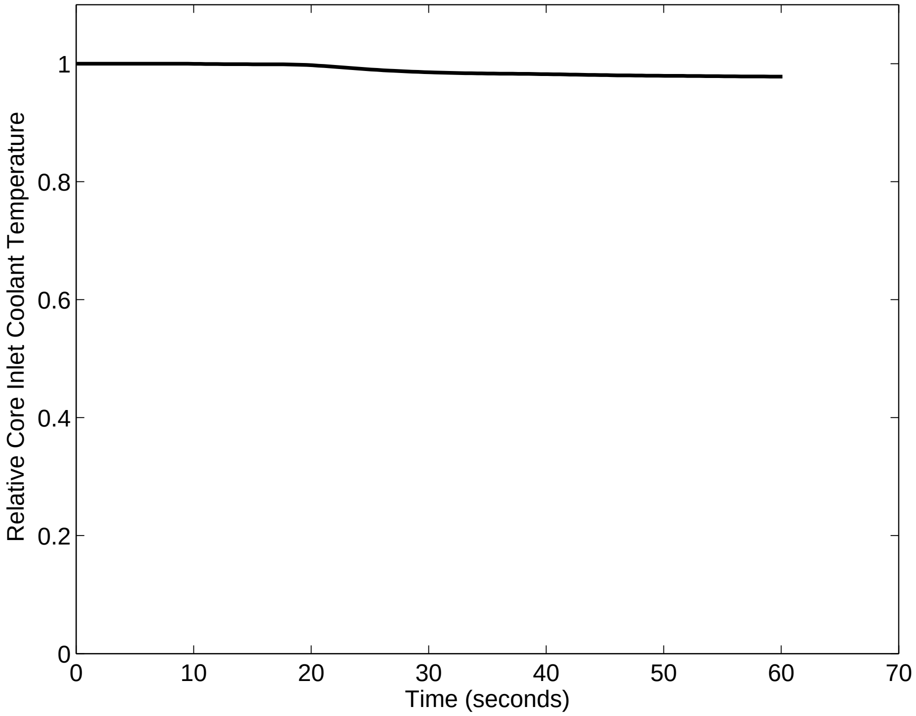

Figure 3.12. Normalized partial LOFA core coolant inlet temperature

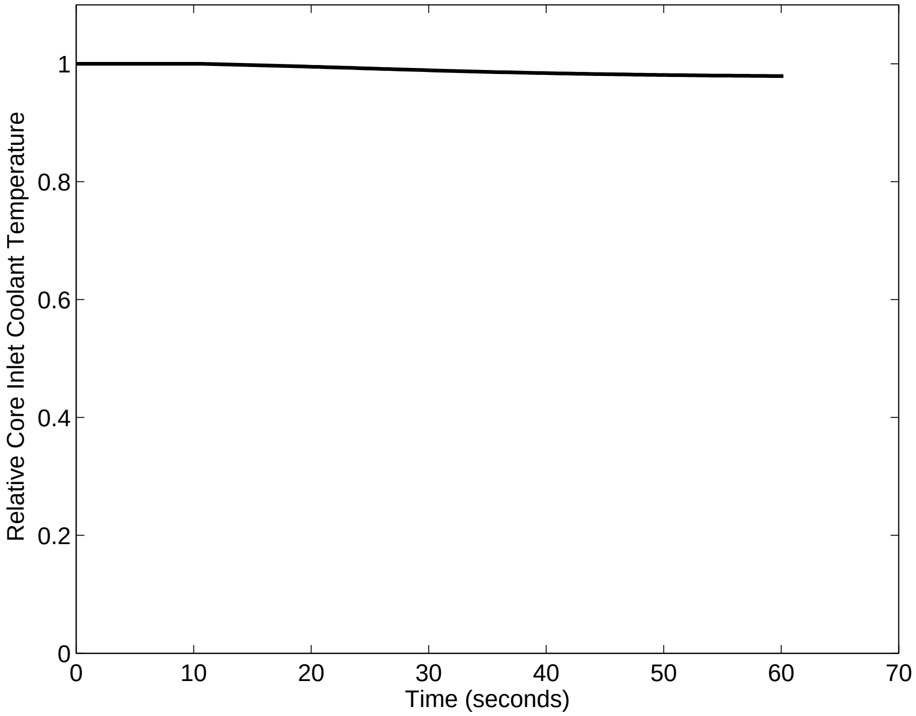

Figure 3.13. Normalized complete LOFA core coolant inlet temperature

sient initiation due to a reduced coolant flow rate through the core with sustained full power output, which causes the coolant to thermally expand. The pressure increase for the complete LOFA in Figure 3.11 is more pronounced than that from the partial LOFA in Figure 3.10 since the coolant mass flow rate decreases more quickly, as shown in Figure 3.9. The spike in primary system pressure in Figure 3.11 reaches a maximum at approximately 10.73 seconds and then promptly drops as reactor power decreases due to the reactor trip at 9.06 seconds. In Figures 3.12 and 3.13 core inlet coolant temperatures remain relatively constant for both events since the secondary plant systems are still available to remove heat from the primary side via the steam generators.

3.4.3 Integration of Neutronic Power Profiles

For the steady-state scoping analysis, all calculations are performed at 118% core power to account for Condition I and II transient events and uncertainties in core-wide power distribution [4, 35]. The 118% power assumption is based on the 112% maximum overpower limit for U.S. PWRs and an additional 6% to account for transient conditions using steady-state analysis. The steady-state, single-pass, hot channel analysis technique is employed, where the hot assembly in the core is relocated from the outer rim of the core to the center of the reactor as demonstrated by Figure 3.14. The hot assembly's relative power factor is increased to give the hottest fuel rod within the assembly the same maximum power peak ($\mathrm{F_Q} = 2.42$) as the reference PWR core. The location and relative power of the hottest rod to the average rod in the hot assembly is determined from neutronic calculations.

Neutronic calculations are performed for an average fuel assembly using $1/8^{\mathrm{th}}$ assembly symmetry. Results from neutronic analyses supply the thermal-hydraulic analyst with the relative rod power for each rod location in the $1/8^{\mathrm{th}}$ section of symmetry, for each incremental increase in burnup. Relative rod power factors for each rod are applied to the hot assembly and are implemented in VIPRE calculations us-

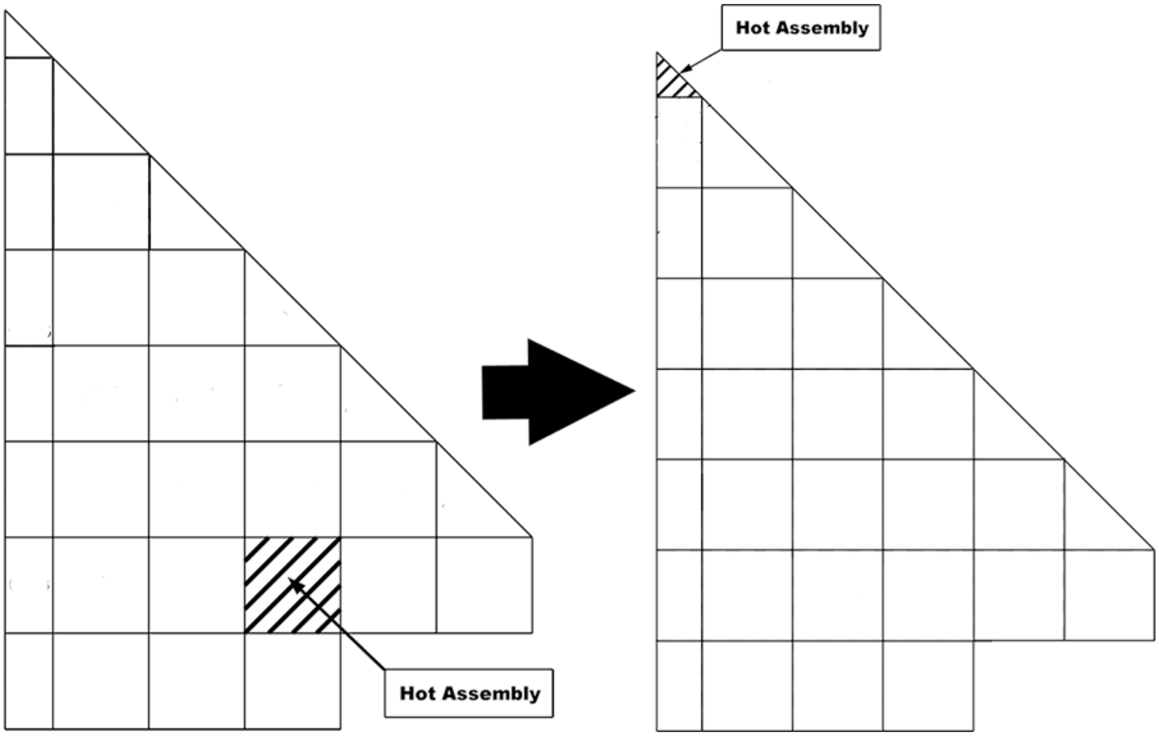

Figure 3.14. 1/8th Core nodalization for steady-state scoping analysis

ing the script-based neutronic / thermal-hydraulic interface described in Section 2. In this way, thermal-hydraulic analyses are performed for an assembly over its entire operational lifetime. Each fuel rod and flow channel in the hot assembly are modeled in VIPRE using the subchannel approach as shown in Figure 3.15. Moving outward in the radial direction from the hot assembly, assemblies are modeled with decreasing resolution with increasing distance from the core's center. All other regions of the core are modeled in VIPRE using the lumped parameter approach, where a single assembly, or group of assemblies, is represented by a single rod and channel with the same heat transfer surface area, fluid flow area, and heat transfer to the coolant as all the rods in the region if they were modeled individually [5].

The hot assembly is surrounded by assemblies with similar relative radial power peaking factors, which creates an insulating 'blanket' that minimizes the effects of

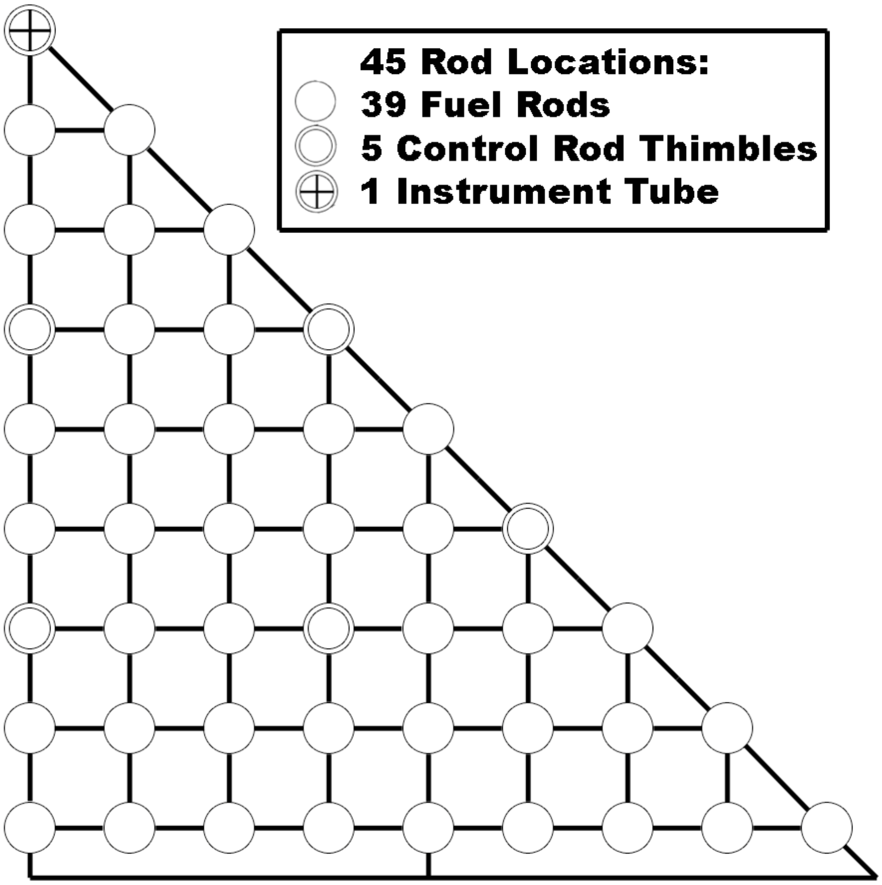

Figure 3.15. 1/8th Hot assembly nodalization for steady-state scoping analysis

mixing among the outer channels in these assemblies and yields conservative DNBR results [35]. The relative radial power peaking factors for the insulating assemblies are set to the same peaking factor as the hot assembly. Additional assembly radial power profiles are adjusted to maintain the correct power normalization for the core. The 1/8th core VIPRE radial assembly power nodalization used in the steady-state scoping analysis is illustrated in Figure 3.16, where assembly relative radial power factors in parentheses indicate insulating assemblies with tentative power factors that depend on the power factor of the hot assembly.

For the purpose of VIPRE calculations, the hot assembly's relative radial power factor is selected by dividing the maximum core power peak, F_Q, by the Nuclear Heat

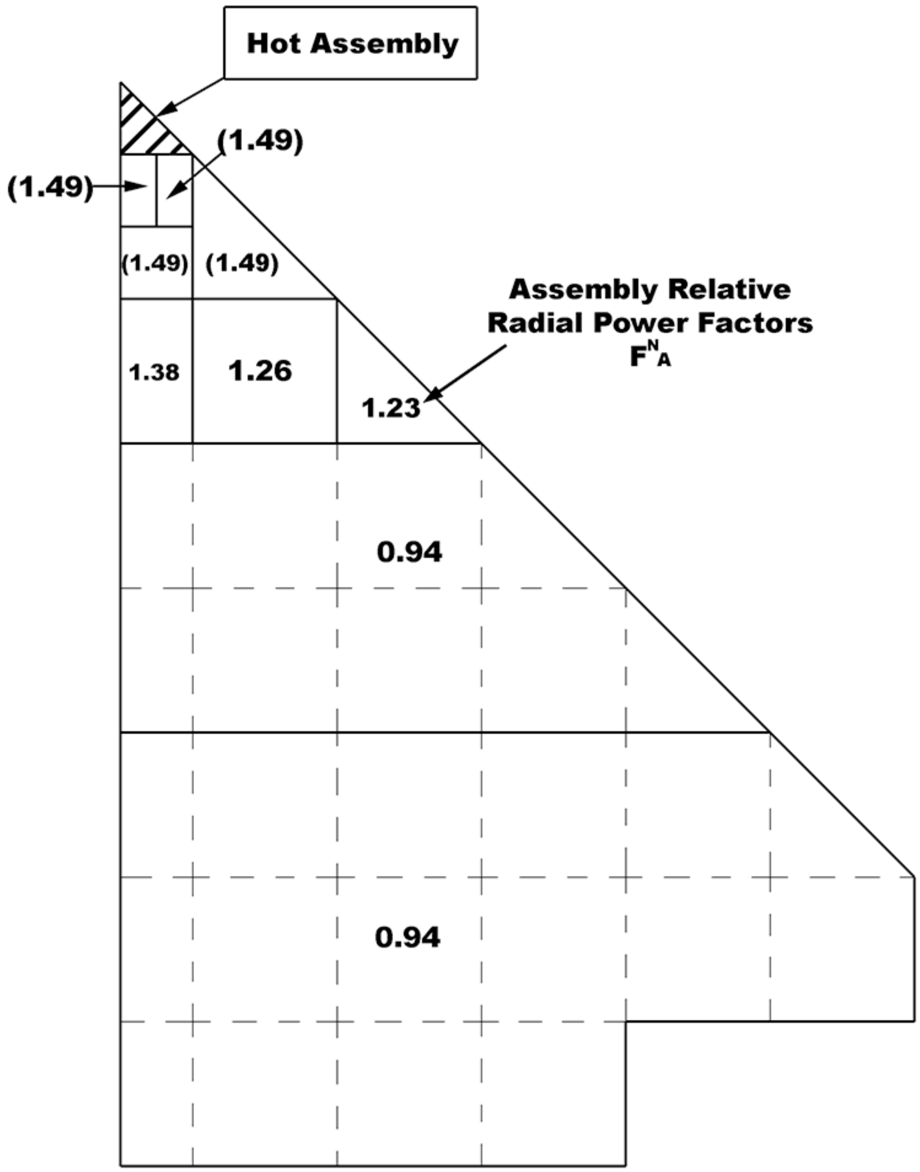

Figure 3.16. VIPRE 1/8th Core nodalization for steady-state scoping analysis

Flux Axial Factor, $F^N{}_Z$, and the maximum relative rod power from 1/8th average assembly neutronic calculations, $F^N{}_{XY,A}$, such that

$$F^V{}_{HA} = \frac{F_Q}{F^N{}_Z \times F^N{}_{XY,A}} \tag{3.5}$$

Benedict et al. [39] claims that a typical value for the hot assembly relative radial power factor is $F^N{}_{HA} = 1.37$ in a conventional PWR core. Therefore, for the reference core, a standard relative power factor for the hottest fuel pin in the hot assembly, $\mathrm{F^N}_{\mathrm{XY,HA}}$, can be determined by using Equations 3.1 and 3.2. Rearranging Equations 3.1 and 3.2 in terms of the relative power factor for the hottest fuel pin in the hot assembly, $\mathrm{F^N}_{\mathrm{XY,HA}}$,

$$\mathrm{F^N}_{\mathrm{XY,HA}} = \frac{\mathrm{F_Q}}{\mathrm{F^E}_{\mathrm{Q}} \times \mathrm{F^N}_{\mathrm{HA}} \times \mathrm{F^N}_{\mathrm{Z}} \times \mathrm{F^N}_{\mathrm{U}}} \tag{3.6}$$

Applying values from Table 3.1, and assuming a peak-to-average axial power profile value of $\mathrm{F^N}_{\mathrm{Z}} = 1.55$, the relative power of the hottest rod to the average rod in the hot assembly is obtained from Equation 3.6:

$$\mathrm{F^N}_{\mathrm{XY,HA}} = \frac{2.42}{1.03 \times 1.37 \times 1.55 \times 1.05} = 1.05$$

Applying this value, $\mathrm{F^N}_{\mathrm{XY,HA}} = 1.05$, as the maximum relative rod power peak factor in the average fuel assembly, $\mathrm{F^N}_{\mathrm{XY,A}}$, in Equation 3.5, the hot assembly relative radial power factor in VIPRE, $\mathrm{F^V}_{\mathrm{HA}}$, is

$$\mathrm{F^V}_{\mathrm{HA}} = \frac{2.42}{1.55 \times 1.05} = 1.49$$

The neutronic / thermal-hydraulic interface calculates the VIPRE hot assembly relative radial power peak factor for each stage of burnup by sampling the individual pin relative radial power peak factors from neutronic calculations, finding the maximum rod power peak factor for the given burnup level, and applying Equation 3.5. In this way, the maximum core power peak, $\mathrm{F_Q}$, in VIPRE is maintained at the reference core value from Table 3.1 as the hot rod location and relative power change with burnup.

Transient analyses performed in VIPRE use the same method for implementing burnup-dependent relative rod power peaking factors from neutronic calculations as the steady-state scoping analysis. The neutronic / thermal-hydraulic interface determines the hot assembly radial power factor for VIPRE calculations, and takes the relative rod power peaking factors from 1/8th assembly neutronic calculations and extrapolates them to the full hot assembly using symmetry. The hot assembly location and remaining assembly radial power factor values in Figure 3.17 are suggested by Benedict et al. [39] for core-wide power distributions in a conventional PWR core.

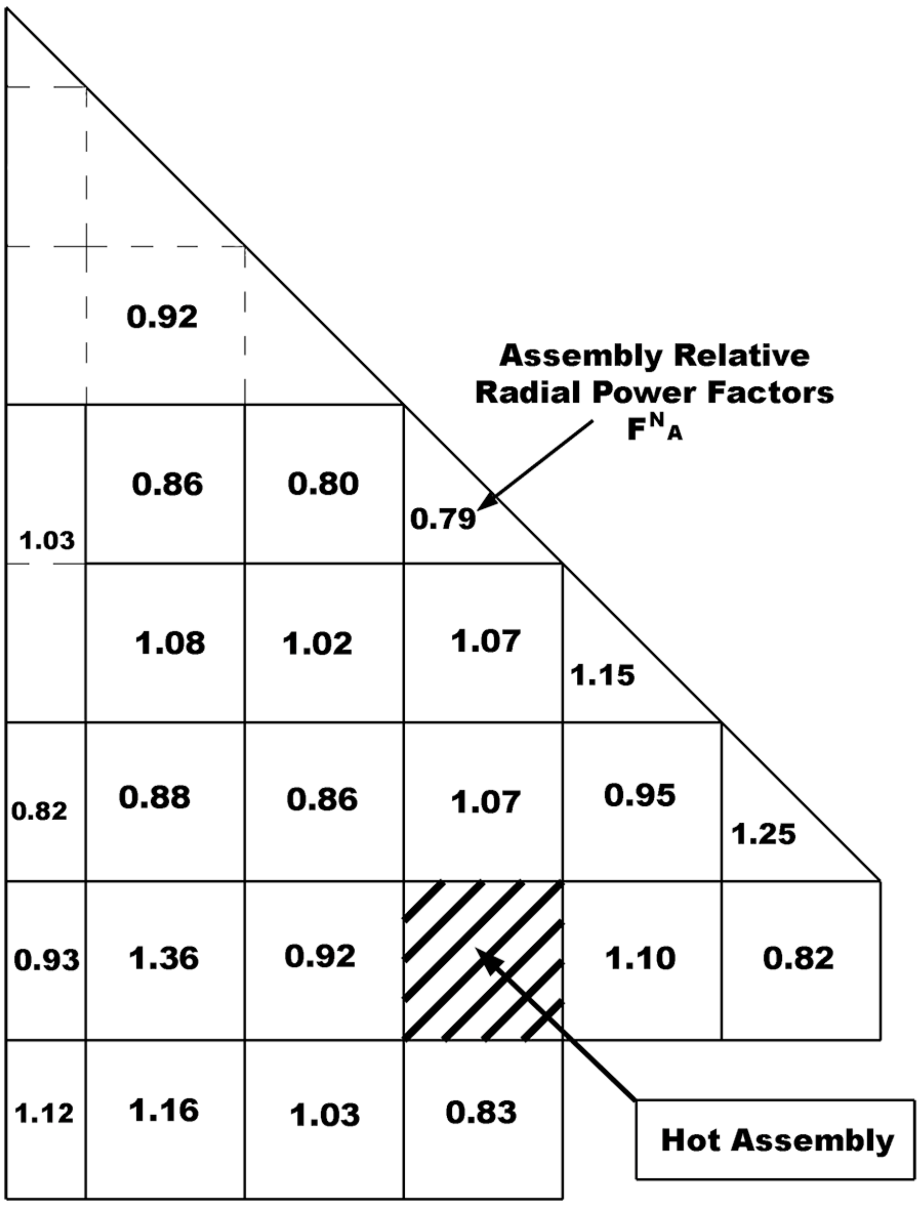

Figure 3.17. VIPRE 1/8$^{\text{th}}$ Core nodalization for transient analysis

3.4.4 Effects of Fuel Assembly Shuffling

In order to maintain criticality and produce the same thermal power output in the core, fresh fuel assemblies must be added and old ones removed from the core on a periodic basis. The process of removing old assemblies from the core and inserting fresh fuel is known as 'reloading', and it occurs during a power plant 'outage'. The time period from one reload to the next is called a 'cycle', which typically lasts 18 to 24 months. An average fuel assembly undergoes 3 to 4 cycles during its lifetime, and can a have discharge burnup upwards of 50 GWd/tHM. Assemblies that have undergone irradiation but are not at their EOL state are reshuffled during an outage. The assembly which is labeled the 'hot assembly' during its first cycle, will not continue to be the hot assembly during subsequent cycles since its radial power peak factor decreases as the fissile content is depleted and it is relocated further towards the center of the core.

To better approximate the reloading process a fuel assembly experiences during its lifetime, the radial core-wide power distribution is flattened and the total power peaking factor, $\mathrm{F_Q}$, is incrementally reduced over three representative cycles for the steady-state scoping analysis in VIPRE. The transition from one higher power cycle to a lower power cycle occurs for burnup levels of 20 and 40 GWd/tHM. These increments produce conservative results since a modeled fuel assembly will operate at a higher power level for a longer period of burnup than what is prototypic of PWR assemblies.

Characteristic maximum assembly radial power factors for the first, second, and third cycle are 1.37, 1.15, 0.95, respectively [39]. The maximum power peak, $\mathrm{F_Q}$, is decreased for the steady-state scoping analysis to approximate fuel reshuffling using the previously determined value of $\mathrm{F^N}_{\mathrm{XY,A}} = 1.05$ from Equation 3.6, and Equations 3.1 and 3.2. For the first cycle, $\mathrm{F^N}_{\mathrm{HA}} = 1.37$ and the maximum power peak is

$$\mathrm{F_Q} = 1.05 \times 1.37 \times 1.55 \times 1.05 \times 1.03 = 2.42$$

For the second and third cycles, the maximum power peaks are $\mathrm{F_Q} = 2.03$ and $\mathrm{F_Q} = 1.68$ using $\mathrm{F^N}_{\mathrm{HA}} = 1.15$ and $\mathrm{F^N}_{\mathrm{HA}} = 0.95$, respectively.

The assembly radial power factors for the insulating assemblies surrounding the hot assembly in the steady-state scoping analysis are scaled down to maintain the same peaking factor as the hot assembly for second and third cycle analyses. The radial relative power factors for the remaining assemblies are adjusted to maintain the correct power normalization for the core. The 1/8th core VIPRE radial assembly power nodalizations used in steady-state scoping analyses for reshuffled cores in the second and third cycles are illustrated in Figures 3.18 and 3.19, where assembly relative radial power factors in parentheses indicate insulating assemblies with tentative power factors that depend on the power factor of the hot assembly. Transient analysis is performed for the most limiting case form the steady-state scoping analysis for each assembly design.

3.4.5 Integration of Burnup-Dependent Fuel Thermal-Physical Properties

Fuel material burnup-dependent thermal-physical properties are utilized in both steady-state and transient analysis. Thermal-physical properties used in VIPRE calculations include thermal conductivity and specific heat. The basic burnup-dependent properties are generated from thermal-physical property models in the fuel element code FRAPCON-3. Section 4 contains a discussion of the thermal-physical property model selection process and the modifications made for actinide additions.

The AMOX fuel property models in Section 4 are integrated into the neutronic / thermal-hydraulic interface. The script-based interface implements the burnup-dependent properties in VIPRE calculations by inserting tables of temperature-dependent thermal conductivity and specific heat values into VIPRE input decks. A table is generated for each stage of burnup in the steady-state scoping analysis. For assembly designs with multiple material regions within a fuel pellet, multiple property tables are generated by the script-based interface for VIPRE to reference for each stage of burnup.

3.5 Summary

The new thermal-hydraulic analysis methodology models many of the effects of burnup on an assembly design by including burnup-dependent variations in fuel pin

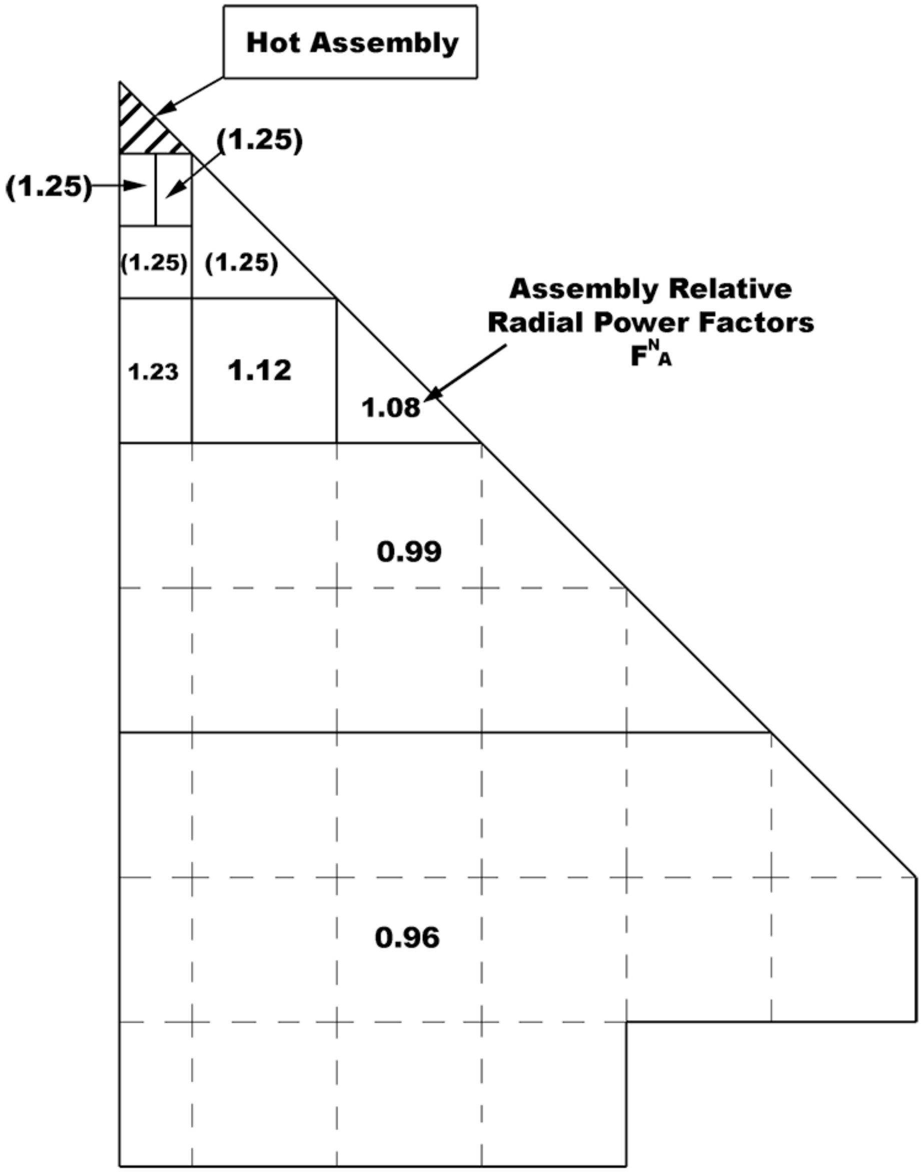

Figure 3.18. VIPRE 1/8th Core steady-state scoping analysis nodalization for second cycle assembly

relative power from neutronic calculations, assembly power reductions due to fissile content depletion and core reshuffling, and fuel material thermal-physical properties. A single VIPRE case contains fuel pin neutronic relative power factors based on burnup calculations, tables of thermal-physical properties, and a representative assembly power level all based on a specified burnup level. A complete thermal-hydraulic anal-

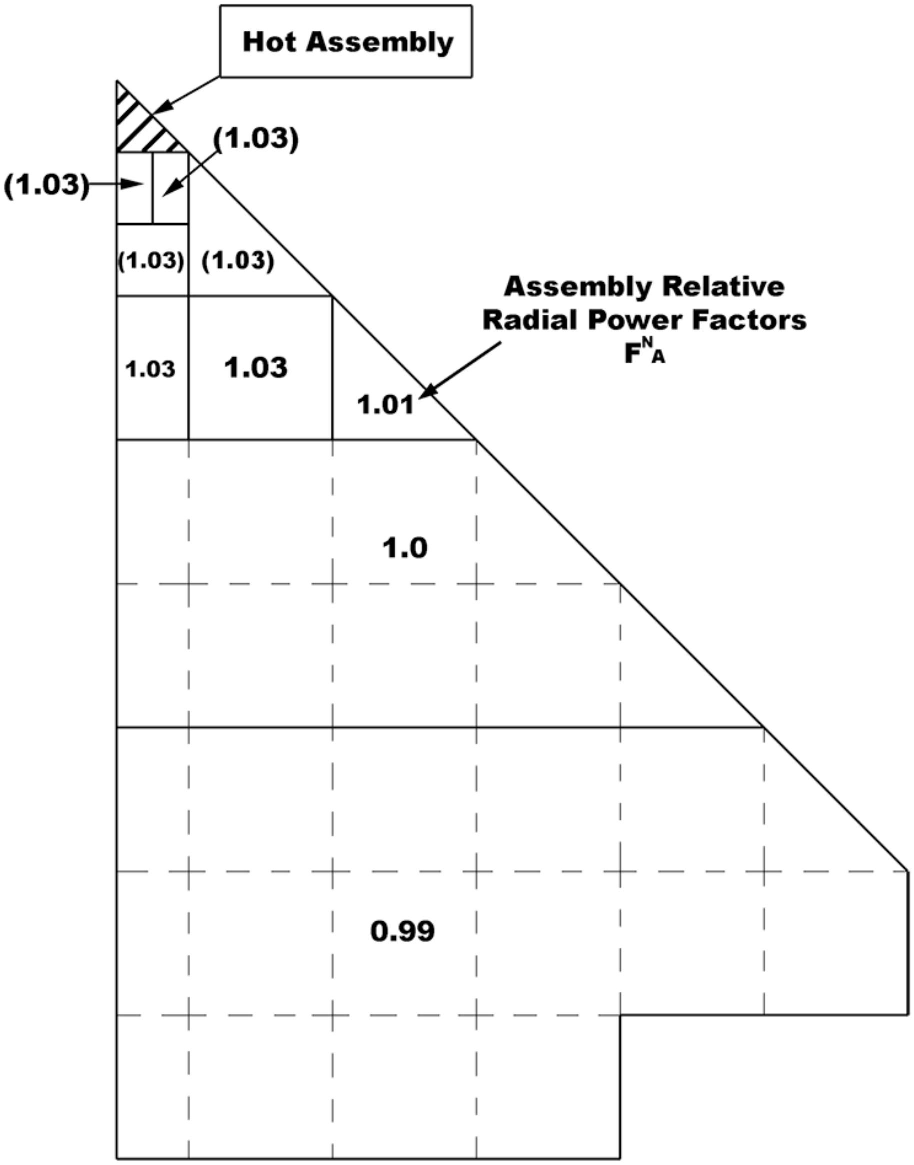

Figure 3.19. VIPRE 1/8th Core steady-state scoping analysis nodalization for third cycle assembly

ysis of an assembly design consists of a steady-state scoping analysis, comprised of 30 to 50 VIPRE cases at different incremental burnup levels, and two transient analyses for partial and complete LOFAs evaluated at the most limiting burnup level from the steady-state analysis. The new methodology effectively covers the entire assembly burnup lifetime and evaluates the thermal-hydraulic performance against ANS Condition I, II, and III events with respect to the MDNBR, peak cladding temperatures, and fuel centerline temperatures.

4. EVALUATION OF ADVANCED FUEL MATERIAL THERMAL CONDUCTIVITY

The primary thermal-physical property of interest for the current research effort is the fuel thermal conductivity. The thermal conductivity of nuclear fuel is one of the most important material properties in fuel assembly design and safety analysis because it indicates how well a material transfers thermal energy, and directly affects assembly design parameters such as fuel temperature, which drive other phenomena, including pore migration and fission gas release. Fuel thermal conductivity is dependent on numerous parameters, including density and other burnup-related properties, and is related to the chemical and physical structure of the material in a very complex manner, rendering it difficult to quantify analytically. Therefore, an accurate representation of the fuel thermal conductivity with its many dependencies is desirable from a design standpoint. In order to select a thermal conductivity model for nuclear fuels in VIPRE, a survey of recent literature was made of various fuel materials, including conventional and advanced fuel types.

4.1 Existing Data and Models

Information is available regarding the thermal and chemical behavior of UO_2, MOX fuels, and IMF fuels for both the validation of the material as an acceptable fuel candidate and for the purpose of developing a representative model for the material's thermal behavior. Currently, information regarding the thermal-physical properties of actinide-doped fuel is limited. Available data comes from measurements taken by Schmidt [40], Nishi et al. [41], Morimoto et al. [42], Ronchi et al. [43], and Raison and Haire [44]. Burnup-dependent thermal conductivity models for actinide-doped fuel are currently unavailable, representing an immediate need for further research and developmental work in advanced fuel material properties so that they may be incorporated into core and system codes for future design analysis. Where models are not available for actinide-doped fuel properties, existing models for UO_2 and MOX fuels have been investigated in order to select reference models to which effects of actinide addition will be added later.

The thermal conductivity of oxide fuels is dependent on a large number of parameters, many of which undergo change throughout the lifetime of the fuel. It is generally agreed upon that the major parameters that affect thermal conductivity are temperature, fuel composition, porosity, burnup, and oxygen-to-metal ratio, or deviations from stoichiometry. Additionally, the presence of fission products in the fuel matrix and effects of radiation damage are known to affect the thermal conductivity at the microscopic level by impeding phenomena that promote thermal conduction. At a molecular level, the thermal conductivity is the sum of contributions from lattice vibrations (phonon transport), electron hole pair formation (ambipolar contribution), and radiant heat transfer.

Thermal energy, or heat, is a form of energy contained by a crystalline lattice by virtue of the vibrational motion of its atoms. The quantized modes of these vibrations occurring in a rigid lattice are classified as phonons. The propagation of phonons is known as phonon transport, and it is the dominant phenomenon governing the thermal conductivity of a solid at lower temperatures.

At higher temperatures it is possible that enough thermal energy exists to excite an electron into a higher state than its previous valence band and create an electron hole. As more of these electron holes are generated, thermal conduction through the crystal lattice is enhanced due to the sharing and migration of electrons in the solid (this is analogous to electrical conduction in conductors and semiconductors).

Work done by Ronchi et al. [45] has shown that in oxide fuels the contribution from radiant heat transfer is negligibly small in comparison to the lattice component and the ambipolar contribution.

Most thermal conductivity models utilize a physically-based lead term that is inversely proportional to the temperature function $[A + B \cdot T]$. This term takes into account the phonon, or lattice, contribution to the thermal conductivity, where A is a constant factor proportional to the point defect contribution to the phonon mean free path and B is a constant factor proportional to the phonon-phonon scattering contribution to the phonon mean free path [46]. Typically, other terms are added that model the electronic (ambipolar) contribution to fuel heat transfer at high temperatures where sufficient thermal energy exist to create significant electron hole pairs such that a generalized form of the thermal conductivity model is as below

$$k(T) = \frac{1}{A + B \cdot T} + C \cdot T^2 \tag{4.1}$$

Therefore, in UO_2 fuels as the temperature increases from relatively low temperatures (300-500K), the fuel thermal conductivity decreases due to increasing phonon-phonon scattering events occurring in the crystal lattice, represented by $[A + B \cdot T]^{-1}$. Around 2000K sufficient thermal energy exists to create significant electron hole pairs and the thermal conductivity begins to increase with increasing temperature as a result of this ambipolar contribution. This general behavior of oxide fuel thermal conductivity is shown in Figure 4.1.

The effects of burnup on oxide fuels are complex, but the combined result is to reduce the thermal conductivity of the fuel as burnup increases. The constant coefficient A in Equation 4.1 is the sum of the thermal resistances due to phonon scattering by individual point defects and dislocations and extended defects [47]. Many defects, such as those caused by vacancies, interstitial atoms, and impurities, already exist in the fuel matrix at BOL conditions. Additional defects are created through radiation damage and the formation of fission products in the lattice structure as a result of the fission process.

The following thermal conductivity models have a similar form to Equation 4.1. Differences involve the methods used to determine the coefficients A, B, and C. The complexity and depth of each model is dependent on the phenomena it is attempting to capture, and can be quite substantial for those models which account for burnup effects.

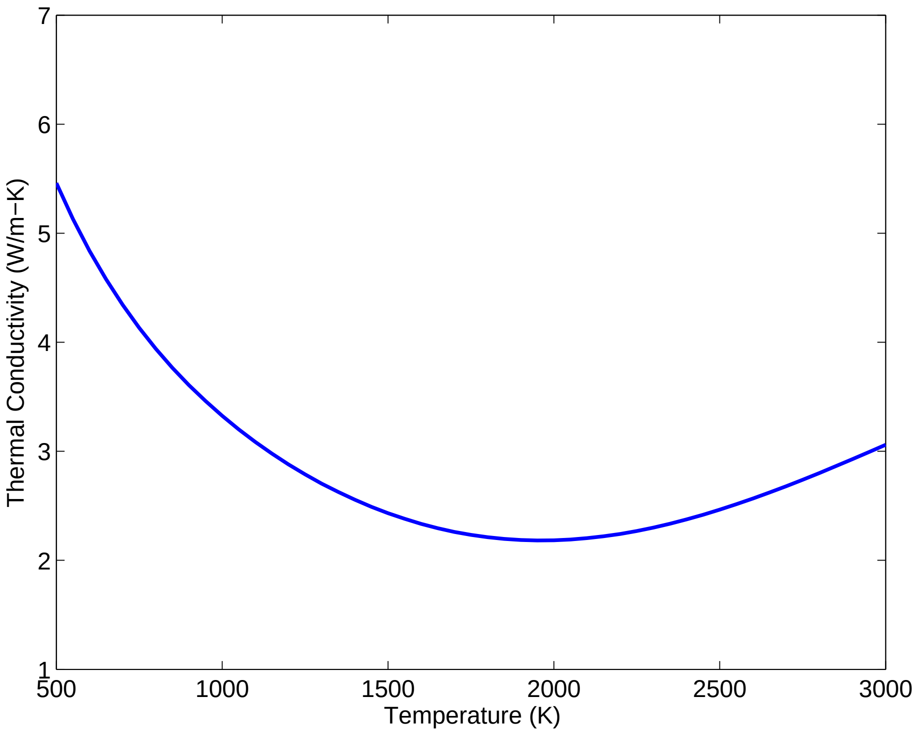

Figure 4.1. Temperature-dependent behavior of oxide fuel thermal conductivity

4.1.1 Ronchi et al. Model for Temperatures up to 2900K

Ronchi et al. [45] determined the thermal conductivity of fresh UO_2 from the simultaneous measurements of the thermal diffusivity and heat capacity from 500 to 2900K using an advanced laser-flash technique. The thermal conductivity values yielded from the experiments were notably smaller than those previously published, which is attributed to improvements in the laser-flash technique that allowed for increased resolution of measured values at higher temperatures. Additionally, the measured contributions revealed that the radiation component was negligible in comparison to the lattice and ambipolar components, and that it had been overestimated in previous work.

4.1.2 Ronchi et al. Model for Burnup up to 100 GWd/tHM

In a separate study, Ronchi et al. [47] calculated the thermal conductivity of reactor-irradiated UO_2 at EOL conditions from the simultaneous measurements of the thermal diffusivity and heat capacity using a laser-flash technique. The samples were collected from irradiated fuel at various burnups. The effects of radiation damage, soluble fission products, and fission gas frozen in dynamical solution were determined. Using a database of several thousand measurements, Ronchi et al. developed a formula for the in-pile thermal conductivity of UO_2 for burnup up to 100 GWd/tHM.

4.1.3 Popov et al. Model for Thermal Conductivity of UO_2

The thermal conductivity model developed by Popov et al. [48] is based primarily on previous work by Lucuta et al. [49] with SIMFUEL. SIMFUEL is a fabricated uranium matrix material which simulates the composition and microstructure of irradiated fuel by introducing 11 stable additives into the UO_2 matrix. This allows analyses to be performed for isolated effects on thermal conductivity, such as fission product buildup and deviations from stoichiometry. These effects are quantified in the form of factors applied to a base thermal conductivity for fully dense (100% theoretical density), unirradiated UO_2. The expressions for each factor are derived from experimental data collected while studying each isolated effect. The Lucuta et al. analytical model accounts for effects produced by the buildup of solid fission products, pores and fission-gas-bubble formation, radiation damage, and changes in the oxygen-to-metal ratio.

4.1.4 FRAPCON-3 Model

The FRAPCON-3 (referred to hereafter as FRAPCON) thermal conductivity model is based on a modified version of the Nuclear Fuels Industries (NFI) model developed by Ohira and Itagaki [50]. The modified version of the NFI model (MNFI) accounts for two inaccuracies found in the previously used Lucuta model [49]: The Lucuta model predicts larger values than are reflected by current data for unirradiated fuel material at high temperatures (> 2000K), and under-predicts the degradation of the thermal conductivity with burnup compared against recent measurements for nominal to high burnup. The MNFI model proposed for FRAPCON by Lanning et al. [28] consists of the typical phonon term that is inversely proportional to temperature, with modified burnup-dependent factors in the denominator, plus additional altered terms that account for the electronic (ambipolar) contribution to fuel heat transfer at high temperatures. Equation 4.2 contains the MNFI model, with a brief explanation of the terms in Table 4.1.

$$k = \frac{1}{A + BT + f(\mathrm{Bu}) + (1 - 0.9\exp(-0.04\mathrm{Bu}))\, g(\mathrm{Bu})h(T)} + \frac{E}{T^2}\exp(-F/T) \quad (4.2)$$

The modified phonon-term in Equation 4.2 applies nearly full annealing of irradiation defects at low burnup, but restores the temperature-dependent annealing at higher burnups. The high temperature term that accounts for the electronic contribution were altered in order to reflect a more theoretically based equation by Hagraman et al. [51] and Popov et al. [28]. The magnitude of the thermal conductivity produced by this model is slightly lower than the original NFI model in order to better represent data from unirradiated PWR fuel pellet material at temperatures approaching fuel melting [45].

4.2 Model Selection

The thermal conductivity models from Ronchi et al. [45, 47] and Popov et al. [48] are examined and compared against the most recent FRAPCON model developed by Lanning et al. [28]. Each model had been validated against available data at the time of its publication, and shown to be in good agreement with the relevant data. However, the surveyed literature covers a time period from 1999 to 2005, and advances in technology have led to improvements in measurement capabilities

Table 4.1
FRAPCON-3 Thermal conductivity model variables (from [28])

Variable	Meaning
k	thermal conductivity, $\mathrm{W/m \cdot K}$
T	temperature, K
Bu	burnup in GWd/tHM
$f(\mathrm{Bu})$	effect of fission products in crystal matrix (solution)
	$= 0.00187 \cdot \mathrm{Bu}$
$g(\mathrm{Bu})$	effect of irradiation defects
	$= 0.038 \cdot \mathrm{Bu}^{0.28}$
$h(T)$	temperature dependence of annealing on irradiation defects $= \dfrac{1}{1 + 396e^{-Q/T}}$
Q	temperature dependence parameter (“Q/R”) = 6380K
A	$= 0.0452\ \mathrm{m \cdot K/W}$
B	$= 2.46 \times 10^{-4}\ \mathrm{m \cdot K/W/K}$
E	$= 3.5 \times 10^{9}\ \mathrm{W \cdot K/m}$
F	$= 16361\mathrm{K}$

and techniques. As such, models based on the most recent fuel property data may be more representative than those from previous work. The following assessment is made with respect to use in the VIPRE code for modeling fuel performance of advanced assembly designs.

The temperature and burnup ranges examined are 500 to 1400K and 0 to 60 GWd/tHM, respectively. These ranges were selected because all the investigated models are applicable within this domain. The predictions are shown as-developed, with no adjustments to account for variations in UO_2 fuel across experiments.

4.2.1 Thermal Conductivity Models for Fresh UO_2

The four examined models for fresh, unirradiated fuel in Figure 4.2 show remarkably similar trends for the temperature-dependent behavior of fresh UO_2 fuel, and only disagree in the magnitude of the thermal conductivity (to within 7-8%). The two most recently developed models, those by Popov et al. [48] and Lanning et al. [28] for FRAPCON, are in excellent agreement and only slightly differ (approximately 2%) at low temperatures. Popov's model predicts slightly lower thermal conductivity values, thereby producing more conservative results from a safety analysis perspective where lower thermal conductivity values may result in an over-estimation of fuel temperatures.

The model developed by the later work of Ronchi et al. [47], which takes into account the effects of burnup and thermal annealing, predicts even lower values of

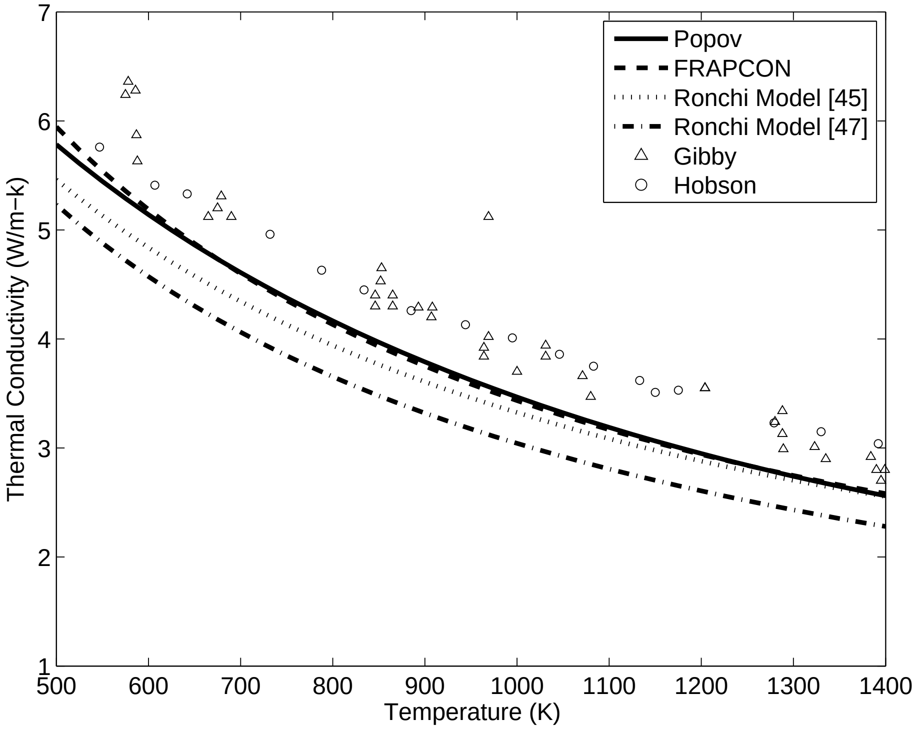

Figure 4.2. Comparison of thermal conductivity models for fresh UO_2 against measurements by Gibby [46] and Hobson [52]

the thermal conductivity in fresh fuel than their earlier work with only fresh, unirradiated UO_2. The Ronchi et al. [47] model was developed for burnup levels of 0 to 100 GWd/tHM and therefore is considered in this analysis for fresh, unirradiated UO_2. The Ronchi et al. [47] model's lower prediction of thermal conductivity values is prevalent in all the following comparisons, and may be explained by two considerations: 1) while a simple correction factor is implemented in Ronchi's model to account for differences in irradiated fuel and fresh fuel, the model was developed using discharged fuel at EOL conditions and therefore tends to be biased towards lower values for fresh fuel, 2) a particular term in the model used in the calculation of A from Equation 4.1 represents the value of A specific to the fuel being measured before reactor irradiation. This term is completely independent of the irradiation effects and capable of being adjusted if a fuel with a different starting thermal conductivity is considered. Therefore, it is believed that if a new beginning value of A were calculated for the fuels examined by Popov and Lanning using the same analysis technique of Ronchi, the Ronchi model with burnup effects would show more agreement with the other examined models with respect to the magnitude of the thermal conductivity.

A comparison of the models and UO_2 thermal conductivity measurements collected by Gibby [46] and Hobson [52] is shown in Figures 4.2 and 4.3. It should be noted that although Figure 4.3 indicates that the most recent models (FRAPCON and Popov et al.) are under-predicting the thermal conductivity by approximately 12%, these data points come from measurements of UO_2 with slightly higher values of theoretical density, and therefore are expected to be larger in magnitude. Again, the models well predict the temperature-dependent behavior of the thermal conductivity. The Popov et al. and FRAPCON models show much better agreement (to within 5-6%) with more recent measurements of 95% dense UO_2 thermal conductivity collected by Ronchi et al. [45] as shown in Figure 4.4.

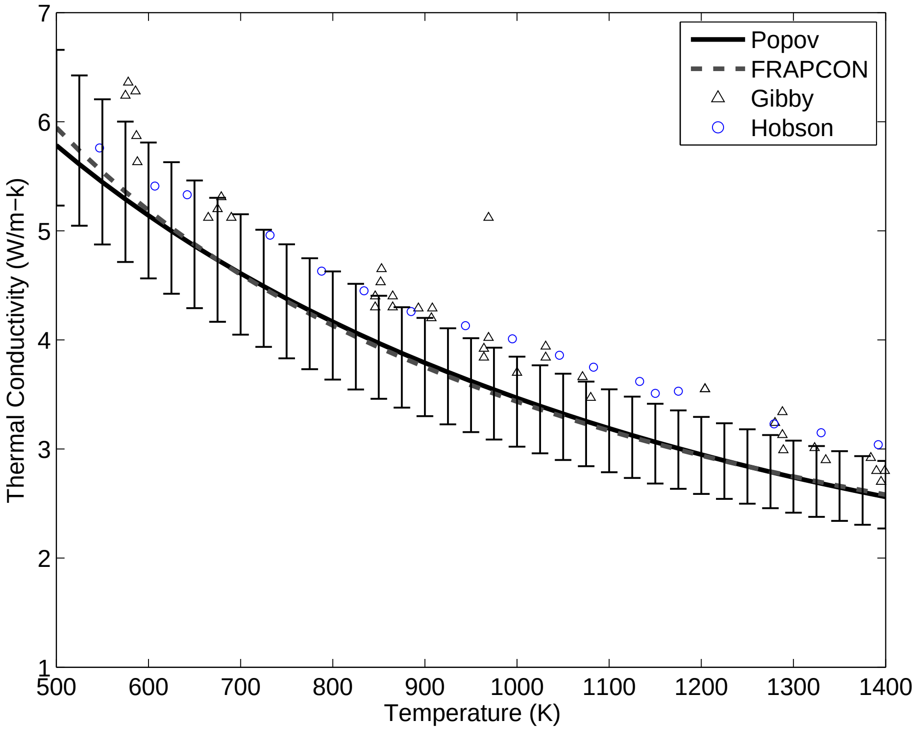

Figure 4.3. Comparison of thermal conductivity models for fresh UO_2 against measurements by Gibby [46] and Hobson [52] with 12% error bars

4.2.2 Thermal Conductivity Models for Irradiated UO_2

The models that include the effects of burnup are next compared: Ronchi et al. [47] with burnup, Popov et al. [48], and the FRAPCON model developed by Lanning et al. [28]. Figure 4.5 shows the predictions of the temperature-dependent thermal conductivity from the three models at 20 GWd/tHM. There is excellent agreement between the models at low temperatures, with deviations in conductivity values occurring around 800K. As expected, the Ronchi et al. [47] model provides the lowest, most conservative values of the three models over the examined temperature range, and is in better agreement with these models, as compared to the previous comparison, since the model was developed using irradiated UO_2.

At nominal LWR operating temperatures, the thermal conductivity values pre-

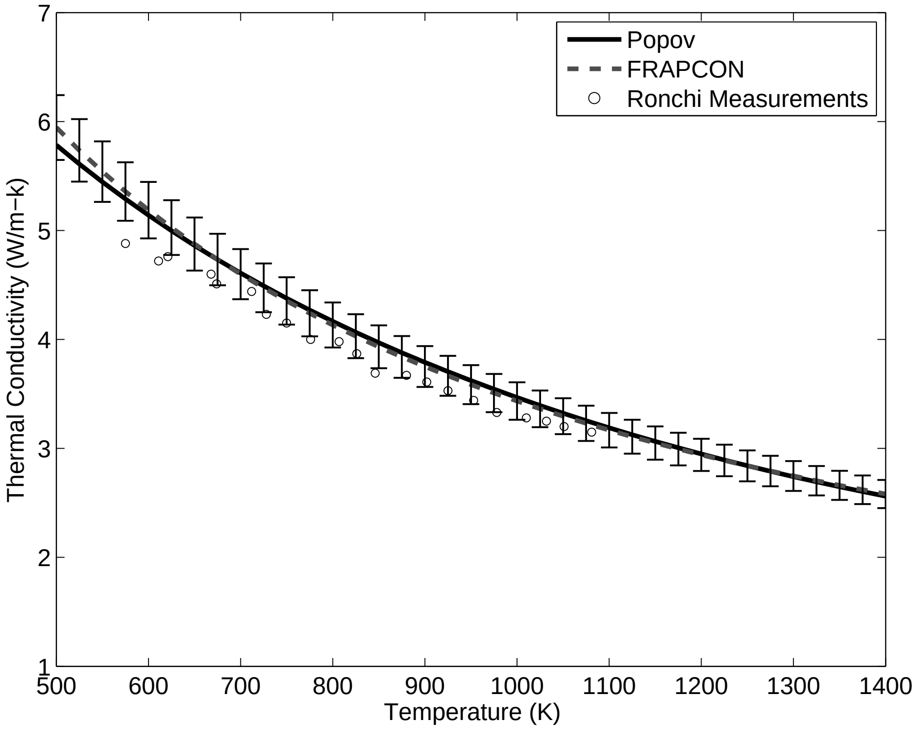

Figure 4.4. Comparison of Popov et al. [48] and FRAPCON [28] thermal conductivity models for fresh UO_2 against measurements by Ronchi et al. [45] with 5% error bars

dicted by the Popov model are higher than those from the FRAPCON model - an inherent trait of the Lucuta-based model, which under-predicts the degradation of the fuel conductivity with burnup [28]. Additionally, the initial lower values of the Popov et al. model are due to a radiation effect factor which significantly reduces the thermal conductivity at temperatures below 900K, but diminishes above 900K in an attempt to represent the effects of thermal annealing of radiation-induced defects. Conversely, the FRAPCON model assumes full annealing of radiation induced defects at low burnup, and returns the temperature-dependence of annealing at higher burnup. Similar behavior is seen in Figure 4.6 between the FRAPCON model and Popov et al. model at 45 GWd/tHM. However, the Ronchi et al. model predicts higher thermal conductivity values at lower temperatures and lower, more conservative values at higher temperatures.

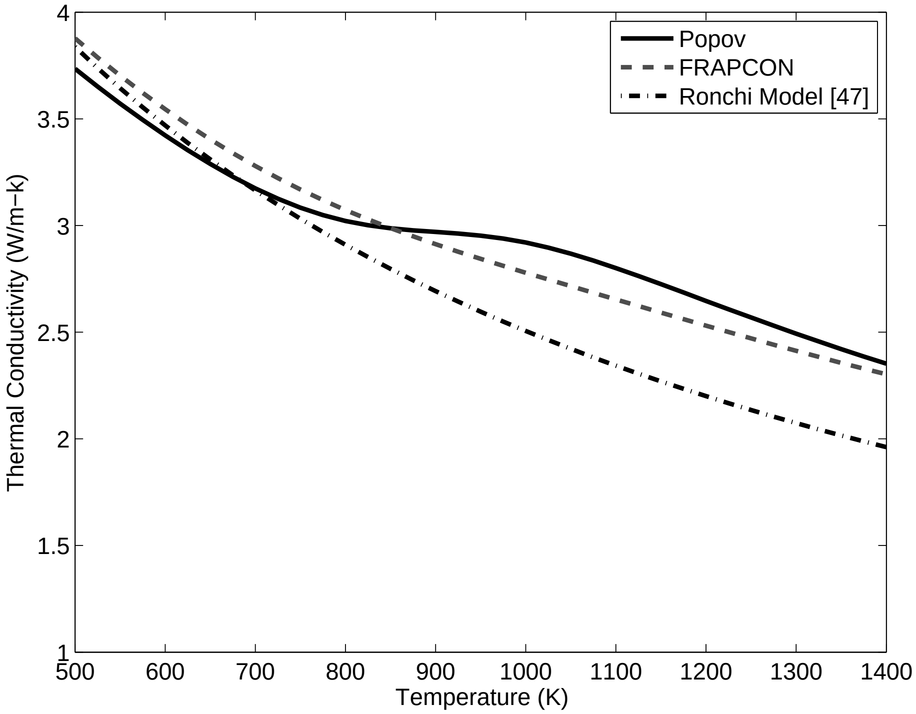

Figure 4.5. Comparison UO_2 thermal conductivity models at 20 GWd/tHM

The behavior of the thermal conductivity with respect to burnup is shown in Figure 4.7. As expected, a monotonically decreasing relationship can be seen in the reduction of thermal conductivity with burnup. This is due to an increasing concentration of phonon scattering centers, which are related to the concentration of fission products, forming a linear dependence on burnup. This dependence is more pronounced in the FRAPCON and Popov et al. models, with the Popov model again predicting higher conductivity values as a result of an underestimation of the degradation of thermal conductivity with increasing burnup. On the other hand, the thermal conductivity predicted by Ronchi et al. [47] begins to level off around 30 GWd/tHM instead of following a continual linear decrease. This behavior may be attributed to a predicted improvement of the lattice contribution to the thermal conductivity at higher burnup levels due to the formation of a rim structure - a phenomenon not necessarily accounted for by the other models.

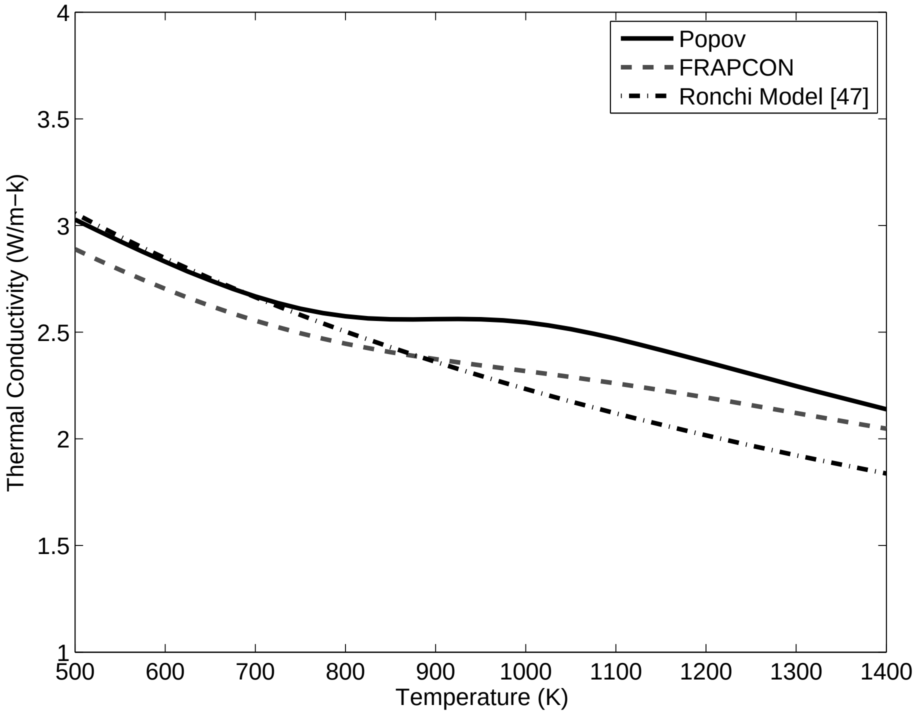

Figure 4.6. Comparison of UO_2 thermal conductivity models at 45 GWd/tHM

All examined models employ a $[A + B \cdot T]^{-1}$ formulation for the thermal conductivity and are in good agreement with each other, to within 7-8%. Differences between the models are attributed mostly to the measurement techniques used in each experiment, and the intended purpose of each model (measurements taken from fresh vs. irradiated vs. SIMFUEL fuels, and intended for predictions with burnup vs. without burnup). Compared against recent experimental measurements of the thermal conductivity, the four models accurately predict the temperature-dependent behavior of the fuel, to within 5-6% for 95% dense UO_2.

Three of the four models account for the effects of burnup on thermal conductivity. Generally, the model by Ronchi et al. [47] estimates the lowest conductivity values, and therefore most conservative values from a safety margin perspective. The lower conductivity values generated from the Ronchi et al. [47] model may be attributed to its prediction of greater fuel degradation with increasing burnup, and

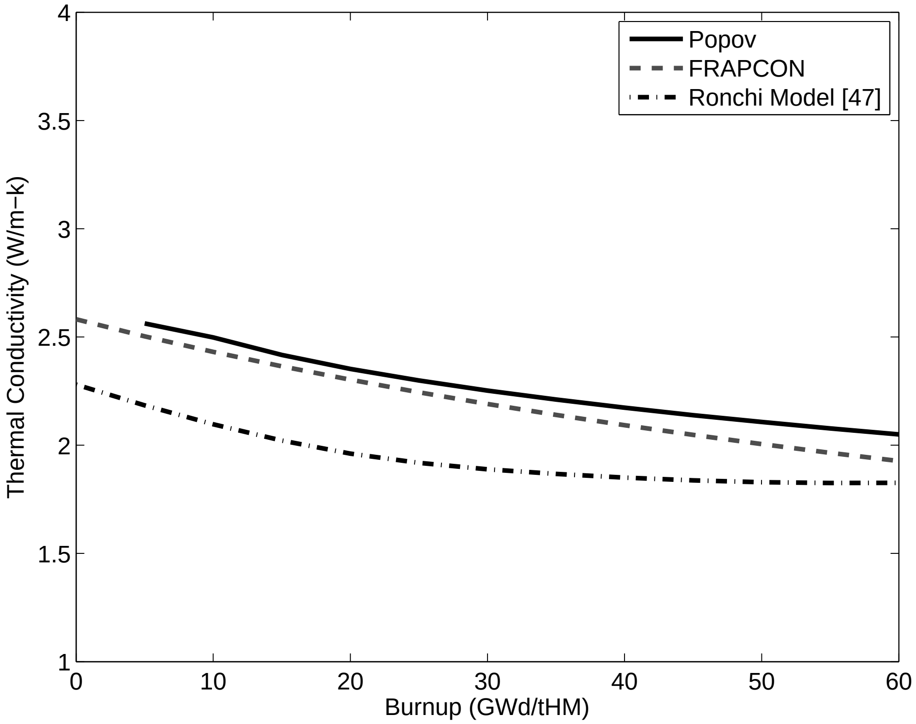

Figure 4.7. Comparison of UO_2 thermal conductivity models with increasing burnup at 1400K

a fuel specific parameter used to calculate the A term in Equation 4.1, tending to bias the results towards lower values. The FRAPCON model consistently predicts lower, more conservative values than the Lucuta-based Popov et al. model due to an updated correlation that reduces the underprediction of burnup effects found in the Lucuta model.

While the Ronchi et al. [47] model is perhaps the most rigorous in its assessment of the thermal conductivity, the fuel-specific term used to calculate A in Equation 4.1 makes it difficult to implement this model into VIPRE since future work to provide appropriate values for various fuel materials is not discussed. Therefore, the FRAPCON model is chosen as the best approach for implementation into the VIPRE code, due to its good agreement with recent conductivity measurements, general applicability to UO_2 and MOX-based nuclear fuels, and lower, more conservative thermal conductivity values in all examined cases as compared to other investigated models.

4.3 Modifications for AMOX Fuels

Future advanced fuel assembly designs are intended to burn MAs. One of the primary MAs under consideration is americium, which has been selected as the representative element for modeling the effects of actinide additions to UO_2 and MOX-based fuels. Advanced fuel compositions under consideration are $(U,Am)O_2$, $(U,Pu,Am)O_2$, AmO_2, and $(Zr,Am)O_2$.

The chemical compositions and atomic structures of $(U,Am)O_2$ and $(U,Pu,Am)O_2$ are comparable to those of UO_2 and $(U,Pu)O_2$. Both $(U,Am)O_2$ and $(U,Pu,Am)O_2$ are uranium-dominant mixed-oxides that share the same fluorite crystalline structure and $[A + B \cdot T]^{-1}$ temperature-dependent thermal conductivity behavior as UO_2 and $(U,Pu)O_2$ [40,44]. Additionally, studies of $(U,Pu,Am)O_2$ by Morimoto et al. [42] have shown that additions of americium to conventional $(U,Pu)O_2$ fuel have no significant effect on the oxygen-to-metal ratio dependence of the A and B coefficients from Equation 4.1. Bakker and Konings [53] estimate that the similar temperature-dependent behavior of the thermal conductivity of $(U,Pu)O_2$ and $(U,Am)O_2$ is attributed to similarities in the ratio of atomic radii for the most common americium and plutonium ions found in their respective compounds. Therefore, since the chemical compositions and atomic structures of $(U,Am)O_2$ and $(U,Pu,Am)O_2$ are analogous to $(U,Pu)O_2$ and they possess equivalent dependences to temperature and stoichiometry, it is assumed that their burnup-dependent behavior is similar and may be approximated using the FRAPCON thermal conductivity model for MOX fuel. The effects of actinide additions to fuel thermal conductivity are addressed by applying actinide-concentration-dependent multiplication factors to the FRAPCON MOX model.

4.3.1 Thermal Conductivity of $(U,Am)O_2$

Thermal conductivity measurements taken from $(U,Am)O_2$ samples fabricated by Schmidt et al. [40] have been compared against FRAPCON $(U,Pu)O_2$ model estimations for the same theoretical density and oxygen-to-metal ratio as the fabricated samples. Thermal conductivity measurements taken by Schmidt come from identical samples using two different approaches. The first set of measurements are taken from a sample as it is heated up from 1100 to 1800K. The second set of measurements come from a sample that is cooled from 1800 to 1300K.

The measurements and FRAPCON estimates are listed in Table 4.2, along with the fractional difference between the two points with respect to the FRAPCON model at each temperature. Both data sets show a monotonic decrease in thermal conductivity for increasing temperature until 1500K, where the electronic contribution becomes significant enough to induce increases in the conductivity. Schmidt measured an initial oxygen-to-metal ratio of 1.83 for the (U,Am)O_2 samples, with a final ratio closer to 1.92 after the heating process. The sudden increase in thermal conductivity, and resulting wide scatter in Schmidt's experimental data, in the second set of measurements for temperatures less than 1500K may be attributed to increases in stoichiometry during the heating and cooling process.

The maximum and minimum fractional difference between the two sets thermal conductivity values are 0.1845 and 0.0172, respectively. In order to determine an appropriate multiplication factor to apply to the FRAPCON (U,Pu)O_2 thermal conductivity model to approximate the temperature and burnup-dependent behavior of (U,Am)O_2, several fractional difference points were selected over the range from Table 4.2 to study the sensitivity of VIPRE calculations to thermal conductivity. The selected fractional differences were applied to the FRAPCON (U,Pu)O_2 thermal conductivity model implemented in VIPRE and calculations were carried out over a range of 0 to 20 GWd/tHM. The results from VIPRE calculations of the maximum fuel temperature in the core versus burnup for each representative thermal conductivity multiplication factor are shown in Figure 4.8. Additional sensitivity studies were performed to determine the sensitivity of VIPRE maximum fuel centerline temperatures to the fuel pellet oxygen-to-metal ratio and initial theoretical density. Appendix E documents the sensitivity study results for the oxygen-to-metal ratio and pellet theoretical density.

Table 4.2
Comparison of thermal conductivity values from Schmidt et al. [40] and FRAPCON MOX model [28]

	Thermal conductivity (W/m · K)		Fractional
Temperature (K)	Schmidt et al.	FRAPCON	difference
1133	1.23	1.42	0.1365
1213	1.15	1.41	0.1818
1313	1.19	1.39	0.1433
1398	1.15	1.38	0.1683
1493	1.13	1.39	0.1845
1593	1.18	1.40	0.1580
1693	1.22	1.43	0.1476
1303	1.35	1.39	0.0290
1373	1.36	1.38	0.0172
1413	1.32	1.38	0.0452
1498	1.33	1.39	0.0405
1513	1.22	1.39	0.1209
1593	1.25	1.40	0.1080
1643	1.26	1.41	0.1092
1673	1.23	1.42	0.1363

The maximum fuel temperatures in the core increase with decreasing thermal

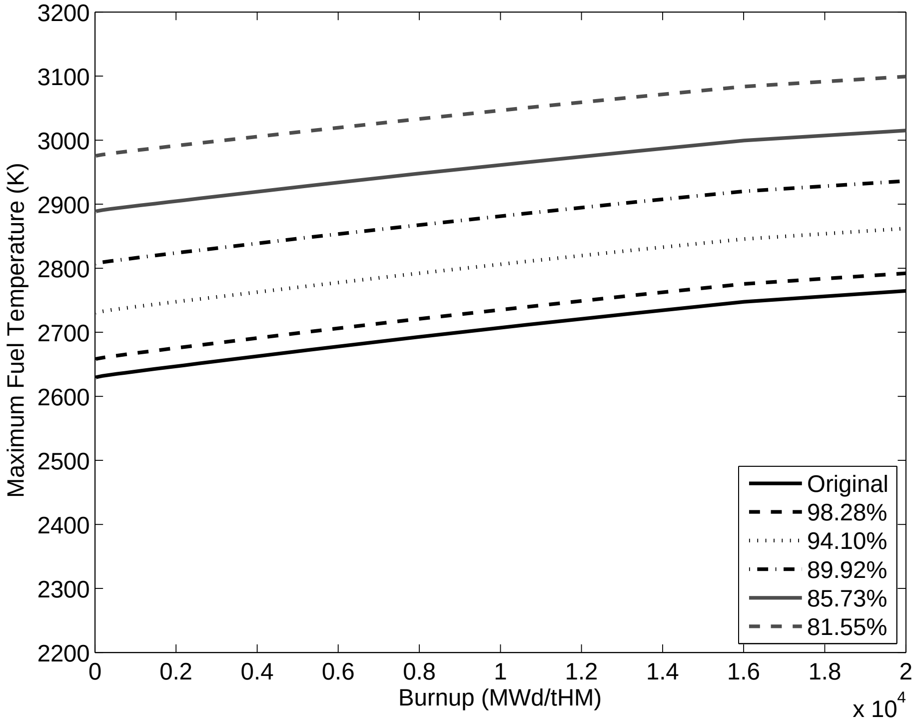

Figure 4.8. Core maximum fuel temperature against burnup, $(U,Am)O_2$

conductivity, as expected. The sensitivity of VIPRE calculations to thermal conductivity values for $(U,Am)O_2$ is shown in Figure 4.9, where sensitivity is defined as the percent change in the maximum fuel temperature divided by the percent change in the thermal conductivity. A sensitivity value of 1 represents a one-to-one (‘strong’) relationship between the VIPRE results and the thermal conductivity. Sensitivity values less than 1, but still close to 1, indicate a fairly strong relationship between VIPRE results and the thermal conductivity, with large changes in the thermal conductivity resulting in relatively smaller changes in the maximum fuel centerline temperatures. Sensitivity values greater than 1 or much closer to 0 represent very strong and negligible relationships, respectively, to the thermal conductivity for VIPRE results.

The sensitivity of VIPRE results to the thermal conductivity values of $(U,Am)O_2$ is approximately 0.78 from Figure 4.9, indicating a fairly strong relationship between

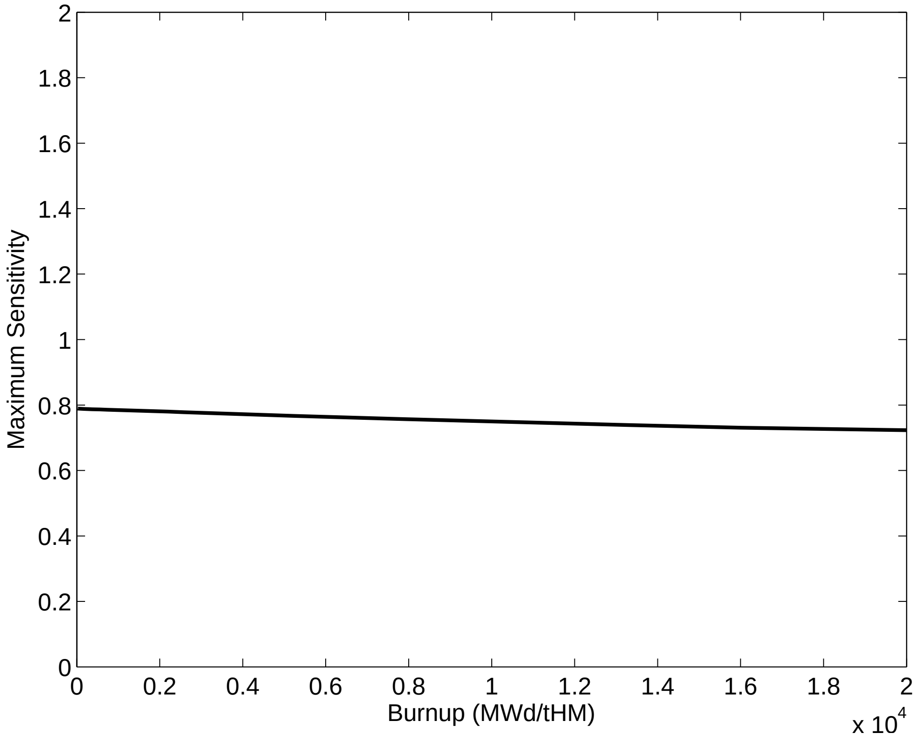

Figure 4.9. VIPRE Fuel temperature sensitivity to changes in thermal conductivity, (U,Am)O_2

the two parameters. Therefore, since the sensitivity of VIPRE results to the thermal conductivity values for (U,Am)O_2 cannot be neglected, the most conservative fractional difference (0.1845) that will lead to lower thermal conductivity values is selected as the multiplication factor for (U,Am)O_2. Reported americium concentrations in the samples fabricated by Schmidt are 50% of the metal content [40]. Therefore, the actinide-concentration-dependent multiplication factor for (U,Am)O_2 is

$$ACF_{(\mathrm{U,Am})\mathrm{O}_2} = \frac{0.1845}{50\%} = 0.0037 \text{ /\% actinide addtion}$$

and the final form of the (U,Am)O_2 thermal conductivity model is the product of Equation 4.2 and the $ACF_{(\mathrm{U,Am})\mathrm{O}_2}$, such that

$$k = (1 - ACF_{(\mathrm{U,Am})\mathrm{O}_2})\left[\frac{1}{A + BT + f(\mathrm{Bu}) + (1 - 0.9\exp(-0.04\mathrm{Bu}))\,g(\mathrm{Bu})h(T)} + \frac{E}{T^2}\exp(-F/T)\right] \tag{4.3}$$

The original FRAPCON (U,Pu)O_2 thermal conductivity model and the modified-MOX model from Equation 4.3 are compared against the (U,Am)O_2 thermal conductivity measurements by Schmidt in Figure 4.10. The new modified FRAPCON model from Equation 4.3 conservatively predicts the thermal conductivity of (U,Am)O_2 with respect to measurements taken by Schmidt and is in good agreement with the less scattered set of measurements from the first sample.

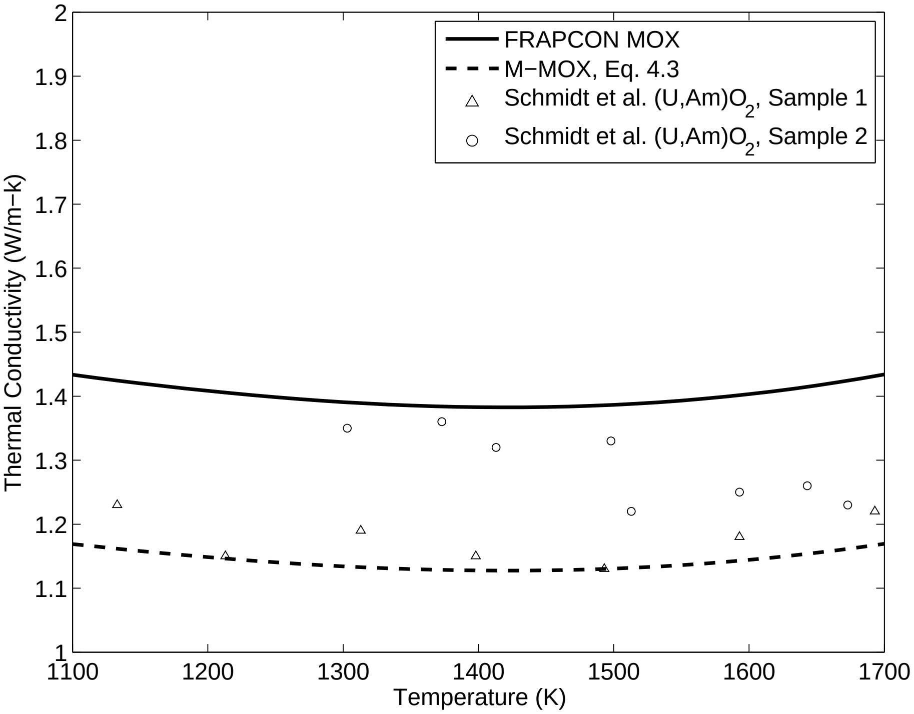

Figure 4.10. (U,Am)O_2 Thermal conductivity model

4.3.2 Thermal Conductivity of $(U,Pu,Am)O_2$

A thermal conductivity model for fresh $(U,Pu,Am)O_2$ developed by Morimoto et al. [42] is compared against FRAPCON $(U,Pu)O_2$ model estimates for 95% dense fuel with oxygen-to-metal ratios of 2.00. The Morimoto model is based on thermal conductivity values obtained from thermal diffusivity measurements from 900 to 1773K, and does not take into account the effects of burnup. The $(U,Pu,Am)O_2$ samples were fabricated with approximately 2.2% americium with respect to the total metal content. The thermal conductivity model follows the $[A + B \cdot T]^{-1}$ behavior of Equation 4.1 with stoichiometry-dependent A and B coefficients. The estimated thermal conductivities for $(U,Pu,Am)O_2$ and $(U,Pu)O_2$, along with the fractional difference between the two estimates with respect to the FRAPCON model at each temperature are listed in Table 4.3.

Surprisingly, the thermal conductivity of $(U,Pu,Am)O_2$ is higher than that of $(U,Pu)O_2$. Most research suggests that additions of actinides to conventional UO_2 and $(U,Pu)O_2$ fuels will result in a reduction of thermal conductivity. However, no other studies on americium-doped $(U,Pu)O_2$ fuel are available to contradict these measurements.

The maximum and minimum fractional difference between the thermal conductivity models' estimates are 0.2315 and 0.1724, respectively. Several fractional difference points were selected over this range from Table 4.3 to study the sensitivity of VIPRE calculations to thermal conductivity of $(U,Pu,Am)O_2$. The selected fractional differences were applied to the FRAPCON $(U,Pu)O_2$ thermal conductivity model implemented in VIPRE and calculations were carried out over a range of 0 to 20 GWd/tHM. The results from VIPRE calculations of the maximum fuel temperature in the core versus burnup for each representative thermal conductivity multiplication factor are shown in Figure 4.11.

The maximum fuel temperatures in the core decrease with increasing thermal conductivity. The sensitivity of VIPRE calculations to thermal conductivity values

Table 4.3
Comparison of thermal conductivity models from Morimoto et al. [42] and FRAPCON MOX model [28]

	Thermal conductivity (W/m · K)		Fractional
Temperature (K)	Morimoto et al.	FRAPCON	difference
900	4.21	3.42	0.2315
925	4.10	3.34	0.2288
950	4.00	3.26	0.2263
975	3.90	3.19	0.2238
1000	3.81	3.12	0.2214
1025	3.72	3.05	0.2190
1050	3.63	2.99	0.2167
1075	3.55	2.92	0.2143
1100	3.47	2.87	0.2119
1125	3.40	2.81	0.2095
1150	3.33	2.76	0.2070
1175	3.26	2.71	0.2044
1200	3.19	2.66	0.2017
1225	3.13	2.61	0.1989
1250	3.07	2.57	0.1958
1275	3.01	2.52	0.1926
1300	2.96	2.49	0.1891
1325	2.90	2.45	0.1854
1350	2.85	2.41	0.1814
1375	2.80	2.38	0.1771
1400	2.75	2.35	0.1724

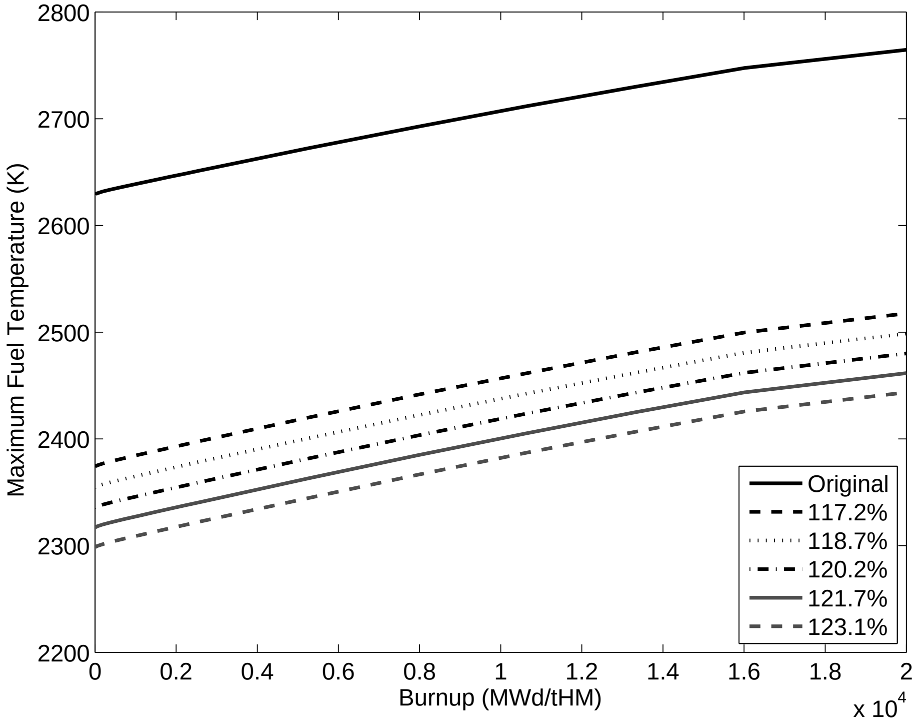

Figure 4.11. Core maximum fuel temperature against burnup, (U,Pu,Am)O_2

for (U,Pu,Am)O_2 is shown in Figure 4.12, where the sensitivity is approximately 0.61. The sensitivity indicates a fairly strong relationship between (U,Pu,Am)O_2 thermal conductivity and the calculated fuel temperatures in VIPRE, therefore, the most conservative fractional difference (0.1724) is selected as the multiplication factor for (U,Pu,Am)O_2 since lower thermal conductivity values lead to higher fuel temperatures in the core.

The actinide-concentration-dependent multiplication factor for (U,Pu,Am)O_2 is

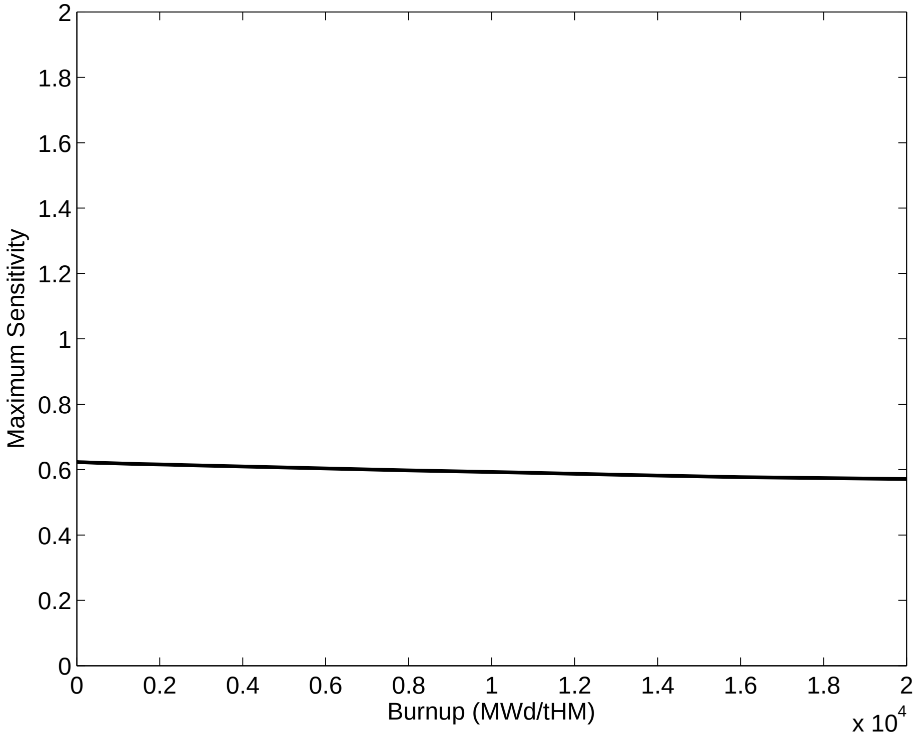

Figure 4.12. VIPRE Fuel temperature sensitivity to changes in thermal conductivity, (U,Pu,Am)O_2

$$ACF_{(\mathrm{U,Pu,Am})\mathrm{O}_2} = \frac{0.1724}{2.2\%} = 0.0784 \text{ /\% actinide addtion}$$

and the final form of the (U,Pu,Am)O_2 thermal conductivity model is the product of Equation 4.2 and the $ACF_{(\mathrm{U,Pu,Am})\mathrm{O_2}}$, such that

$$\begin{aligned} k =&(1 + ACF_{(\mathrm{U,Pu,Am})\mathrm{O_2}}) \left[\frac{1}{A + BT + f(\mathrm{Bu}) + (1 - 0.9 \exp(-0.04\mathrm{Bu}))\, g(\mathrm{Bu}) h(T)} \right. \\ &\left. + \frac{E}{T^2} \exp(-F/T) \right] \end{aligned} \tag{4.4}$$

The original FRAPCON (U,Pu)O_2 thermal conductivity model and the modified-MOX model from Equation 4.3 are compared against the (U,Pu,Am)O_2 thermal conductivity model by Morimoto in Figure 4.13. The new modified FRAPCON model from Equation 4.4 is in good agreement with the Morimoto model, while producing conservative (U,Pu,Am)O_2 thermal conductivity estimates.

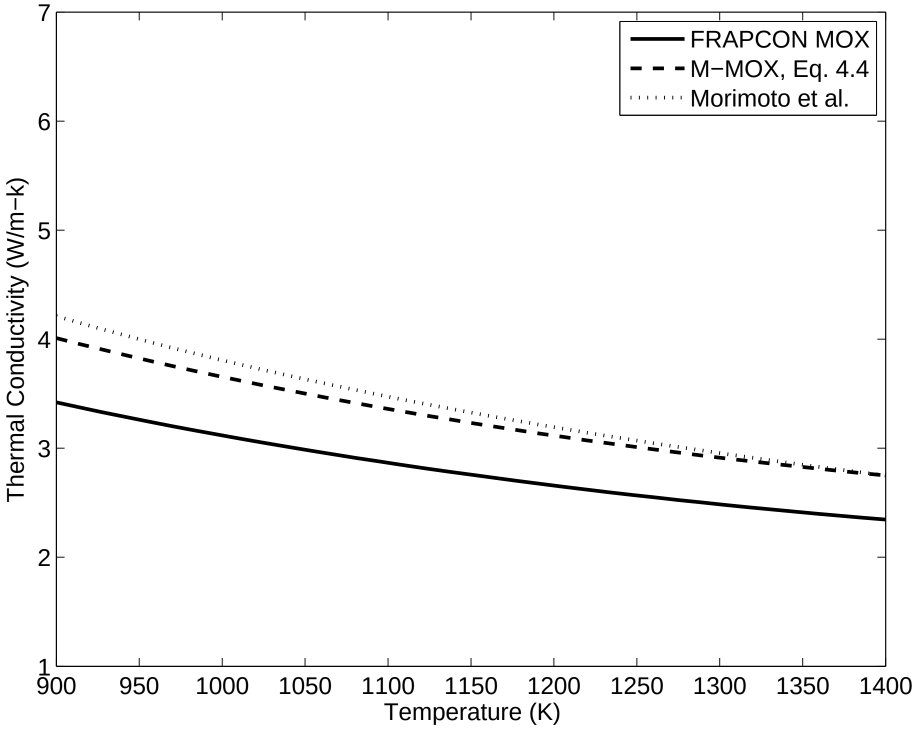

Figure 4.13. (U,Pu,Am)O_2 Thermal conductivity model

4.3.3 Thermal Conductivity of AmO_2 and $(Am,Zr)O_2$

The chemical compositions of AmO_2 and $(Am,Zr)O_2$ are not as similar to UO_2 and $(U,Pu)O_2$ as the uranium-dominant mixed-oxides $(U,Am)O_2$ and $(U,Pu,Am)O_2$. Thermal conductivity measurements for americium-dominant oxides are difficult to obtain due to the highly radioactive nature of americium, for which special facilities are required for its handling. Experimental measurements of AmO_2 have been taken by Schmidt et al. [40] and Nishi et al. [41], and Ronchi et al. [43] for $(Am,Zr)O_2$.

Americium dioxide is a non-uranium-dominant oxide material with a fluorite crystal structure comparable to UO_2 and $(U,Pu)O_2$ [44]. Measurements for AmO_2 taken by Schmidt et al. [40] and Nishi et al. [41] indicate thermal conductivity values lower than those for conventional MOX fuel. Bakker and Konings [53] believe that the thermal conductivity of AmO_2 follows the same $[A + B \cdot T]^{-1}$ trend as UO_2 and MOX, but with significantly different values for A and B, and have developed a theoretically-based thermal conductivity model to approximate the temperature and stoichiometric dependencies of AmO_2. Values for A_0, $A_1(x)$, and B in Equation 4.5 come from theoretical models developed for oxides with major actinides uranium and plutonium [53].

$$k(T) = \frac{1}{A_0 + A_1(x) + B \cdot T} \tag{4.5}$$

where

$$A_0 = 0.02 \text{ m} \cdot \text{K/W}$$

$$A_1 = 1.528(x + 0.00931)^{1/2} - 0.1474 \text{ m} \cdot \text{K/W}$$

$$x = 2.00 - \text{oxygen-to-metal ratio}$$

and

$$B = 3.19 \times 10^{-4} \text{ m/W}$$

Comparison by Sobolev [54] of this model to measurements by Nishi and Schmidt are in relatively good agreement. The effects of burnup on the thermal conductivity of AmO_2 are not modeled in the current research due to large uncertainties associated with the burnup dependencies of americium-dominant oxides. Therefore, the

Bakker and Konings model for AmO_2 thermal conductivity is implemented in the script-based neutronic / thermal-hydraulic interface without burnup modifications for thermal-hydraulic analyses with VIPRE.

Zirconium-americium dioxide is a zirconium-dominant oxide with less in common with the chemical and atomic structure of UO_2 and $(U,Pu)O_2$ than AmO_2. Zirconia-based matrices are ideal for the transmutation of actinides due to their good radiation resistance, chemical inertness, and the fact that all major actinides are soluble in the ZrO_2 lattice [43]. Despite these benefits, the thermal conductivity of crystalline zirconia is very low, and typically decreases with further additions of lattice impurities, such as actinides. Two samples of $(Am,Zr)O_2$ have been fabricated by Ronchi et al. [43], with 6 and 20 mol% americium. Measurements taken by Ronchi reveal a near constant thermal conductivity value for $(Am,Zr)O_2$ over the temperature range 600 to 1700K. The near constant thermal conductivity values of the 6 and 20 mol% americium samples are approximately 1.70 and 1.25 $W/m \cdot K$, respectively. The effects of burnup on the thermal conductivity of $(Am,Zr)O_2$ are not modeled in the current research due to the lack of available data on the burnup dependencies of a zirconia matrix doped with americium. Therefore, the constant thermal conductivity value of 20 mol% americium-doped zirconia is implemented in the script-based neutronic / thermal-hydraulic interface without burnup modifications for thermal-hydraulic analyses with VIPRE.

Fuel regions consisting of AmO_2 or $(Am,Zr)O_2$ in multi-region fuels are anticipated to be relatively thin in comparison to the dimensions of the fuel and located on the outer rim of the pellet. Under these conditions, the temperature and temperature gradients experience by these materials are expected to be small, thereby reducing the effects of uncertainties on VIPRE calculations for fuel centerline temperatures. Additional uncertainties associated with a lack of burnup dependence for the thermal conductivities of AmO_2 and $(Am,Zr)O_2$ are addressed by reducing their values by 5%.

5. FUEL ASSEMBLY MODELING

VIPRE input decks have been created to model the proposed fuel assembly designs. The input decks consist of reactor core boundary conditions, fuel and cladding material description, axial and radial power profiles, geometrical descriptions of fuel pins and assemblies, and VIPRE case specifications, such as flow-field and heat transfer correlations, solution method, and convergence criteria. The geometrical description of the reference core and proposed fuel assembly designs, as well as a brief overview of the VIPRE input deck structure are presented within this section. Appendices A and B document the input deck calculation notebook and VIPRE input decks, respectively.

5.1 VIPRE Input Structure and Deck Formulation

The VIPRE input structure is divided into multiple sections called ‘groups’. Subsections of a group are called ‘cards’ and a specific set of instructions or user-input for each card are called ‘records’. For example, the title of a VIPRE run will always go in group `VIPRE` on card `VIPRE.2`. The primary groups for which input is always required are `VIPRE`, `GEOM`, `OPER`, and `RODS`. The following is a description of the functions of each group:

VIPRE Title and number of cases to be executed

GEOM Geometrical description of fluid subchannels

PROP Contains options governing fluid properties

OPER Core boundary conditions and implementation method

CORR Contains options for two-phase flow, CHF, heat transfer, and void / quality correlations

MIXX Contains options for turbulent mixing of energy and momentum between subchannels

DRAG Governs lateral and axial friction factors

GRID Contains options for modeling axial pressure losses due to grid-spacers and other structural obstructions

CONT Governs numerical solution method, convergence criteria, and output options

RODS Description of rod types, fuel material properties, and power profiles

The `GEOM` and `RODS` groups are the most important for modeling new assembly designs. Input in `GEOM` defines the flow area, wetted and heated perimeter, and gap connections to other channels for each subchannel. A subchannel defined in `GEOM` may describe an individual channel between connecting rods or a large region of the core which encompasses multiple fuel assemblies. The number of subchannels and axial nodes for a problem are input variables in `GEOM`. Input in `RODS` defines the number and type of rods to be modeled, the pin, cladding, gap, and fuel pellet dimensions and materials for a `nuclear` type rod, as well as pin axial and radial power profiles. Channel connections for each rod and material thermal-physical properties are also input into `RODS`.

For the purpose of the current research, the `VIPRE`, `GEOM`, `PROP`, `OPER`, `CORR`, `DRAG`, `GRID`, `CONT`, and `RODS` groups are used to describe the proposed assembly and reference plant designs. Only the `RODS` and `GEOM` groups change for each investigated assembly design, and only the `RODS` group changes from case to case as a design is analyzed over the entire burnup lifetime. The other groups are used to implement modeling assumptions from Section 3, and describe the operating conditions of the reference core and similarities shared by all designs, such as grid-spacers. Input options for

VIPRE are set to default values, unless otherwise noted here or in the modeling assumptions in Section 3.

5.2 Reference Plant and UO_2 Assembly Design Description

The reference plant is Luminant's Comanche Peak Nuclear Unit 1 reactor and the plant characteristics from Table 3.1 are implemented as the boundary conditions for VIPRE calculations in the group `OPER`. Modifications to the boundary conditions are listed in the assumptions in Section 3.4.1. For transient calculations, temporal forcing functions for normalized coolant inlet temperature, inlet temperature, core coolant mass flow rate, and core power listed in Tables A.32, A.33, A.34, and A.35, are input as time-dependent tables in group `OPER`.

The reference plant uses fuel assemblies with 8 grid-spacers. The locations and form loss coefficient for the grid-spacers are not available. Therefore, the spacers are modeled as being located at equal intervals over the assembly length every 50.8cm starting 5.08cm above the beginning of the core's active height. The grid-spacer form loss coefficient is set to 0.61 on card `GRID.2` in group `GRID` to produce the same 0.12 MPa core pressure drop in VIPRE as for the reference UO_2 assembly design at normal steady-state operating conditions [35]. Grid-spacer locations and the form loss coefficient are input into group `GRID`. All correlations in group `CORR` necessary for VIPRE calculations are set to their default values, except for those defining the peak of the boiling curve and the critical heat flux. The Westinghouse W-3L CHF correlation with a 1.3 MDNBR limit is selected for calculating the DNBR and boiling curve peak in the current research effort.

While the geometry of the core can change for each assembly design, the subchannel nodalization for the hot assembly and core will remain the same. The subchannel identification numbers in Figures 5.1 and 5.2 correspond to input channels in group `GEOM` for the steady-state scoping analysis. For transient analysis, the number of subchannels increases since each channel in the hot assembly is modeled. The transient

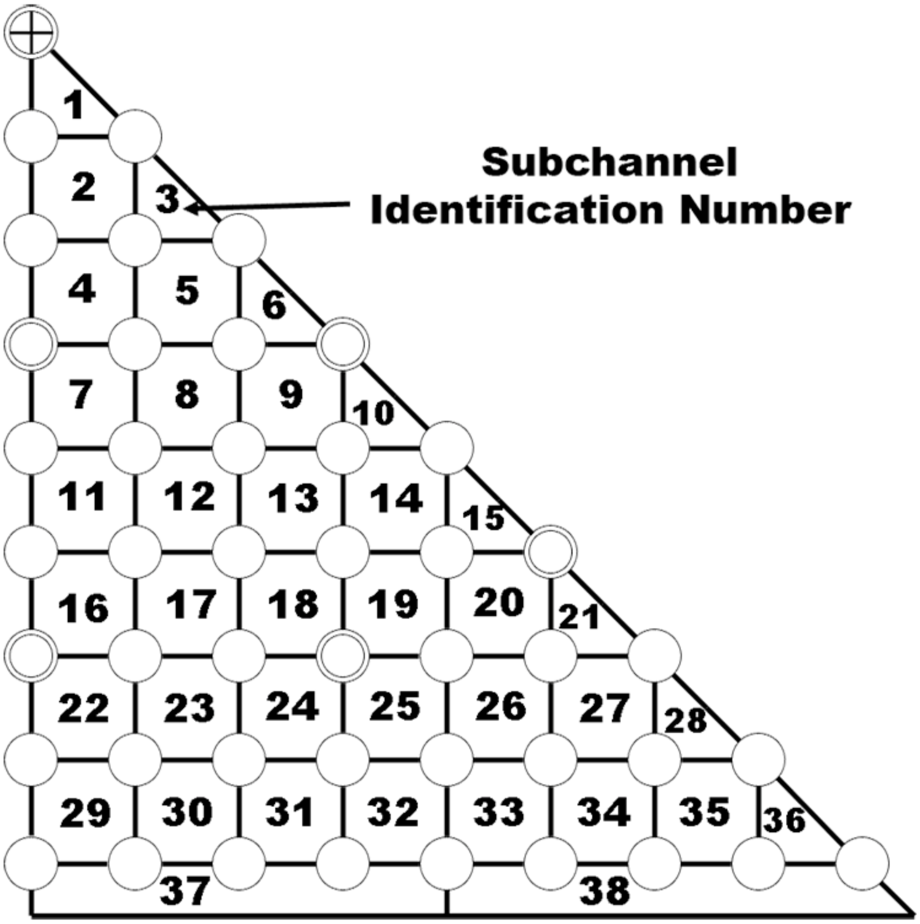

Figure 5.1. VIPRE 1/8th Hot assembly subchannel nodalization for steady-state scoping analysis

analysis subchannel identification scheme for the 1/8th core nodalization is shown in Figure 5.3. The location of the hot channel in Figure 5.3 is suggested by Benedict et al. [39]. The transient subchannel nodalization provides maximum resolution within the hot assembly while maintaining computational efficiency by increasing the subchannel size with increasing distance from the hot assembly. The hot assembly is surrounded by 4 fuel assemblies that are each modeled as 4 subchannels, for a total of 16 subchannels surrounding the hot assembly. The surrounding fuel assemblies are divided into 4 subchannels each due to a VIPRE modeling criteria which limits the maximum number of modeled fuel rod connections for any subchannel to 6. Therefore, channels 13, 14, 15, 16, 21, 22, 23, 24, 281, 282, 283, 284, 289, 290, 291, and, 292 are connected to 5 rods within the hot assembly and 1 lumped rod within their own channel.

The fuel pin and assembly design for the reference plant is a standard West-

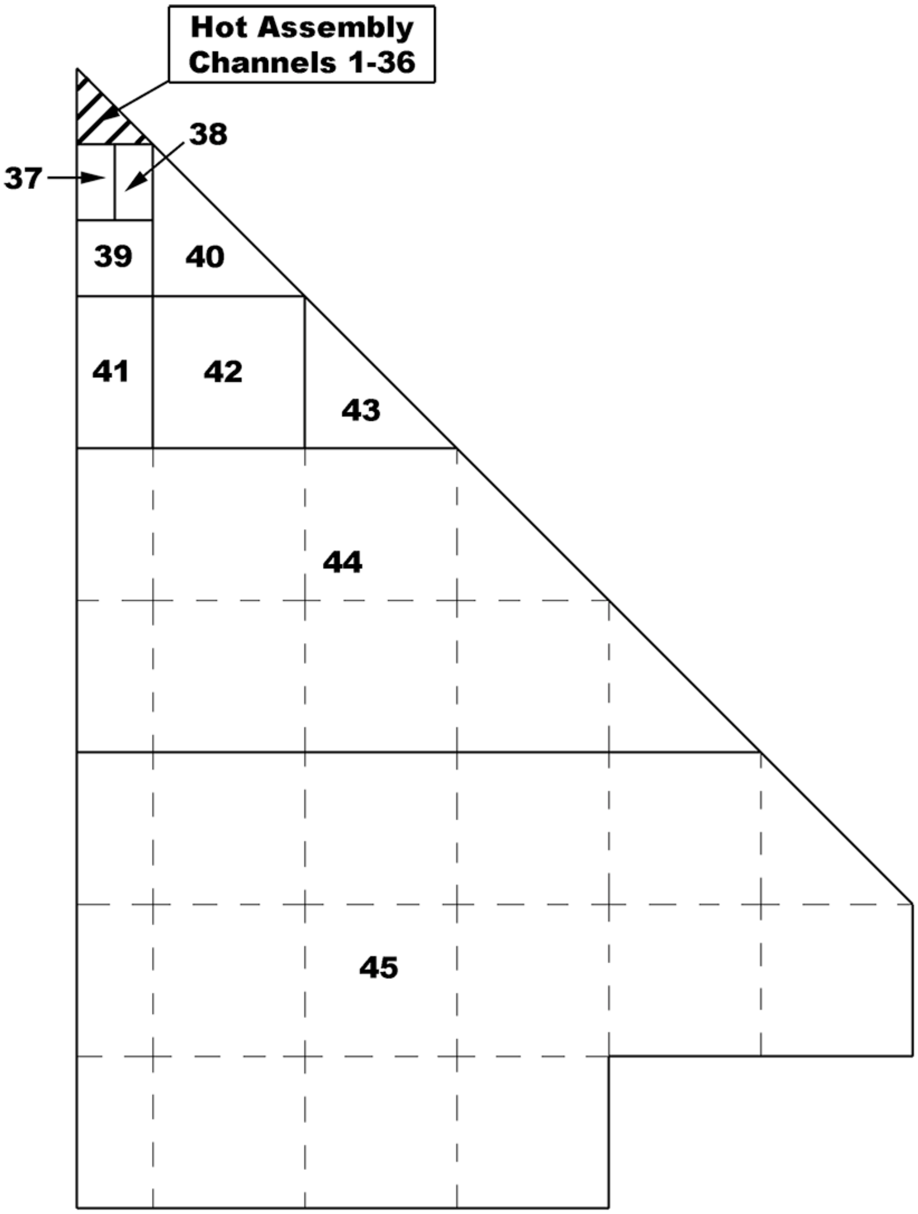

Figure 5.2. VIPRE 1/8th Core subchannel nodalization for steady-state scoping analysis

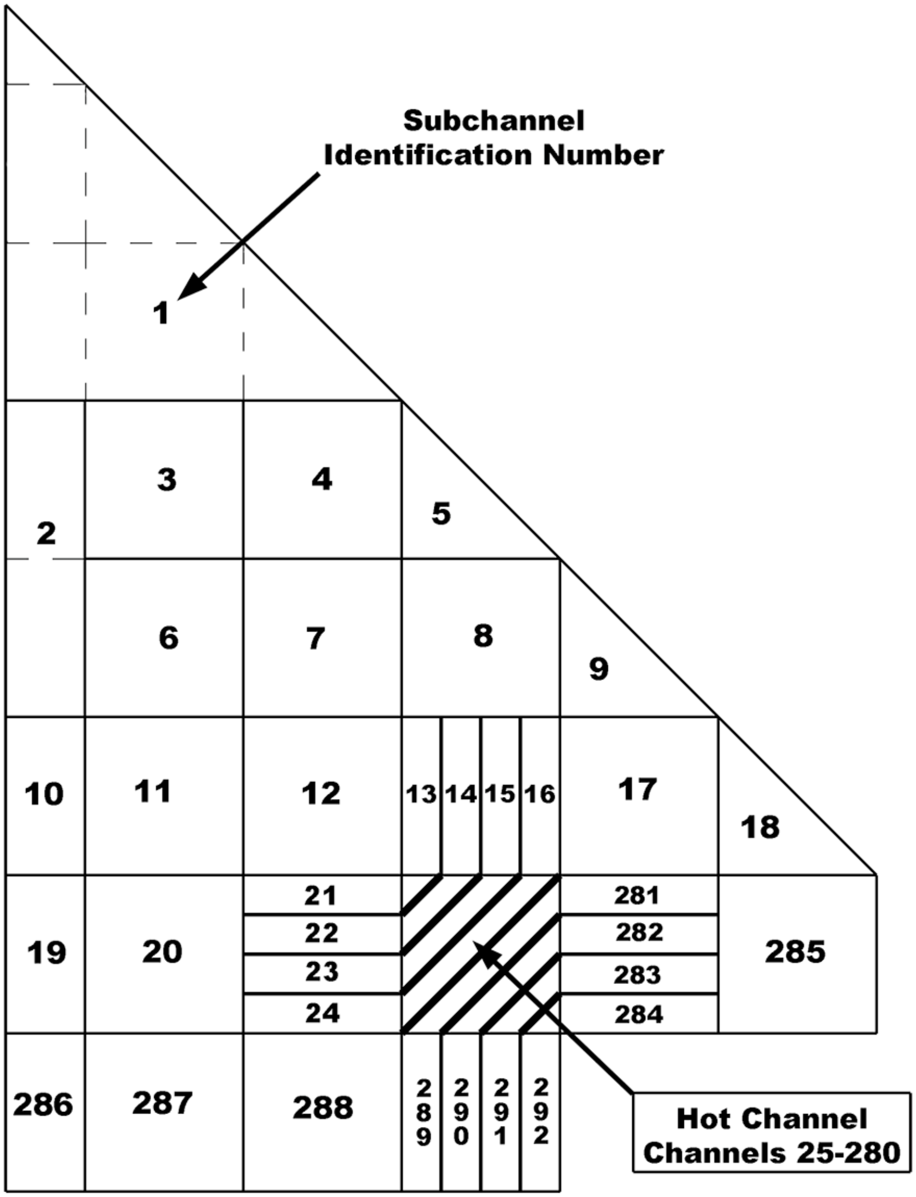

Figure 5.3. VIPRE 1/8th Core subchannel nodalization for transient analysis

inghouse design used in the majority of U.S. PWRs [34]. The fuel pin consists of a solid ceramic UO_2 fuel pellet that is separated from the outer cladding by a small gap initially filled with helium gas. The cladding material is the zirconium alloy Zircaloy-4 [34]. All fuel pins share the same dimensions, and all fuel rods within an assembly share the same fissile enrichment. The assembly is a 17×17 design with 289 rod locations: 264 fuel rods, 24 control rods, and 1 instrument tube located in the center of the assembly. The control rods and instrument tube share a common outer diameter that is larger than that of a fuel pin [29].

All proposed fuel assembly designs share the same control rod and instrument tube locations and dimensions. All fuel pin designs retain the same cladding material and thickness, and initial cold gap distance as the reference plant design. Assembly and fuel pin design characteristics for the reference plant are listed in Table 5.1 and Figure 5.4.

The UO_2 fuel rods are modeled in VIPRE using the `nuclear` rod type. Burnup-dependent UO_2 thermal-physical properties are implemented in VIPRE by selecting the option for user-input fuel material properties on card `RODS.63` in group `RODS`. A table of temperature-dependent thermal-physical properties generated from the UO_2 FRAPCON model is entered on card `RODS.70` in group `RODS` by the script-based interface. A thermal-physical property table is generated and placed in a separate VIPRE case for each incremental increase in burnup. A complete steady-state VIPRE analysis of an assembly design can consist of 30 to 50 cases, depending on the assembly burnup lifetime and the refinement of the neutronic burnup computational discretization.

A table of temperature-dependent thermal-physical properties is entered for partial and complete LOFA transient analyses on card `RODS.70` in group `RODS` by the script-based interface for the most limiting burnup stage from the steady-state scoping analysis. Fuel rod relative power factors for the same burnup stage are input for the hot assembly on card `RODS.9` in group `RODS`. Temporal forcing functions are entered in group `OPER` for the core inlet pressure, inlet coolant temperature, coolant

Table 5.1
Fuel pin and assembly design parameters of reference Westinghouse PWR plant (from [29, 34])

Parameter	Quantity
Fuel rod outer diameter (mm)	9.50
Fuel pellet outer diameter (mm)	8.26
Gap thickness (mm)	0.05
Cladding thickness (mm)	0.57
Fuel chemical composition	UO_2
Fissile content (wt.%)	4.90 ^{235}U
Cladding material	Zircaloy-4
Control rod & instrument tube diameter (mm)	12.24
Assembly geometry	17 × 17
Lattice pin-to-pin pitch (cm)	1.26
Fuel assembly pitch (cm)	21.50

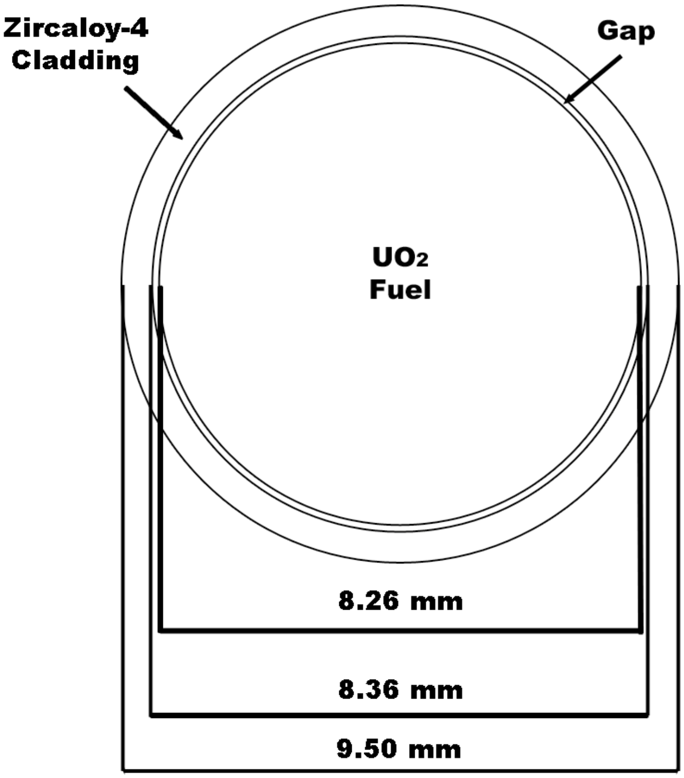

Figure 5.4. Reference UO_2 fuel rod design

mass flow rate, and reactor power on cards `OPER.13`, `OPER.14`, `OPER.17`, and `OPER.20`, respectively.

5.3 AMOX Assemblies

AMOX fuel assembly designs retain the same 17 × 17 layout, control rod and instrumentation tube locations, and dimensions as the reference plant design. Fuel pins in the new designs utilize multi-region fuels where the pellet has multiple radial regions of distinct fuel material. VIPRE's `nuclear` rod type is incapable of modeling multiple regions of fuel material within a single pellet, therefore, the `heater` rod type is used to model multi-region fuels. Unlike the `nuclear` rod type, the `heater` rod type does not have a dedicated gap region, and consists of concentric rings of different material regions, as shown previously in Figure 2.5. VIPRE assumes perfect contact between each material region, but contact resistance can be modeled by including a region one node wide with the material properties that result in the approximate thermal resistance [5].

The helium-filled gap between the fuel pellet outer surface and cladding inner surface can be modeled with VIPRE using the method of thermal resistances [35]. For a gap having outside and inside radii r_{go} and r_{gi}, respectively, and gap conductance h_g based on the gap average radius r_g, an effective thermal conductivity, k_g, can be obtained from the expression

$$\frac{1}{2\pi r_g h_g} = \frac{1}{2\pi k_g} \ln\left(\frac{r_{go}}{r_{gi}}\right) \tag{5.1}$$

Rearranging Equation 5.1, the effective gap thermal conductivity, k_g is

$$k_g = h_g r_g \ln\left(\frac{r_{go}}{r_{gi}}\right) \tag{5.2}$$

VIPRE calculates the heat transfer through the gap by using the effective gap thermal conductivity from Equation 5.2 to solve for the thermal resistance, R, of the gap region. The thermal resistance is used in Equation 2.10 to find the conductance, K, which is then applied to Equation 2.8 to calculate the heat transfer, Q. The gap outer and inner radii from Table 5.1 for the reference UO_2 pin design are 4.18 and 4.13mm, respectively. For a constant gap conductance of $11,346\ \mathrm{W/m^2 \cdot K}$ and an average gap radius of 4.16mm, the effective gap thermal conductivity, k_g is

$$k_g = (11,346\ \mathrm{W/m^2 \cdot K})(0.00416\ \mathrm{m}) \ln\left(\frac{0.00418\ \mathrm{m}}{0.00413\ \mathrm{m}}\right) = 0.57\ \mathrm{W/m \cdot K}$$

Burnup-dependent UO_2 or $(U,Pu)O_2$ thermal-physical properties are implemented in VIPRE by selecting the option for user-input fuel material properties on card `RODS.68` in group `RODS`. A table of temperature-dependent thermal-physical properties generated from the UO_2 or $(U,Pu)O_2$ FRAPCON model is entered on card `RODS.70` in group `RODS` by the script-based interface. Thermal-physical properties for $(Zr,Am)O_2$ are entered as a second user-defined material on card `RODS.70`. As discussed in section 4.3.3, the thermal conductivity of $(Zr,Am))_2$ is assumed to be a constant $1.25\ \mathrm{W/m \cdot K}$, independent of temperature and burnup. A thermal-physical property table for each material region is generated and placed in a separate VIPRE case for each incremental increase in burnup.

A table of temperature-dependent thermal-physical properties is entered for partial and complete LOFA transient analyses on card `RODS.70` in group `RODS` by the script-based interface for the most limiting burnup stage from the steady-state scoping analysis. Fuel rod relative power factors for the same burnup stage are input for the hot assembly on card `RODS.9` in group `RODS`. Temporal forcing functions are entered in group `OPER` for the core inlet pressure, inlet coolant temperature, coolant mass flow rate, and reactor power on cards `OPER.13`, `OPER.14`, `OPER.17`, and `OPER.20`, respectively.

5.3.1 UO_2 Fuel with $(Zr,Am)O_2$ Coating

AMOX fuel pins loaded with UO_2+$(Zr,Am)O_2$ consist of a UO_2 fuel pellet coated with an outer layer of $(Zr,Am)O_2$, a gap between the $(Zr,Am)O_2$ outer and cladding inner surfaces, and a thin Zircaloy-4 clad. The UO_2+$(Zr,Am)O_2$ fuel pellet has the same outer diameter as the reference UO_2 fuel pellet from Table 5.1. The gap and cladding dimensions remain unchanged from the reference UO_2 design.

The UO_2+(Zr,Am)O_2 AMOX fuel pin design uses 4.90% ^{235}U enriched uranium as the primary fuel source with a 0.02mm coating of 20 wt.% Am (Zr,Am)O_2. Assembly and fuel pin characteristics for the UO_2+(Zr,Am)O_2 AMOX design are listed in Table 5.2. A UO_2+(Zr,Am)O_2 AMOX rod diagram is given in Figure 5.5.

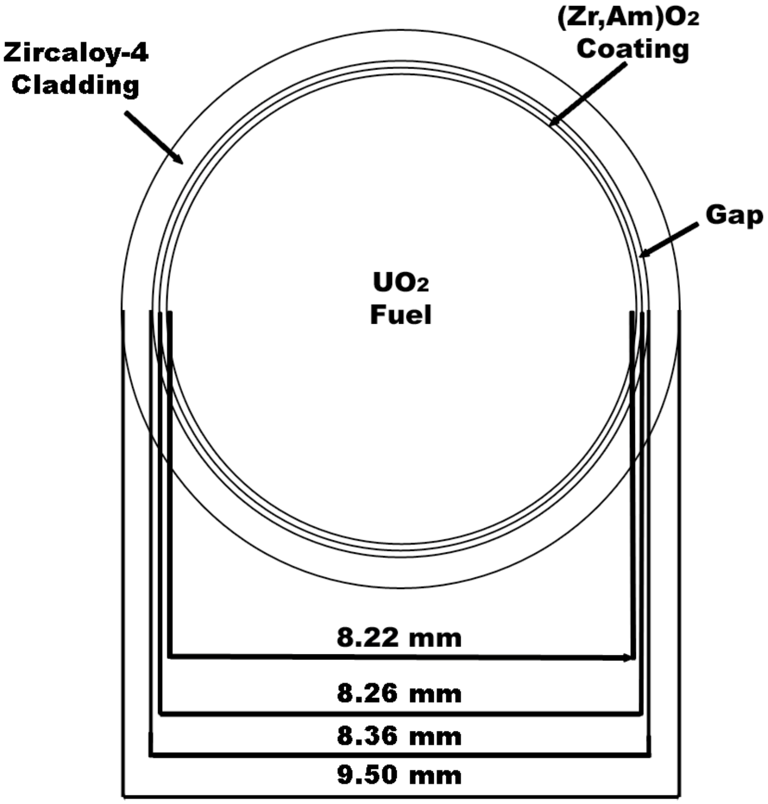

Figure 5.5. UO_2+(Zr,Am)O_2 AMOX Fuel rod design

5.3.2 (U,Pu)O_2 Fuel with (Zr,Am)O_2 Coating

AMOX fuel pins loaded with (U,Pu)O_2+(Zr,Am)O_2 consist of a (U,Pu)O_2 fuel pellet coated with an outer layer of (Zr,Am)O_2, a gap between the (Zr,Am)O_2 outer and cladding inner surfaces, and a thin Zircaloy-4 clad. The (U,Pu)O_2+ (Zr,Am)O_2 fuel pellet has the same outer diameter as the reference UO_2 fuel pellet from Table 5.1.

Table 5.2
Fuel pin and assembly parameters for UO_2+(Zr,Am)O_2 AMOX design

Parameter	Quantity
Fuel rod outer diameter (mm)	9.50
Fuel pellet outer diameter (mm)	8.26
(Zr,Am)O_2 coating thickness (mm)	0.02
Gap thickness (mm)	0.05
Cladding thickness (mm)	0.57
Fuel chemical composition	UO_2+(Zr,Am)O_2
Fissile content (wt.%)	4.90 ^{235}U
	20.00 Am
Cladding material	Zircaloy-4
Control rod & instrument tube diameter (mm)	12.24
Assembly geometry	17 × 17
Lattice pin-to-pin pitch (cm)	1.26
Fuel assembly pitch (cm)	21.50

The gap and cladding dimensions remain unchanged from the reference UO_2 design.

The $(U,Pu)O_2$+$(Zr,Am)O_2$ AMOX fuel pin design uses 2.50% ^{235}U enriched uranium and 8.0 wt.% plutonium as the primary fuel source with a 0.02mm coating of 20 wt.% Am $(Zr,Am)O_2$. Assembly and fuel pin characteristics for the $(U,Pu)O_2$+ $(Zr,Am)O_2$ AMOX design are listed in Table 5.3. A $(U,Pu)O_2$+$(Zr,Am)O_2$ AMOX rod diagram is shown in Figure 5.6.

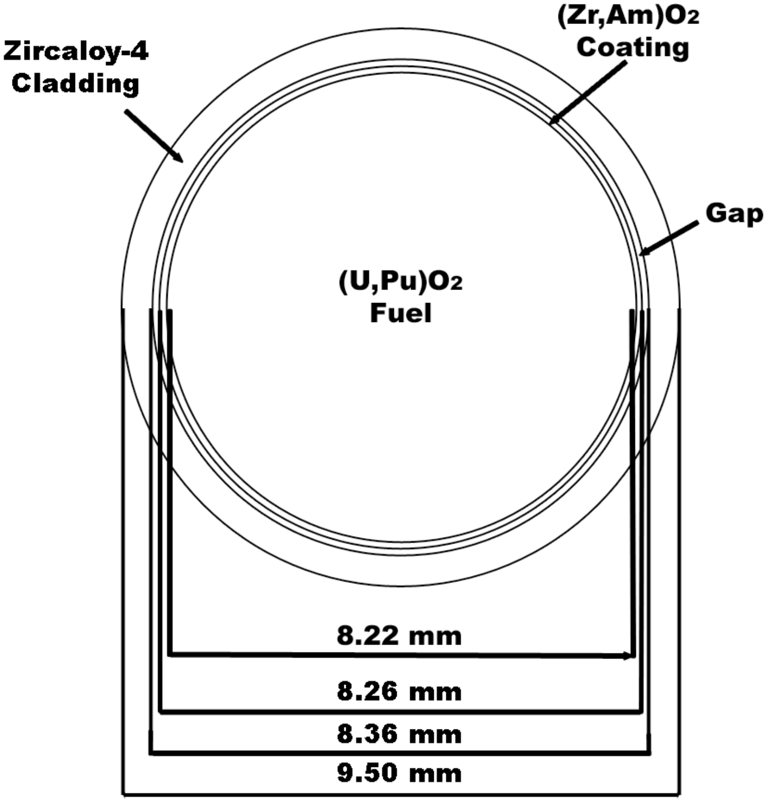

Figure 5.6. $(U,Pu)O_2$+$(Zr,Am)O_2$ AMOX Fuel rod design

Table 5.3
Fuel pin and assembly parameters for $(U,Pu)O_2$+$(Zr,Am)O_2$ AMOX design

Parameter	Quantity
Fuel rod outer diameter (mm)	9.50
Fuel pellet outer diameter (mm)	8.26
$(Zr,Am)O_2$ coating thickness (mm)	0.02
Gap thickness (mm)	0.05
Cladding thickness (mm)	0.57
Fuel chemical composition	$(U,Pu)O_2$+$(Zr,Am)O_2$
Fissile content (wt.%)	2.50 ^{235}U
	8.00 Pu
	20.00 Am
Cladding material	Zircaloy-4
Control rod & instrument tube diameter (mm)	12.24
Assembly geometry	17 × 17
Lattice pin-to-pin pitch (cm)	1.26
Fuel assembly pitch (cm)	21.50

6. THERMAL-HYDRAULIC ANALYSIS

The new thermal-hydraulic methodology and advanced fuel thermal-physical property models are implemented in the script-based interface, which generates input decks for each fuel assembly design and calls VIPRE as an executable. Thermal-hydraulic analysis of the designs discussed in Section 5 are performed within this section using VIPRE, and include both the steady-state scoping analysis and transient analyses for partial and complete LOFA events. The available thermal margin of each design is discussed in terms of the following primary parameters of interest: MDNBR, fuel centerline temperatures, and peak cladding temperatures (PCT).

The MDNBR limit for the reference plant is unavailable, therefore, the standard 1.3 value associated with the W-3L CHF correlation is used for the current research effort [6]. The peak cladding temperature limit is 948K, above which chemical reactions between the fuel pellet and cladding surfaces can lead to future pellet cladding interaction (PCI) failure [11]. Maximum fuel temperature limits for UO_2 and $(U,Pu)O_2$ are set to 200K below their respective melting temperatures. Melting temperatures for UO_2 and $(U,Pu)O_2$ are calculated as functions of burnup from the following FRAPCON model [28]:

$$T_{\text{melt}} = 3113.15 - 5.41395 PuCon + 7.468390 \times 10^{-3} PuCon^2 - 3.2 \times 10^{-3} Bu \quad (6.1)$$

where $PuCon$ is the PuO_2 content (wt.%), and Bu is the burnup in MWd/tHM. Results from the AMOX fuel design analyses are compared against the set design limits and the results from the UO_2-loaded reference design.

6.1 Reference UO_2 Model

The UO_2 core and assembly design are modeled after the reference plant using plant operational characteristics from Table 3.1 and the standard Westinghouse 17×17 assembly design discussed in Section 5. Boundary conditions for steady-state VIPRE calculations include: coolant inlet temperature, RCS pressure, coolant mass flow rate, and the average fuel pin linear heat generation rate (LHGR). The average fuel pin LHGR has been adjusted to produce a core thermal power output equivalent to that of the reference core. VIPRE results for the reference UO_2 design at nominal, steady-state operation are listed in Table 6.1.

Table 6.1
VIPRE Reference core model nominal performance characteristics

Parameter	Quantity
Reactor core power (MWt)	3455
Core pressure drop (MPa)	0.12
Average coolant temperature rise (K)	32.92
Average fuel centerline temperature (K)	1397
Maximum fuel centerline temperature (K)	2017
Average LHGR (kW/m)	17.56
Maximum LHGR (kW/m)	42.48
Core MDNBR	2.48

The core pressure drop and average coolant temperature rise in Table 6.1 are identical to those values reported for the operational characteristics of the reference core in Table 3.1. The calculated MDNBR for the reference assembly design is reasonable, and the actual UO_2 assembly design has a sufficiently large thermal margin to accommodate core anomalies and anticipated transient conditions [34]. Therefore, the UO_2 assembly MDNBR can be used as a benchmark to which the thermal margin of the AMOX fuel assembly designs can be compared. The fuel temperature results for the reference plant design are in good agreement with values from the literature. Tong and Weisman [11] report that under typical operating conditions for a PWR, the fuel centerline temperature of an average rod with 96% theoretical density UO_2 fuel pellets is 1473K with a LHGR of 33 kW/m and 2073K for the hottest rod in the core with a LHGR of 50 kW/m. The average and maximum LHGR from Table 6.1 are lower than those reported by Tong and Weisman.

The reason that the lower LHGRs from the VIPRE analysis produce fuel temperatures similar to those from Tong and Weisman is that VIPRE does not model the formation of a central void in the fuel pellets for the hottest rods in the core after the first rise to power. The formation of a central void in fresh fuel pellets occurs within the first few days of full power operation for the hottest rods in the core, and reduces the maximum fuel centerline temperature of the rods [29]. Additionally, the gap conductance between the fuel pellet and inner cladding surfaces increases after the first rise to power due to fuel pellet thermal expansion; however, the gap conductance is assumed to be constant in the new thermal-hydraulic methodology, resulting in higher fuel temperatures than might otherwise occur. Therefore, the VIPRE analyses in this section will always produce conservative fuel temperature results by calculating higher temperatures for a given LHGR.

6.1.1 Steady-State Scoping Analysis

A steady-state scoping analysis from the new thermal-hydraulic methodology has been applied to the reference UO_2 fuel assembly design using VIPRE. The core-wide MDNBR and 1.3 DNBR limit are plotted against burnup in Figure 6.1. The incremental step-increases of the MDNBR in Figure 6.1 are due to the reshuffling of the assembly from higher to lower power regions of the core at 20 and 40 GWd/tHM. As the fuel is relocated to lower power regions, the relative power of the fuel assembly, and therefore the fuel pins, are reduced. Lower fuel pin power results in a reduced

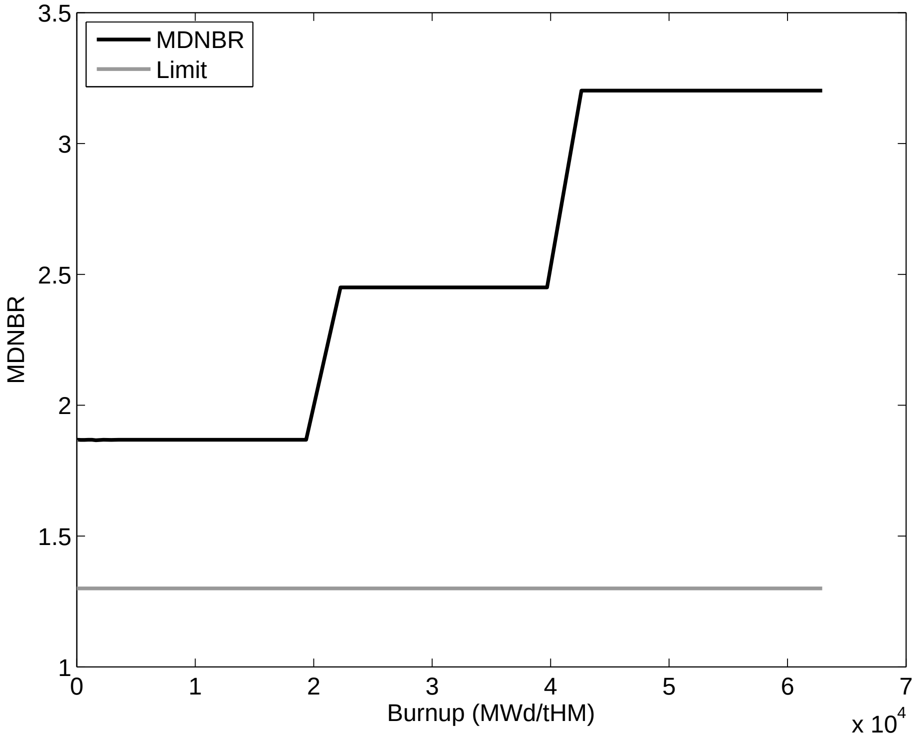

Figure 6.1. UO_2 Reference design MDNBR

heat flux from the fuel pin to the surrounding coolant. If all other coolant channel performance characteristics remain unchanged, then the critical heat flux remains constant and the MDNBR increases due to the reduced fuel pin surface heat flux. At 1614 MWd/tHM, the lowest MDNBR is 1.87, which is significantly larger than the 1.3 DNBR limit.

The maximum fuel temperatures for the reference design are plotted against burnup in Figure 6.2. The UO_2 melting temperature is also shown, with the design limit being 200K below the melting temperature. The sudden drops in temperature at 20 and 40 GWd/tHM in Figure 6.2 are due to the reshuffling of the assembly from higher to lower power regions of the core as burnup increases. For each cycle of burnup the fuel temperatures increase with increasing burnup due to degradation of the fuel thermal conductivity, as discussed in Section 4. The fuel temperatures drop suddenly when the assembly power decreases as a result of fuel assembly shuffling. A

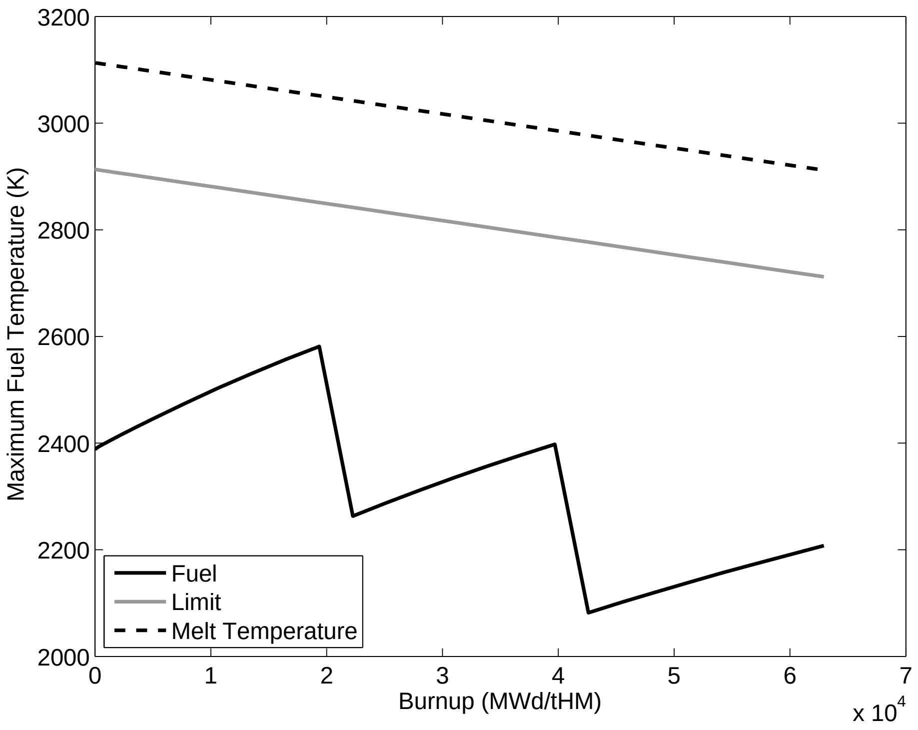

Figure 6.2. UO_2 Reference design fuel temperatures

maximum fuel temperature of 2581K occurs at 19, 362 MWd/tHM and is well below the design limit.

The maximum cladding temperature and 948K design limit are plotted for increasing burnup in Figure 6.3. The incremental decreases of the maximum cladding temperature at 20 and 40 GWd/tHM are less noticeable in Figure 6.3 because the cladding outer surfaces are tightly coupled to the surrounding coolant temperature. The temperature gradient across the cladding is relatively small in comparison to that of the fuel pellet, and the inner cladding surface temperature remains a few tens-of-degrees Celsius above that of the outer surface. Therefore, as the fuel assembly is relocated from a higher to lower power region of the core, the cladding temperature drop is on the order of 2 to 3K. A maximum cladding temperature of 621K occurs at 6.45 MWd/tHM. The cladding temperature is more than 300K below the design limit over the entire operational lifetime of the assembly. The 948K design limit is

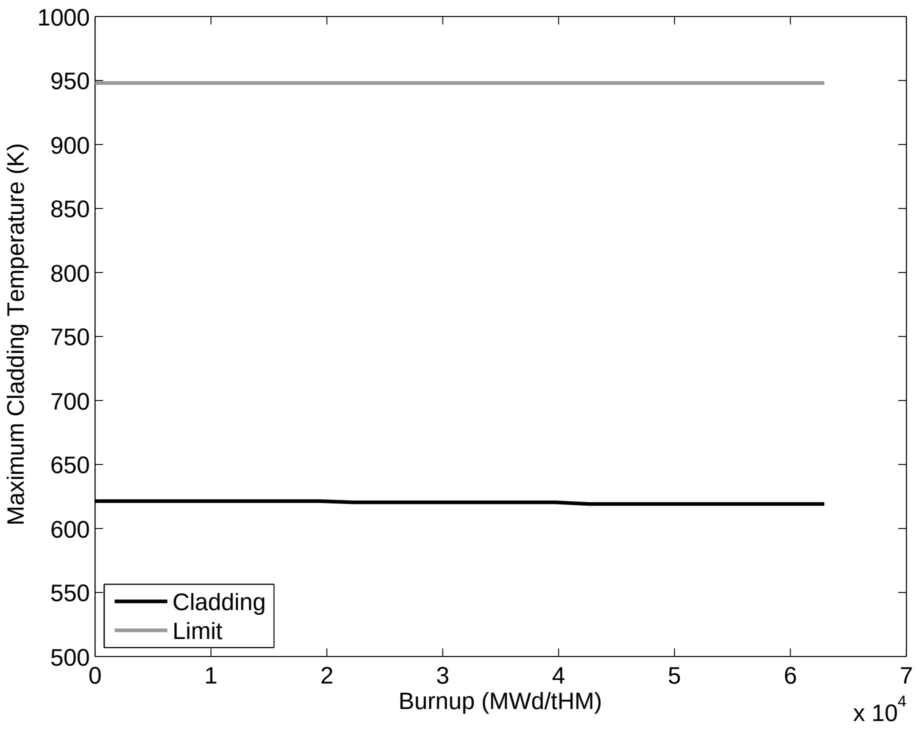

Figure 6.3. UO_2 Reference design cladding temperatures

not expected to be reached as long as coolant is in contact with the cladding and a CHF condition does not occur.

6.1.2 Transient Analyses

Partial and complete LOFA transient analyses from the new thermal-hydraulic methodology have been performed for the reference UO_2 fuel assembly design using VIPRE. A description of partial and complete LOFA transients, along with a discussion of the MELCOR transient analysis used to generate VIPRE transient boundary conditions, are presented in Section 3.4. Analyses are conducted at $19,362$ MWd/tHM since the MDNBR, and fuel and cladding temperatures are at their most limiting conditions in Figures 6.1, 6.2, and 6.3. Partial LOFA (PLOFA) analysis results for the core-wide MDNBR are plotted against time in Figure 6.4 along with the 1.3 DNBR limit. After the transient initiation at 5 seconds, one reactor coolant pump

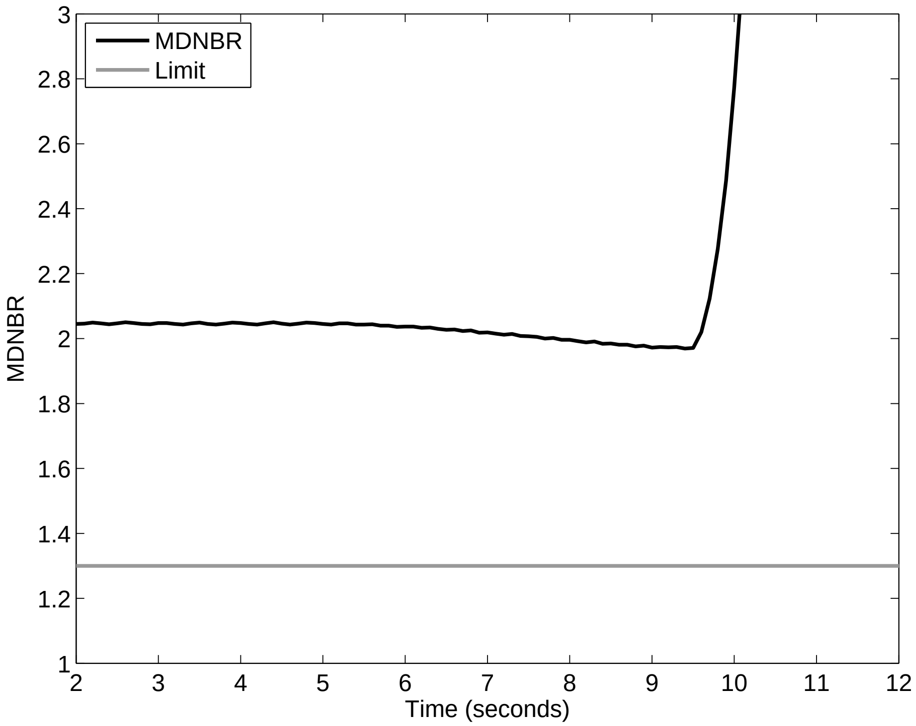

Figure 6.4. UO_2 Reference design PLOFA MDNBR

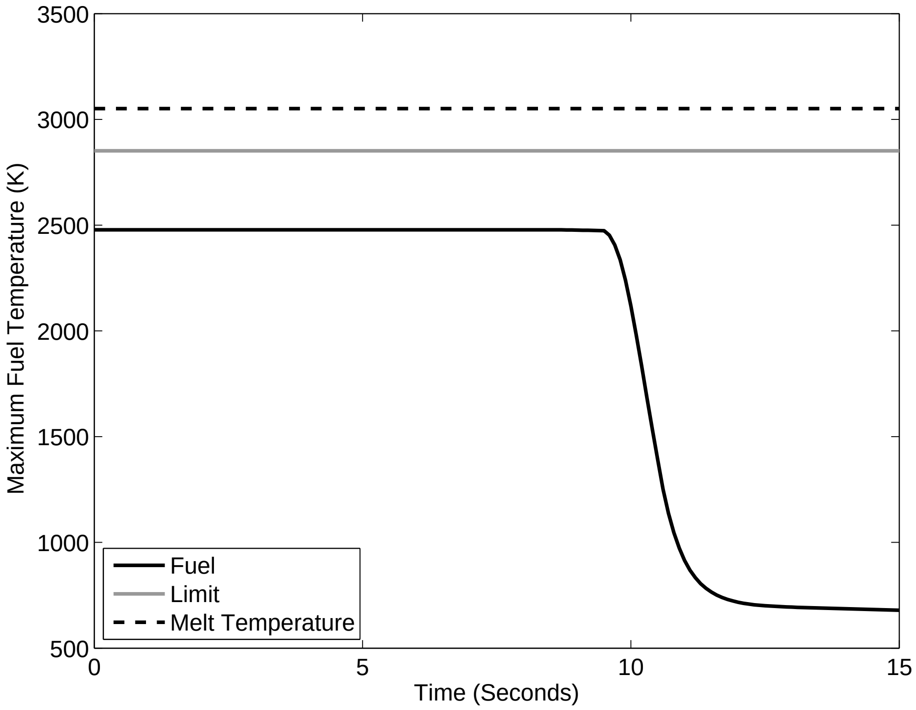

Figure 6.5. UO_2 Reference design PLOFA fuel temperatures

is lost and the MDNBR begins to slowly decrease from 2.05 to a minimum value of 1.97 at 9.40 seconds due to a decreasing coolant mass flow rate. From 5 seconds to 9.18 seconds when the reactor is finally shutdown, the core continues to operate at 112% power while the coolant mass flow rate decreases. As the coolant mass flow rate decreases the heat removal capacity of the coolant is diminished, which causes the coolant temperature to rise slightly above its nominal operating temperature. Additionally, the reduced coolant mass flow rate results in a diminished heat transfer coefficient from the fuel rods to the coolant. The combined effect from a decreasing mass flow rate is a reduction in the critical heat flux. Since the core thermal power output remains relatively unchanged while the critical heat flux decreases from 5 seconds till the reactor trips at 9.18, the MDNBR decreases until core power has been substantially reduced following shutdown. A large MDNBR thermal margin is maintained throughout the transient.

Maximum fuel temperatures for the reference core design during a partial LOFA transient are shown in Figure 6.5, along with the UO_2 melting temperature and design limit. At 112% reactor power, the maximum fuel temperatures are approximately 2478K. Following the loss of one reactor coolant pump at 5 seconds, the fuel temperatures remain constant until the reactor is shutdown at 9.18 seconds, where they rapidly decrease due to a substantial reduction in the core thermal power. The decreasing coolant mass flow rate and increasing coolant temperatures primarily result in a reduction in of the critical heat flux. The fuel pin heat flux remains unchanged over the short 5 second transient time period, and the fuel temperatures remain unchanged. Maximum fuel temperatures are maintained below their design limit during transient.

Maximum cladding temperatures during a partial LOFA transient and the 948K design limit are shown in Figure 6.6. The maximum cladding temperatures are initially at 621K. Following the loss of one reactor coolant pump at 5 seconds, the cladding temperatures remain constant until 9.5 seconds due to the fact the cladding temperatures are much less susceptible to the small increases in coolant temperature

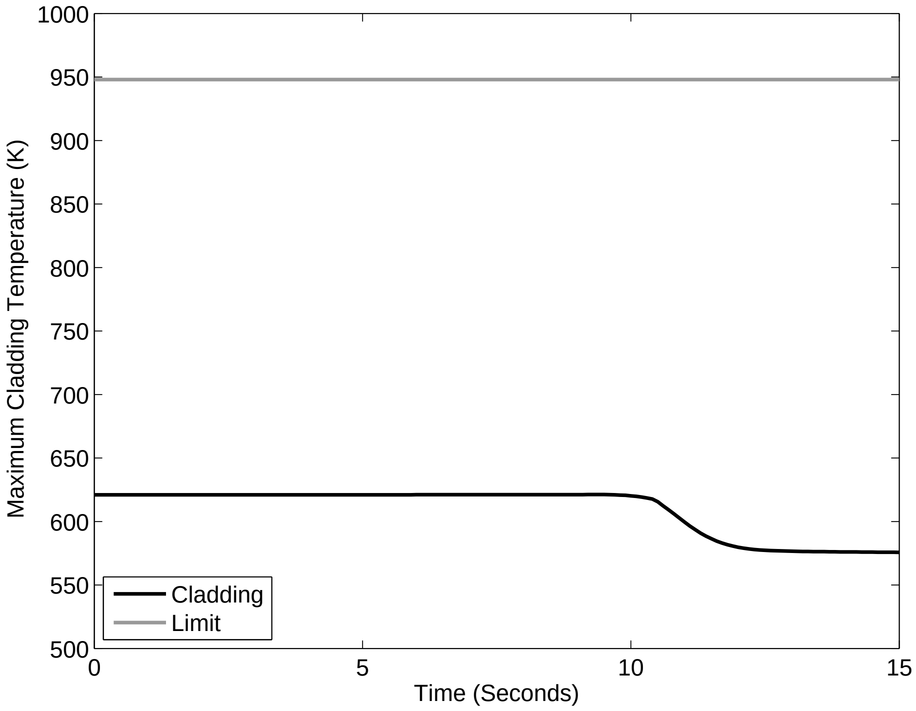

Figure 6.6. UO_2 Reference design PLOFA cladding temperatures

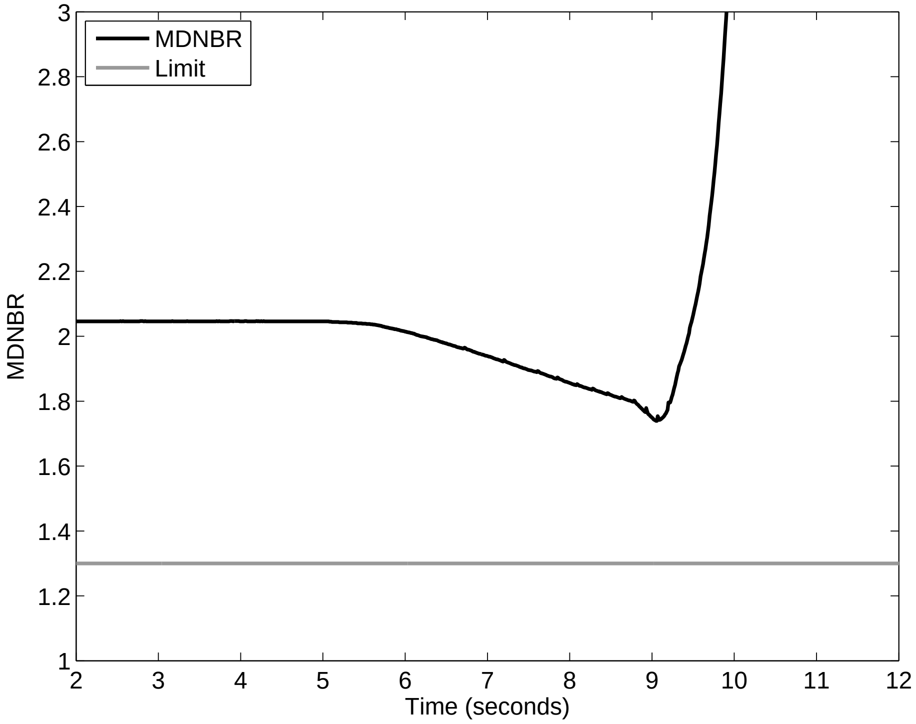

Figure 6.7. UO_2 Reference design CLOFA MDNBR

than the critical heat flux. The reactor is shutdown at 9.18 seconds and the cladding temperatures quickly decrease until the cladding comes into near-thermal equilibrium with the surrounding coolant. The maximum cladding temperatures remain well below the design limit throughout the duration of the transient.

MDNBR results for the complete LOFA (CLOFA) transient analysis are shown in Figure 6.7. The reduction of the MDNBR during a CLOFA is much more pronounced than in the PLOFA due to a greater loss of coolant flow through the core as all 4 reactor coolant pumps are lost at 5 seconds. Therefore, the critical heat flux decreases more for the complete LOFA than for the partial LOFA, while the average fuel pin heat flux remains constant for both analyses. The MDNBR is initially at 2.05. At 5.08 seconds the MDNBR begins to monotonically decrease to the minimum value of 1.74 at 9.06 seconds. The MDNBR then quickly increases as reactor power is reduced to only decay heat. A large MDNBR thermal margin is maintained throughout the transient.

The complete LOFA analysis maximum fuel temperatures for the UO_2 reference design, UO_2 melting temperature, and design limit are plotted in Figure 6.8. The reactor core is initially at 112% power and the maximum fuel temperatures are 2478K. At 5 seconds, all four reactor coolant pumps are lost and the fuel temperatures remain constant until 9.13 seconds, where they begin to decrease as the reactor core power decreases. As in the PLOFA analysis, the fuel pin heat flux remains unchanged over the short 5 second transient time period, and the fuel temperatures remain unchanged. Maximum fuel temperatures are maintained below their design limit during transient.

Complete LOFA analysis results for the maximum cladding temperatures are plotted in Figure 6.9. As with the partial LOFA event, the cladding temperatures are initially at 621K. After the loss of all four reactor coolant pumps at 5 seconds, the cladding temperatures increase to 622K at 9.21 seconds due to increasing coolant temperatures and a diminished heat transfer coefficient between the coolant and the cladding surface. At 9.62 seconds the cladding temperatures begin to slowly decrease

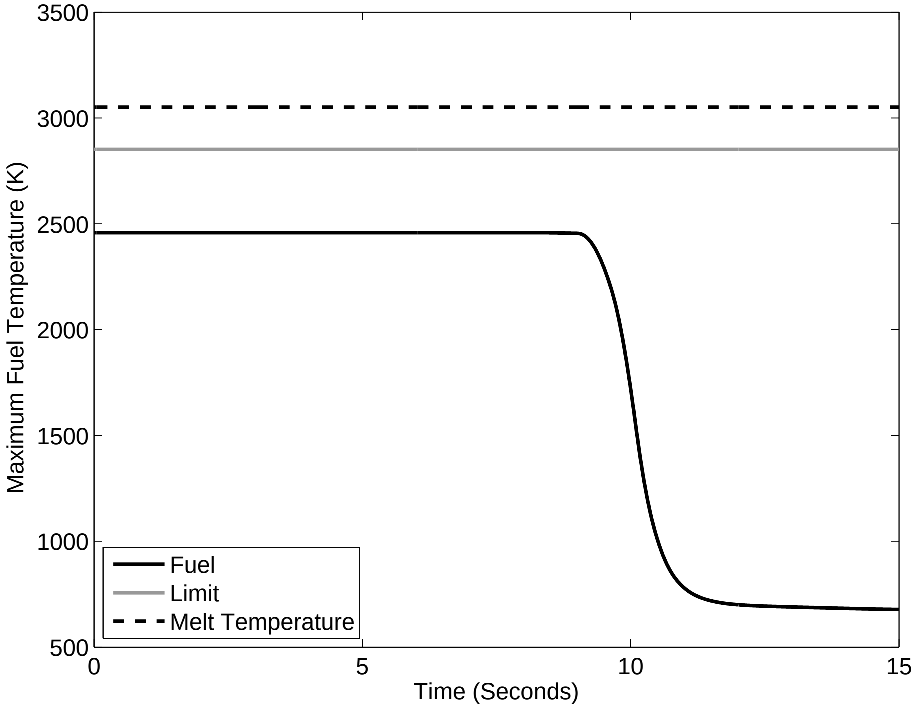

Figure 6.8. UO_2 Reference design CLOFA fuel temperatures

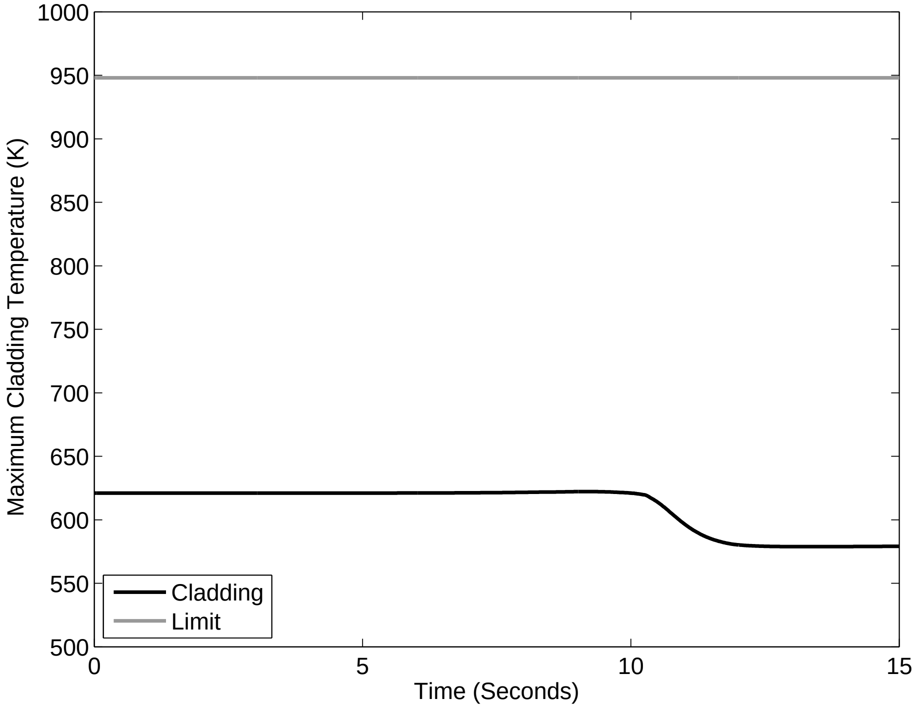

Figure 6.9. UO_2 Reference design CLOFA cladding temperatures

as reactor power begins to decrease. At 10.30 seconds the reactor power has been substantially reduced, and the cladding temperatures quickly decrease until the cladding comes into near-thermal equilibrium with the surrounding coolant. The maximum cladding temperatures remain well below the design limit throughout the duration of the transient.

6.2 Steady-State Scoping Analysis

The steady-state scoping analysis has been performed for the UO_2+(Am,Zr)O_2 and (U,Pu)O_2+(Am,Zr)O_2 fuel assembly designs. The scoping analysis provides a less computationally costly means of analyzing the proposed AMOX designs against ANS Condition I and II events.

6.2.1 UO_2+(Am,Zr)O_2 Design

The core-wide MDNBR and 1.3 DNBR limit are plotted against burnup in Figure 6.10. At 1781 MWd/tHM, the lowest MDNBR is 1.87, which is significantly larger than the 1.3 lower limit. The MDNBR increases as the assembly is reshuffled from higher to lower power regions of the core at 20 and 40 GWd/tHM.

The maximum fuel temperatures for the UO_2+(Am,Zr)O_2 design are plotted against burnup in Figure 6.11. The UO_2 melting temperature is also shown, with the design limit being 200K below the melting temperature. The fuel temperatures drop suddenly at 20 and 40 GWd/tHM when the assembly power decreases as a result of fuel assembly shuffling. Fuel temperatures increase with increasing burnup due to degradation of the fuel thermal conductivity. A maximum fuel temperature of 2595K occurs at $17,098$ MWd/tHM, and is well below the design limit.

The maximum cladding temperature and 948K design limit are plotted for increasing burnup in Figure 6.12. A maximum cladding temperature of 621K occurs at the assembly's BOL state. The cladding temperature is more than 300K below the

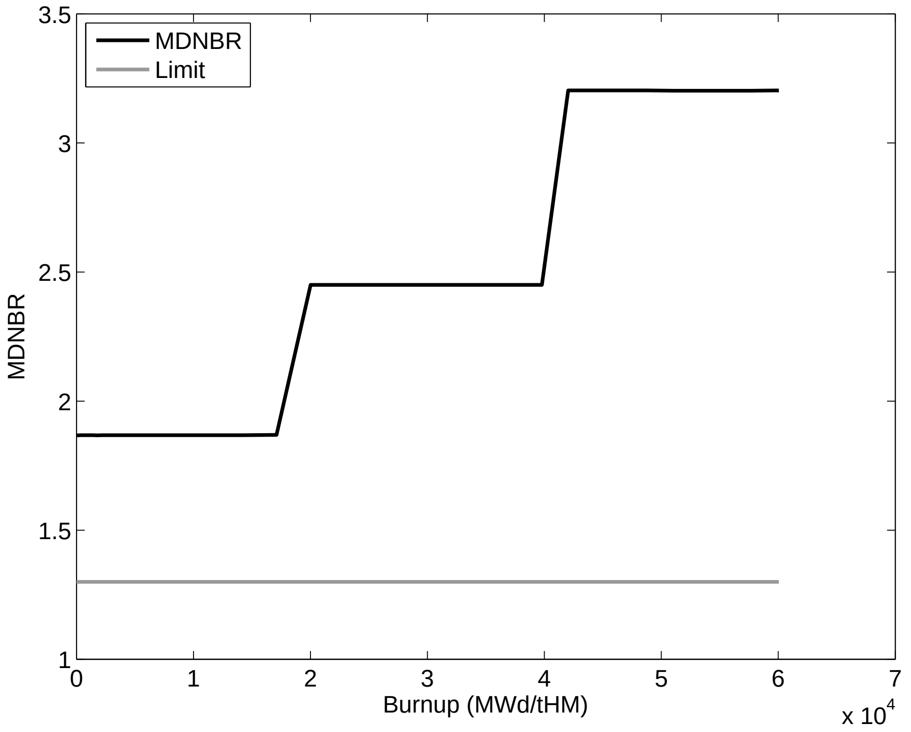

Figure 6.10. UO_2+(Am,Zr)O_2 Design MDNBR

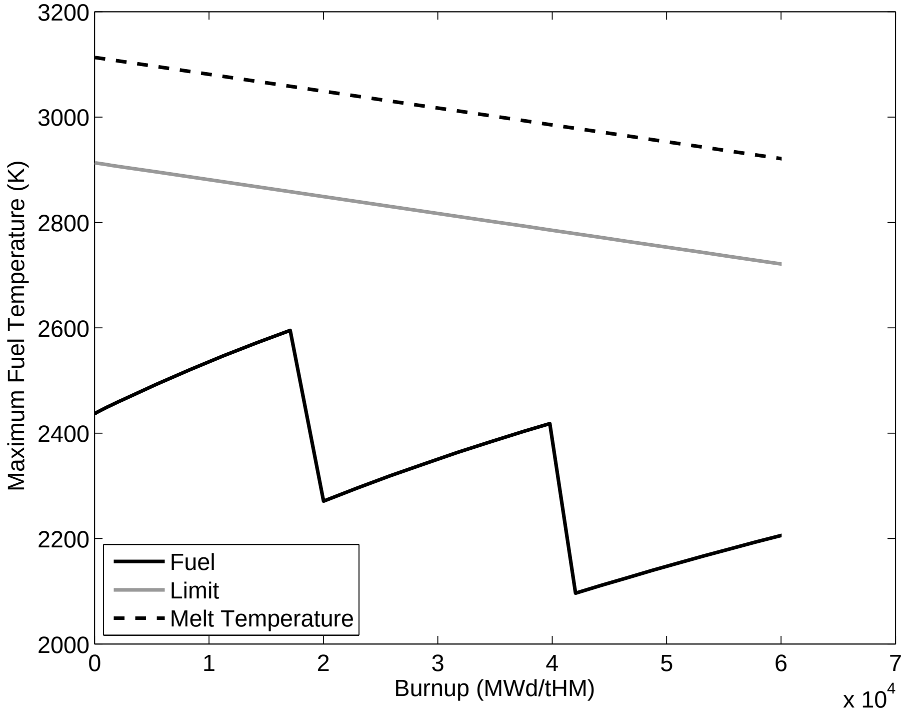

Figure 6.11. UO_2+(Am,Zr)O_2 Design fuel temperatures

design limit over the entire operational lifetime of the assembly.

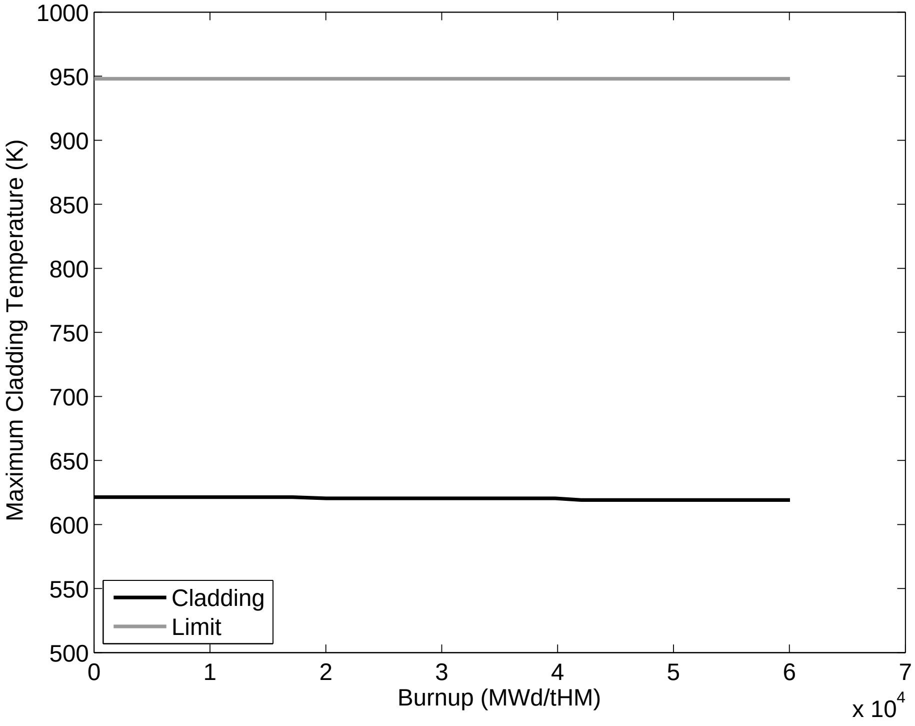

Figure 6.12. UO_2+$(Am,Zr)O_2$ Design cladding temperatures

6.2.2 $(U,Pu)O_2$+$(Am,Zr)O_2$ Design

The core-wide MDNBR and 1.3 DNBR limit are plotted against burnup in Figure 6.13. At $10,571$ MWd/tHM, the lowest MDNBR is 1.87, which is significantly larger than the lower limit. The MDNBR increases as the assembly is reshuffled from higher to lower power regions of the core at 20 and 40 GWd/tHM.

The maximum fuel temperatures for the $(U,Pu)O_2$+$(Am,Zr)O_2$ design are plotted against burnup in Figure 6.14. The $(U,Pu)O_2$ melting temperature is also shown, with the design limit being 200K below the melting temperature. The fuel temperatures drop suddenly at 20 and 40 GWd/tHM when the assembly power decreases as a result of fuel assembly shuffling. Fuel temperatures increase with increasing burnup

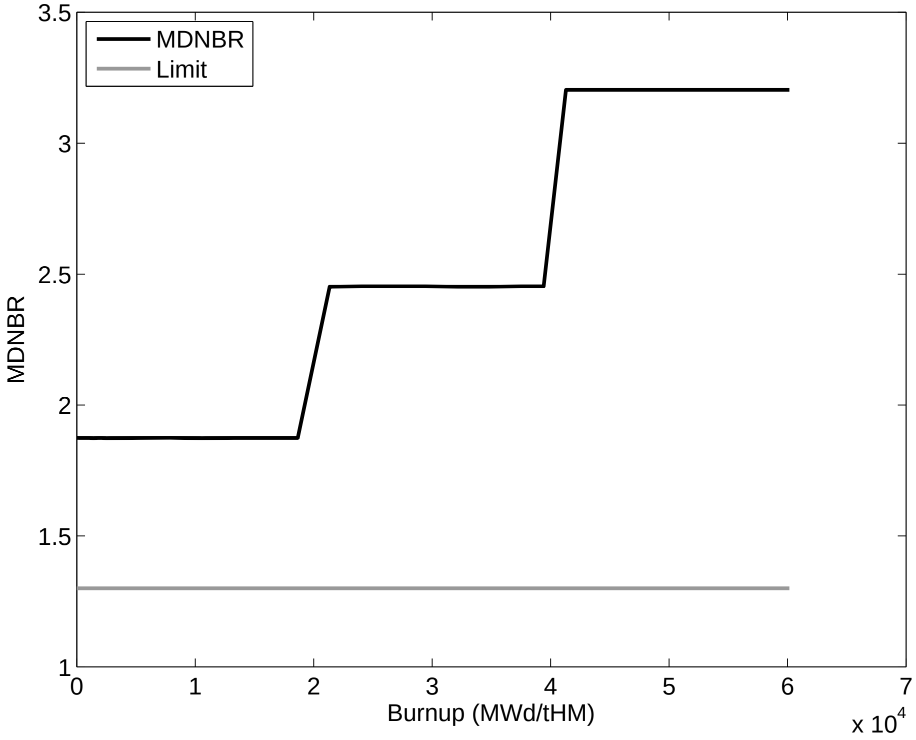

Figure 6.13. $(U,Pu)O_2$+$(Am,Zr)O_2$ Design MDNBR

due to degradation of the fuel thermal conductivity. A maximum fuel temperature of 2661K occurs at 18,658 MWd/tHM, which is well below the design limit.

The maximum cladding temperature and 948K design limit are plotted for increasing burnup in Figure 6.15. A maximum cladding temperature of 621K occurs at 10,571 MWd/tHM. The cladding temperature is more than 300K below the design limit over the entire operational lifetime of the assembly.

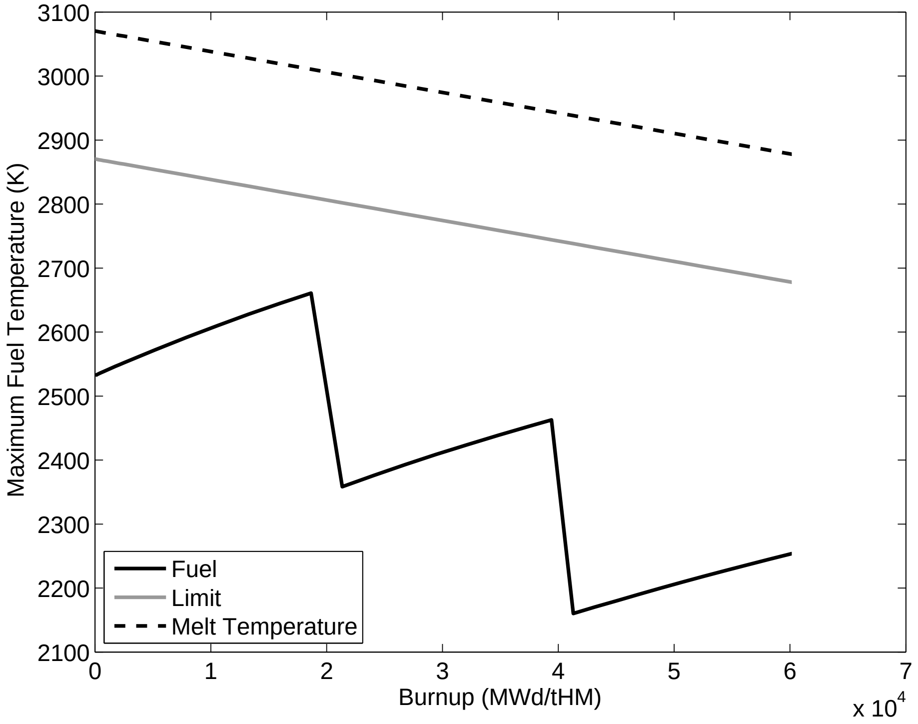

Figure 6.14. (U,Pu)O_2+(Am,Zr)O_2 Design fuel temperatures

6.3 Transient Analysis

Partial and complete LOFA transient analyses from the new thermal-hydraulic methodology has been performed for the two proposed AMOX fuel assembly designs using VIPRE. Analyses are conducted at 17,098 and 18,658 MWd/tHM for

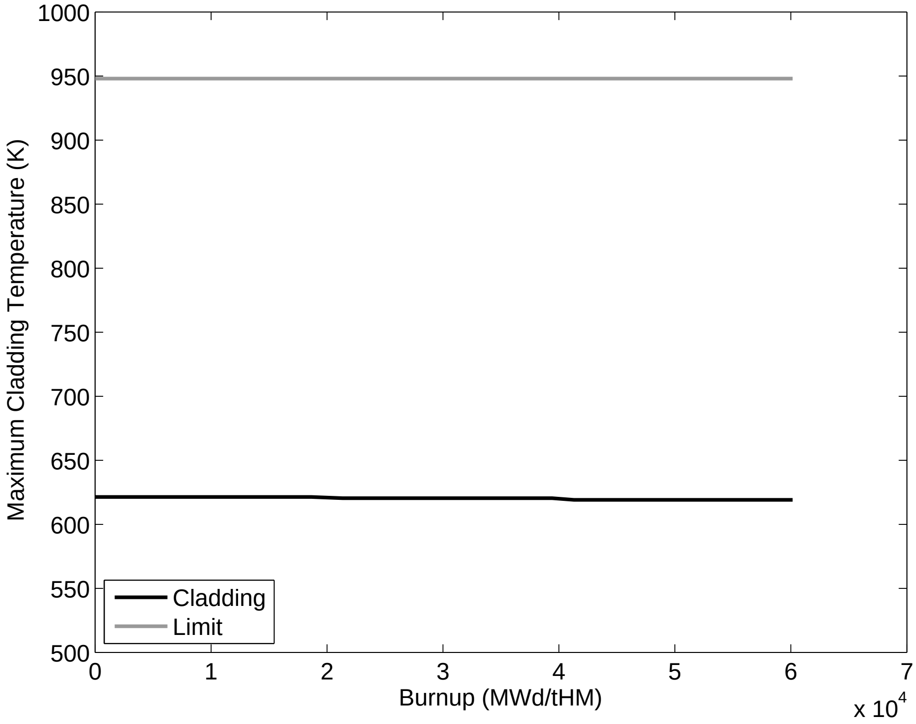

Figure 6.15. $(U,Pu)O_2$+$(Am,Zr)O_2$ Design cladding temperatures

the UO_2+(Am,Zr)O_2 and (U,Pu)O_2+(Am,Zr)O_2 designs, respectively, where the MDNBR, and fuel and cladding temperatures are at their most limiting conditions.

6.3.1 UO_2+(Am,Zr)O_2 Design

Partial LOFA analysis results for the UO_2+(Am,Zr)O_2 design core-wide MDNBR are plotted against time in Figure 6.16 along with the 1.3 DNBR limit. After the transient initiation at 5 seconds, the MDNBR begins to slowly decrease from 2.05 to 1.97 at 9.45 seconds, just shortly after the reactor is shutdown at 9.18 seconds. The MDNBR then quickly increases as reactor power is reduced to only decay heat. A large MDNBR thermal margin is maintained throughout the transient.

Maximum fuel temperatures for the UO_2+(Am,Zr)O_2 design during a partial LOFA transient are shown in Figure 6.17, along with the UO_2 melting temperature and design limit. At 112% reactor power, the maximum fuel temperatures are approx-

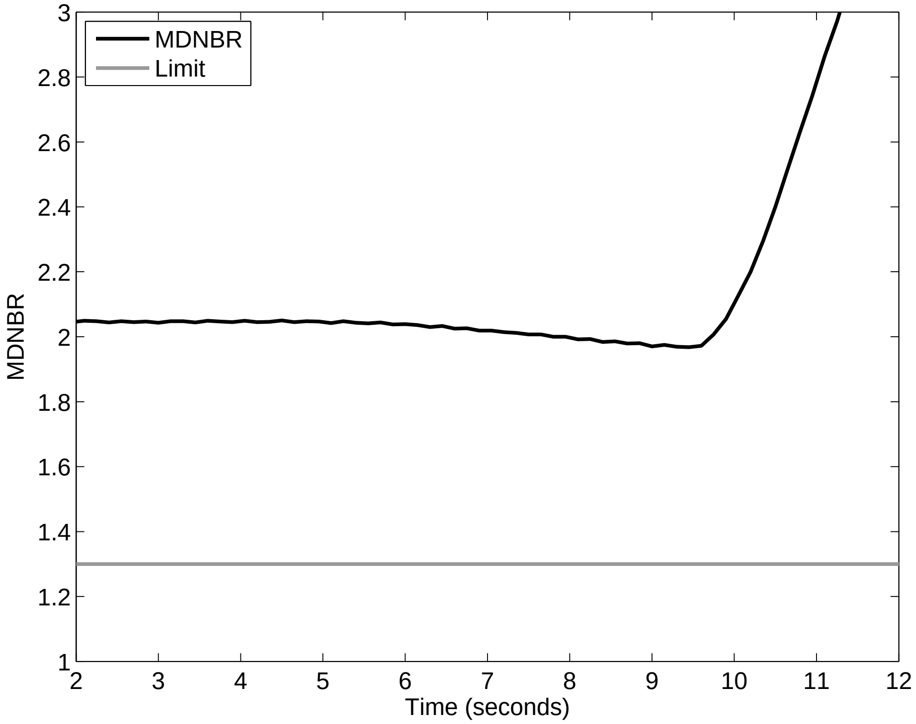

Figure 6.16. UO_2+(Am,Zr)O_2 Design PLOFA MDNBR

imately 2490K. Following the loss of one reactor coolant pump at 5 seconds, the fuel temperatures remain constant until the reactor is shutdown at 9.18 seconds, where they begin to decrease monotonically. Maximum fuel temperatures are maintained below their design limit during transient.

Maximum cladding temperatures during a partial LOFA transient and the 948K design limit are shown in Figure 6.18. The maximum cladding temperatures are initially at 621K. Following the loss of one reactor coolant pump at 5 seconds, the cladding temperatures remain constant until 10.20 seconds, even after the reactor is shutdown at 9.18 seconds. The cladding temperatures begin to slowly decrease over time. The maximum cladding temperatures remain well below the design limit throughout the duration of the transient.

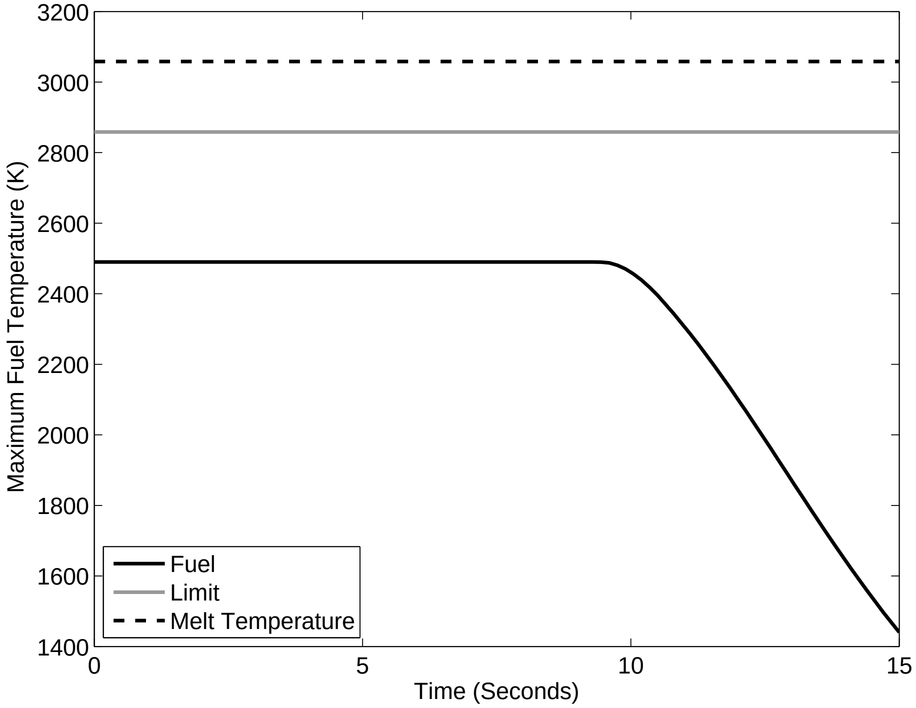

Figure 6.17. UO_2+$(Am,Zr)O_2$ Design PLOFA fuel temperatures

MDNBR results for the complete LOFA transient analysis are shown in Figure 6.19. The MDNBR is initially at 2.05. At 5.09 seconds the MDNBR begins to

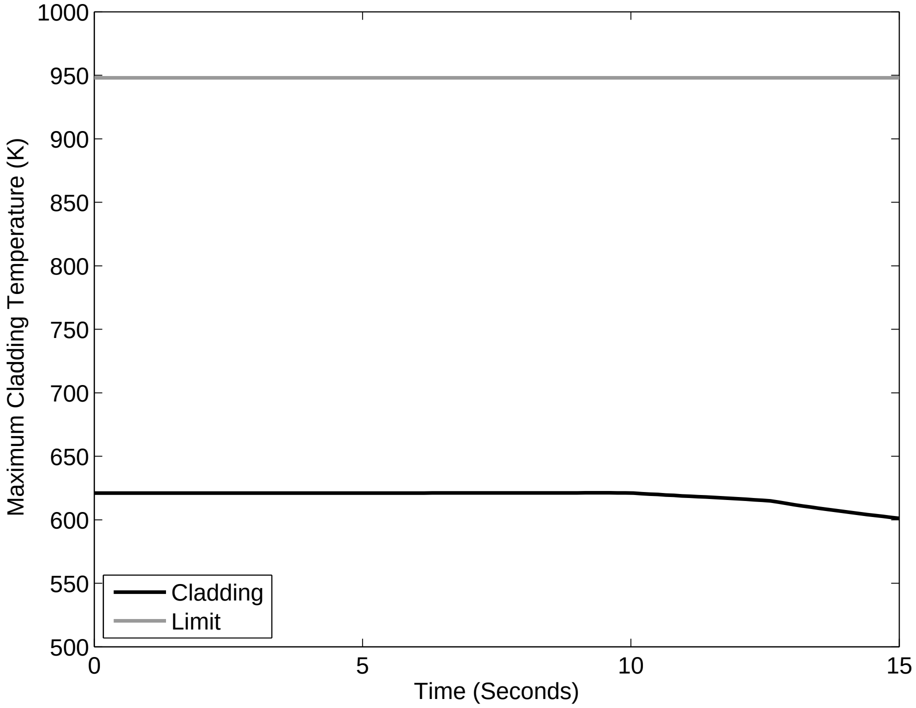

Figure 6.18. UO_2+$(Am,Zr)O_2$ Design PLOFA cladding temperatures

monotonically decrease to the minimum value of 1.71 at 9.32 seconds. The MDNBR then quickly increases as reactor power is reduced to only decay heat. A large MDNBR thermal margin is maintained throughout the transient.

The maximum fuel temperatures, UO_2 melting temperature, and design limit

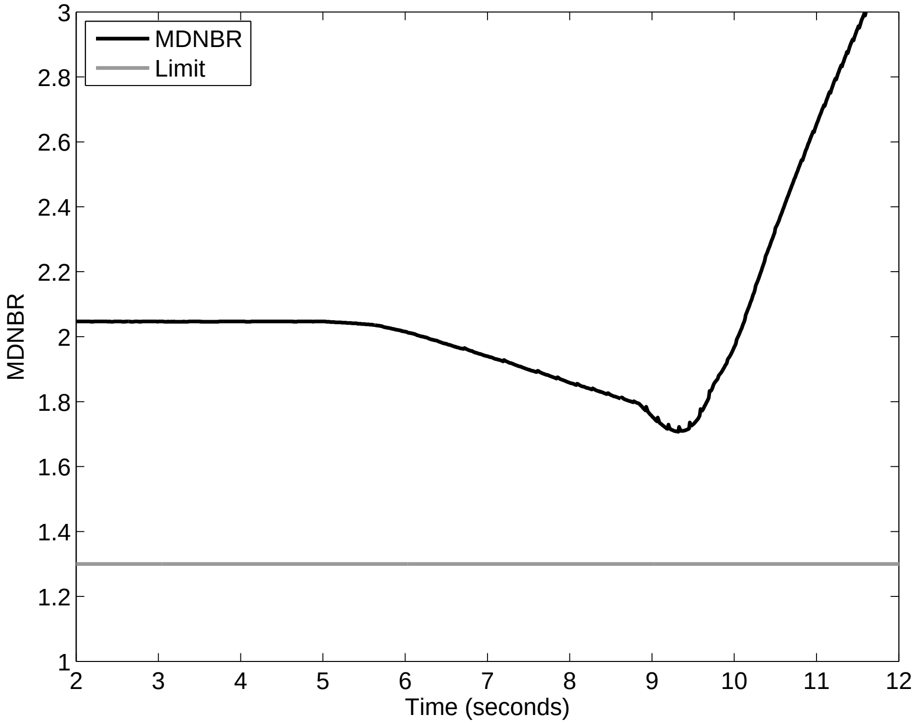

Figure 6.19. UO_2+(Am,Zr)O_2 Design CLOFA MDNBR

of the UO_2+(Am,Zr)O_2 design from the complete LOFA analysis are plotted in Figure 6.20. The reactor core is initially at 112% power and the maximum fuel temperatures are 2490K. At 5 seconds, all four reactor coolant pumps are lost and the fuel temperatures remain constant until 9.34 seconds, where they begin to decrease as the reactor core power decreases. Maximum fuel temperatures are maintained below their design limit during transient.

Complete LOFA analysis results for the maximum cladding temperatures are plotted in Figure 6.21. As with the partial LOFA event, the cladding temperatures are initially at 621K. After the loss of all four reactor coolant pumps at 5 seconds,

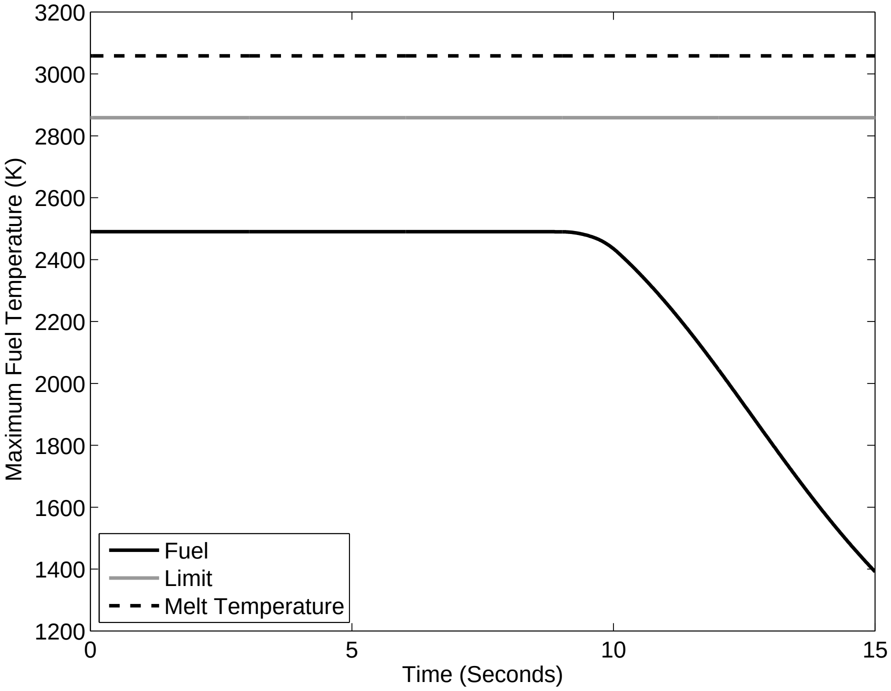

Figure 6.20. UO_2+(Am,Zr)O_2 Design CLOFA fuel temperatures

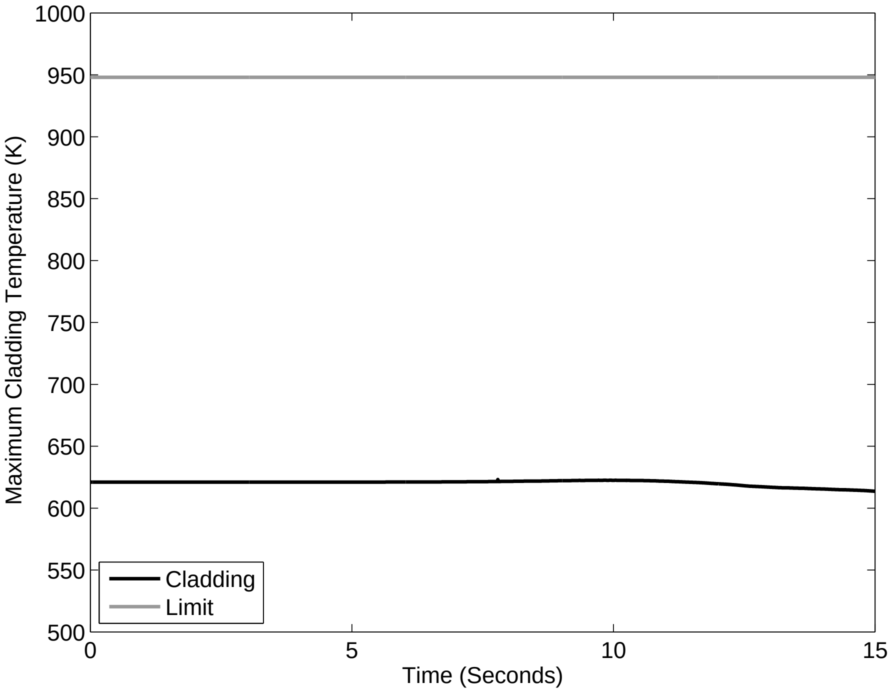

Figure 6.21. UO_2+(Am,Zr)O_2 Design CLOFA cladding temperatures

the cladding temperatures increase to 623K at 9.59 seconds. At 10.10 seconds the cladding temperatures begin to slowly decrease. The maximum cladding temperatures remain well below the design limit throughout the duration of the transient.

6.3.2 $(U,Pu)O_2+(Am,Zr)O_2$ Design

Partial LOFA analysis results for the $(U,Pu)O_2+(Am,Zr)O_2$ design core-wide MDNBR are plotted against time in Figure 6.22 along with the 1.3 DNBR limit. After the transient initiation at 5 seconds, the MDNBR begins to slowly decrease from 2.05 to 1.97 at 9.58 seconds, just shortly after the reactor is shutdown at 9.18 seconds. The MDNBR then quickly increases as reactor power is reduced to only decay heat. A large MDNBR thermal margin is maintained throughout the transient.

Maximum fuel temperatures for the $(U,Pu)O_2+(Am,Zr)O_2$ design during a partial LOFA transient are shown in Figure 6.23, along with the $(U,Pu)O_2$ melting

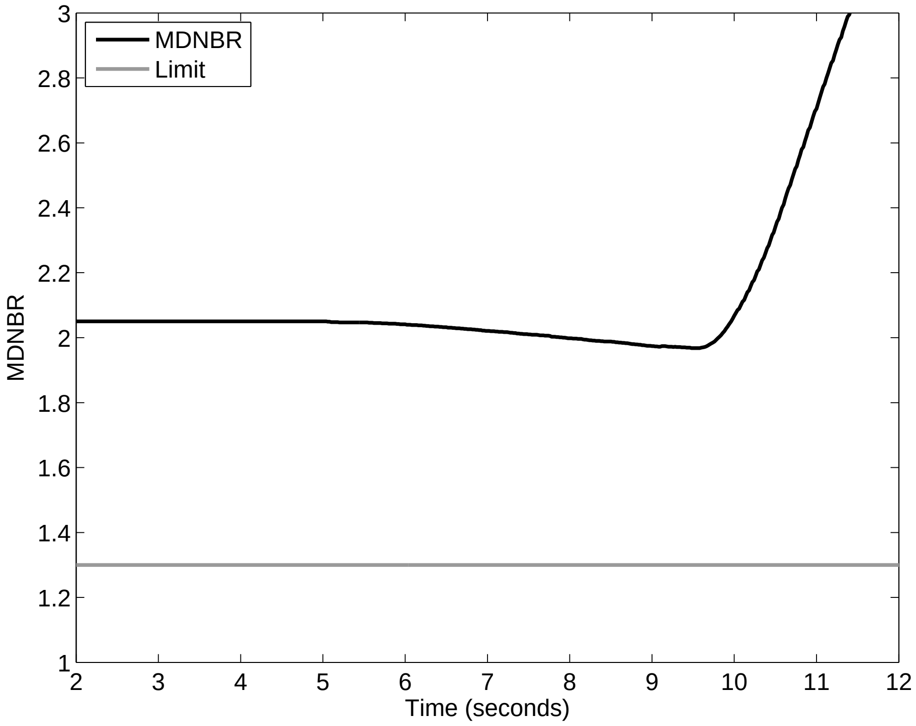

Figure 6.22. $(U,Pu)O_2+(Am,Zr)O_2$ Design PLOFA MDNBR

temperature and design limit. At 112% reactor power, the maximum fuel temperatures are approximately 2565K. Following the loss of one reactor coolant pump at 5 seconds, the fuel temperatures remain constant until the reactor is shutdown at 9.18 seconds, where they begin to decrease monotonically. Maximum fuel temperatures are maintained below their design limit during transient.

Maximum cladding temperatures during a partial LOFA transient and the 948K design limit are shown in Figure 6.24. The maximum cladding temperatures are initially at 621K. Following the loss of one reactor coolant pump at 5 seconds, the cladding temperatures remain constant until 10.18 seconds, and then the cladding temperatures begin to slowly decrease over time. The maximum cladding temperatures remain well below the design limit throughout the duration of the transient.

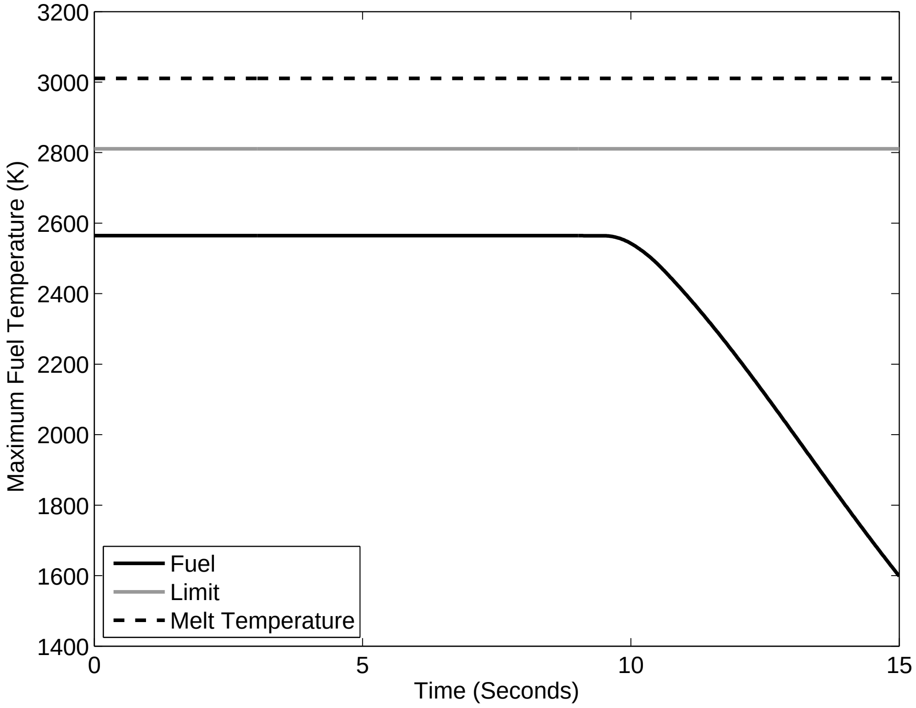

Figure 6.23. $(U,Pu)O_2$+$(Am,Zr)O_2$ Design PLOFA fuel temperatures

MDNBR results for the complete LOFA transient analysis are shown in Figure 6.25. The MDNBR is initially at 2.05. At 5.03 seconds the MDNBR begins to

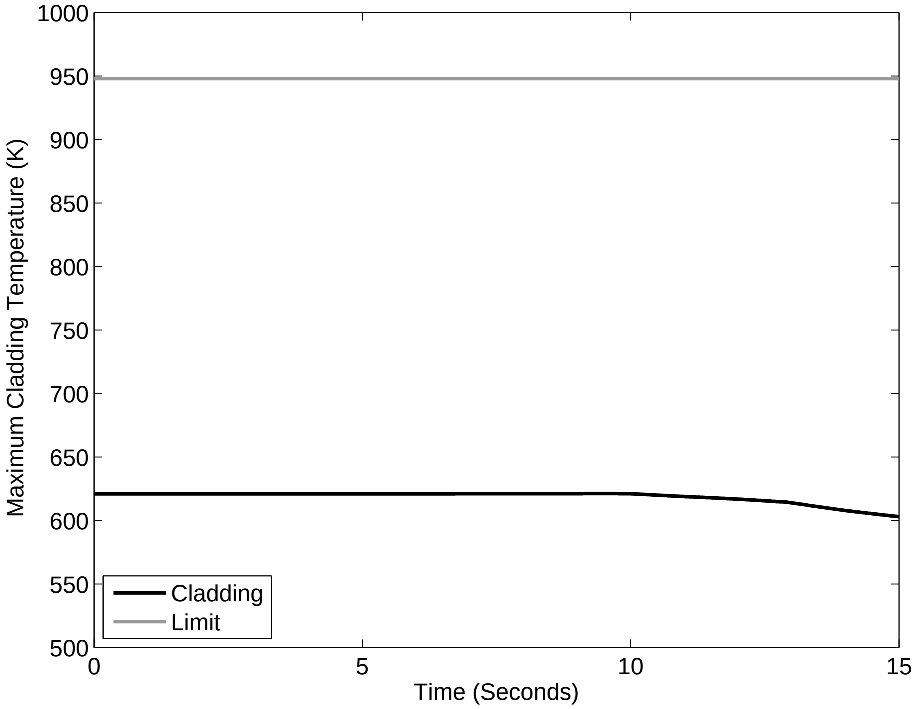

Figure 6.24. (U,Pu)O_2+(Am,Zr)O_2 Design PLOFA cladding temperatures

monotonically decrease to the minimum value of 1.70 at 9.32 seconds. The MDNBR then quickly increases as reactor power is reduced to only decay heat. A large MDNBR thermal margin is maintained throughout the transient.

The complete LOFA analysis maximum fuel temperatures for the $(U,Pu)O_2$ $+(Am,Zr)O_2$ design, $(U,Pu)O_2$ melting temperature, and design limit are plotted in Figure 6.26. The reactor core is initially at 112% power and the maximum fuel temperatures are 2565K. At 5 seconds, all four reactor coolant pumps are lost and the fuel temperatures remain constant until 9.35 seconds, where they begin to decrease as the reactor core power decreases. Maximum fuel temperatures are maintained below their design limit during transient.

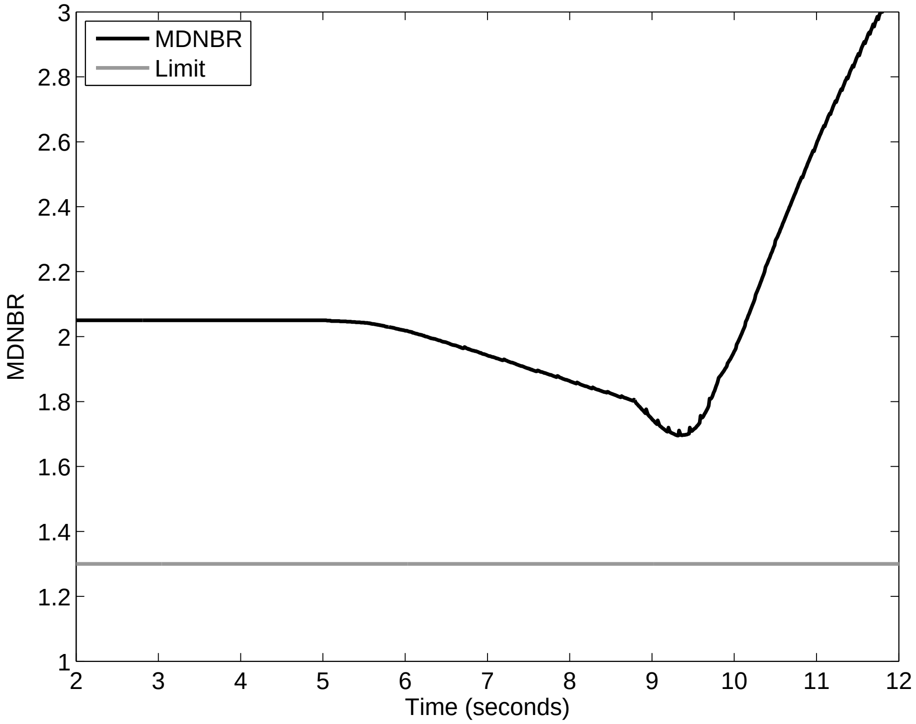

Figure 6.25. $(U,Pu)O_2+(Am,Zr)O_2$ Design CLOFA MDNBR

Complete LOFA analysis results for the maximum cladding temperatures are plotted in Figure 6.27. The cladding temperatures are initially at 621K. After the loss of all four reactor coolant pumps at 5 seconds, the cladding temperatures increase

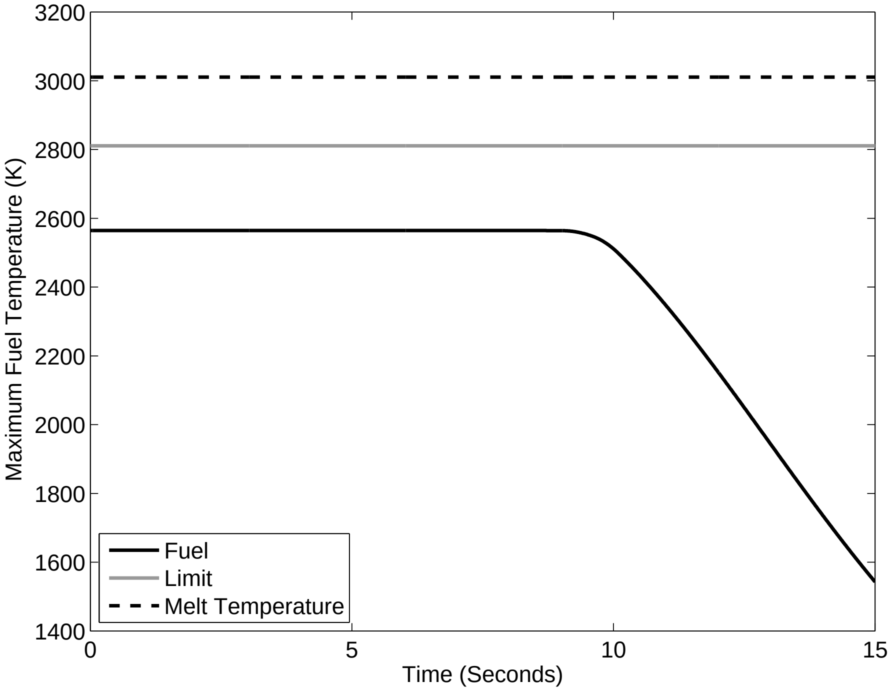

Figure 6.26. (U,Pu)O_2+(Am,Zr)O_2 Design CLOFA fuel temperatures

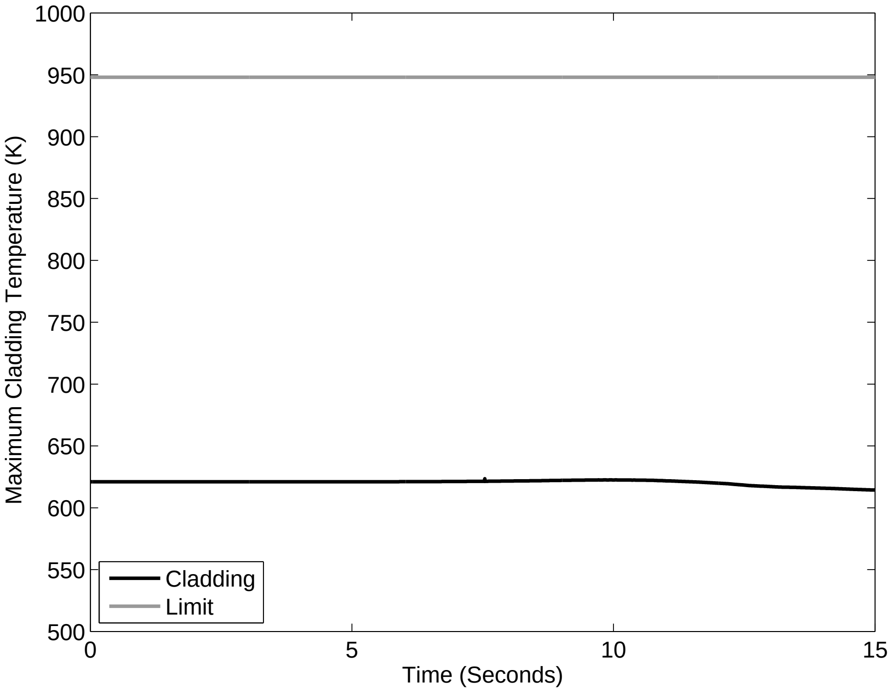

Figure 6.27. (U,Pu)O_2+(Am,Zr)O_2 Design CLOFA cladding temperatures

to 623K at 9.93 seconds. At 10.19 seconds the cladding temperatures begin to slowly decrease. The maximum cladding temperatures remain well below the design limit throughout the duration of the transient.

6.4 Analysis of Results

The results from steady-state and transient thermal-hydraulic analyses for the reference UO_2, UO_2+(Am,Zr)O_2, and (U,Pu)O_2+(Am,Zr)O_2 designs are listed in Table 6.2. The limits for each of the primary parameters of interest are listed for each analysis type. There are two maximum fuel temperature limits for each analysis because the melting temperatures, and therefore the limit temperatures, are different for UO_2 and (U,Pu)O_2. The maximum temperature limits in Table 6.2 are established for the most limiting burnup level for the UO_2 and (U,Pu)O_2-based fuels: $19,362$ and $18,658$ MWd/tHM, respectively.

Within each analysis type, the MDNBR and PCT for each design are in excellent agreement with each other. The maximum fuel temperature for the UO_2+(Am,Zr)O_2 design is 12 to 14K higher than the reference UO_2 design for all analyses due the addition of a thin (Am,Zr)O_2 outer layer. The outer (Am,Zr)O_2 layer has a low thermal conductivity and acts as an insulating layer for the central UO_2 pellet, which increases the fuel pellet centerline temperature and reduces the rate at which heat is extracted from the fuel during the LOFA transients, as shown in Figures 6.28 and 6.29. Similar results are shown for the (U,Pu)O_2+(Am,Zr)O_2 design in Figures 6.30 and 6.31. The (U,Pu)O_2+(Am,Zr)O_2 design has higher maximum fuel temperatures for all analysis types due to the presence of the insulating (Am,Zr)O_2 layer and an inherently lower thermal conductivity for the (U,Pu)O_2 central pellet than that of UO_2.

While the fuel temperatures are higher for the UO_2+(Am,Zr)O_2 and (U,Pu)O_2 +(Am,Zr)O_2 designs, the presence of a thin (Am,Zr)O_2 outer coating on the fuel pellet has a negligible effect on the maximum cladding temperature. The cladding temperatures calculated by VIPRE remain essentially constant for all analysis types, with a

Table 6.2
Thermal-hydraulic analysis results

	Steady-state scoping analysis			Partial LOFA			Complete LOFA		
	MDNBR	Max. fuel temp. (K)	Peak cladding temp. (K)	MDNBR	Max. fuel temp. (K)	Peak cladding temp. (K)	MDNBR	Max. fuel temp. (K)	Peak cladding temp. (K)
Limits	1.30	2851	948	1.30	2851	948	1.30	2851	948
UO_2	1.87	2581	621	1.97	2478	621	1.74	2478	622
UO_2 +$(Am,Zr)O_2$	1.87	2595	621	1.97	2490	621	1.71	2490	623
Limits	1.30	2811	948	1.30	2811	948	1.30	2811	948
$(U,Pu)O_2$ +$(Am,Zr)O_2$	1.87	2661	621	1.97	2565	621	1.70	2565	623

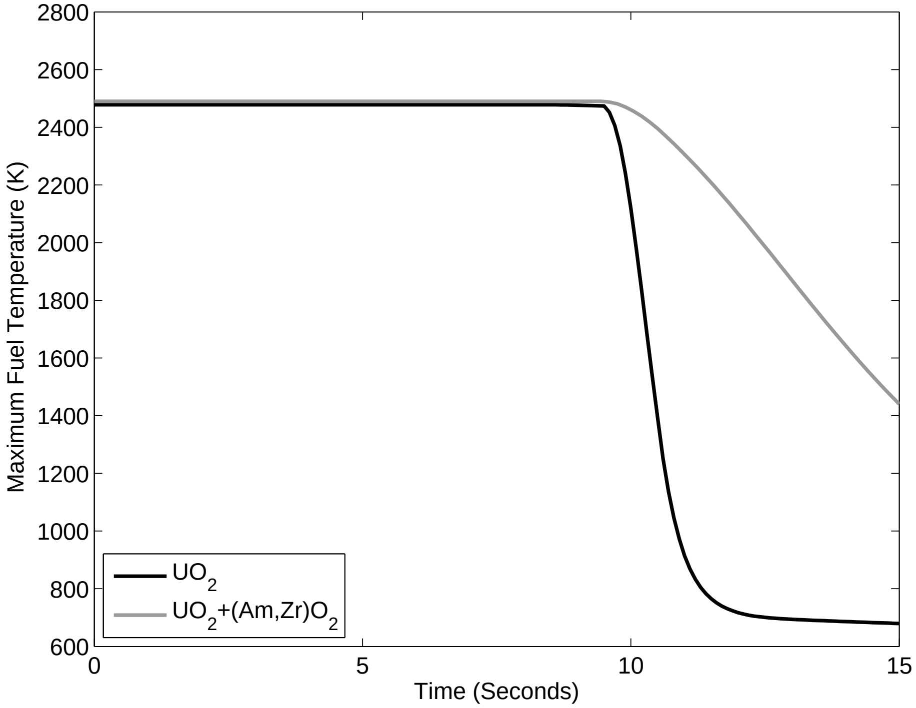

Figure 6.28. UO_2+(Am,Zr)O_2 Design PLOFA fuel temperature comparison

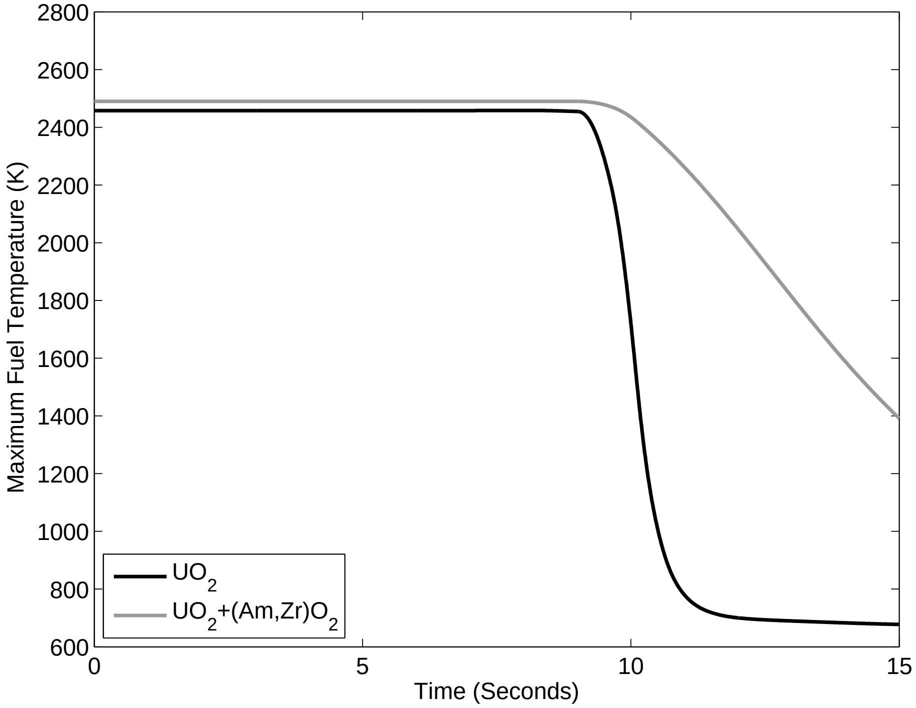

Figure 6.29. UO_2+(Am,Zr)O_2 Design CLOFA fuel temperature comparison

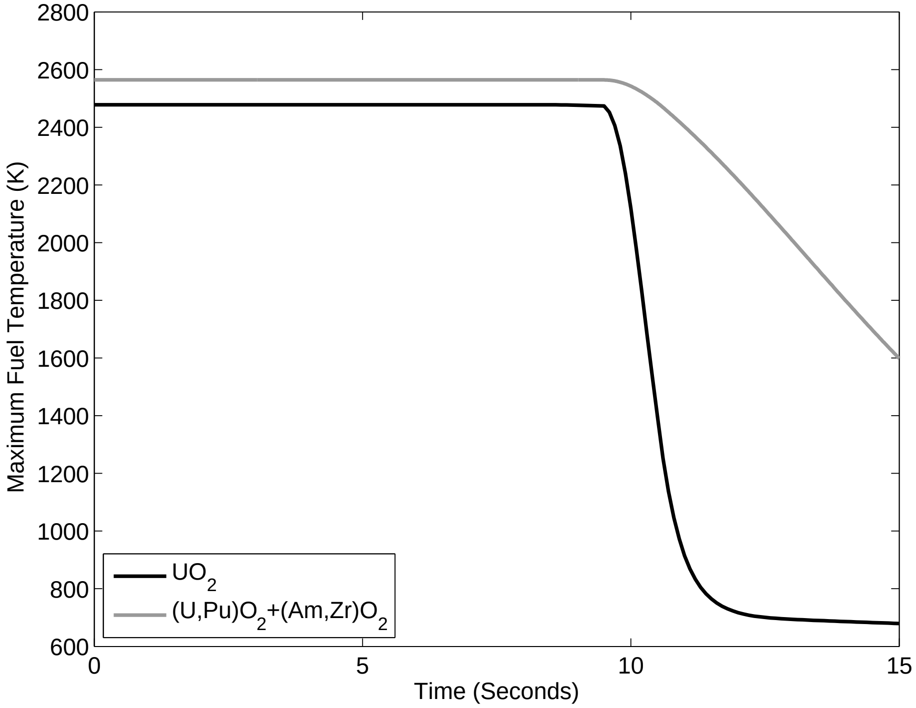

Figure 6.30. $(U,Pu)O_2$+$(Am,Zr)O_2$ Design PLOFA fuel temperature comparison

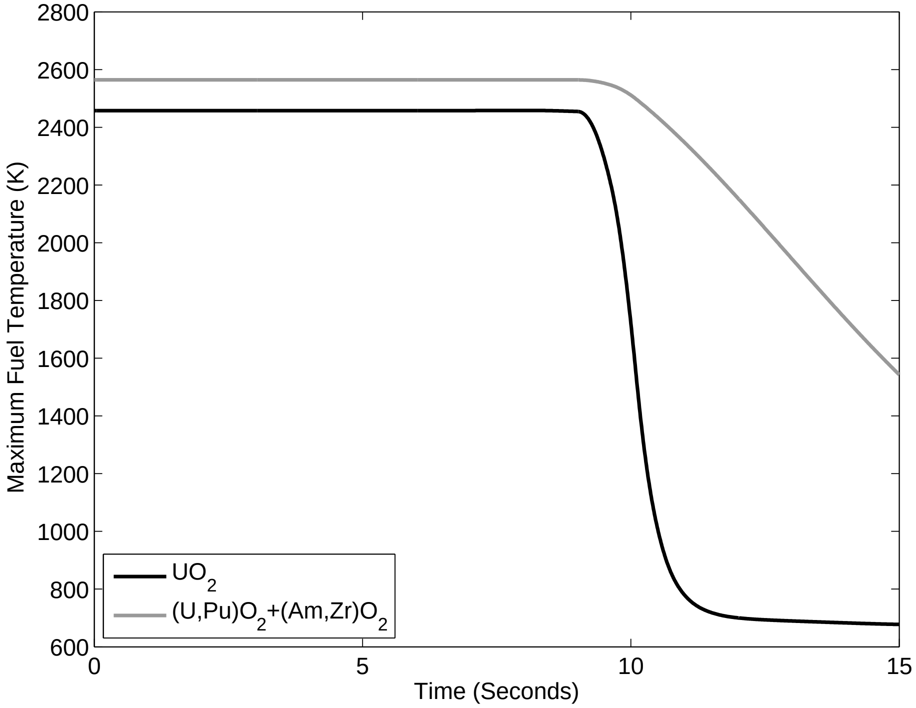

Figure 6.31. $(U,Pu)O_2$+$(Am,Zr)O_2$ Design CLOFA fuel temperature comparison

slight increase in temperature during the complete LOFA analysis for all three designs. The smaller temperature loss rate seen for the cladding in Figures 6.18, 6.21, 6.24, and 6.27 for the UO_2+(Am,Zr)O_2 and (U,Pu)O_2+(Am,Zr)O_2 designs are attributed the lower heat removal rate from the central fuel pellet as a result of the (Am,Zr)O_2 layer.

The MDNBR values for each analysis type are in excellent agreement with the reference UO_2 case. However, the values for the UO_2+(Am,Zr)O_2 and (U,Pu)O_2 +(Am,Zr)O_2 designs are slightly lower than for the UO_2 design for the complete LOFA analysis. The lower values are believed to be a result of the reduced heat removal rate from the fuel pellets due to the outer (Am,Zr)O_2 layer, which causes fuel and cladding temperatures to remain at higher temperatures for longer periods of time as the coolant mass flow rate continues to decrease. The heat flux from cladding to coolant is dependent on the temperature gradient between the two mediums. Therefore, as long as the cladding temperatures remain at their normal operating temperature while the coolant mass flow rate decreases the critical heat flux will decrease, which causes the MDBNR to decrease for a constant rod heat flux.

6.5 Summary

Steady-state and transient thermal-hydraulic analyses have been performed for a standard UO_2 and two AMOX fuel assembly designs using the new burnup-dependent thermal-hydraulic analysis methodology. All three designs have been shown to maintain a sufficiently large thermal margin with respect to the MDNBR, and maximum cladding and fuel temperatures during the investigated ANS Conditions I, II, and III transient events. AMOX fuel assembly MDNBR values are in excellent agreement with the UO_2 design. The most limiting results come from the complete LOFA analysis, where the lowest MDNBR is 1.7, although the maximum cladding and fuel temperature thermal margins remain on the order of hundreds-of-degrees Celsius. The net effects of a thin (Am,Zr)O_2 outer layer on the fuel pellet are an increase in fuel centerline temperatures and a diminished heat removal rate from the fuel pellet following reactor shutdown. This lower heat removal rate is believed to be responsible for the small reductions in the MDNBR values for the AMOX fuel assembly designs due to the fuel and cladding temperatures remain hotter for a longer period of time. The prolonged time period during which the cladding temperatures remain at their normal operating temperature causes the fuel pin heat flux to decrease less rapidly than for the reference UO_2 design. Therefore, as the coolant mass flow rate decreases during the LOFA transient, the critical heat flux decreases while the actual fuel pin heat flux remains essentially constant, causing further reductions in the MDNBR. The MDNBR reaches a minimum and begins to increase after sufficient heat has been removed from the fuel pin to induce a cladding temperature drop.

7. SUMMARY

New fuel assembly designs for LWRs using AMOX fuel assemblies have been proposed to reduce the radiotoxicity of UNF discharged from nuclear power plants. Many fuel types and assembly designs have been proposed for reducing the radiotoxicity of UNF from a neutronics point of view. However, few of them have considered that neutronic design parameters such as fuel enrichment, loading, and discharge burnup are limited by material and thermal-hydraulic factors. Of the work that has considered material and thermal-hydraulic factors, only simplified steady-state or limited transient thermal-hydraulic analyses have been performed. Additionally, no work has been found that investigates the deleterious effects of burnup on the thermal-hydraulic performance of these advanced fuel assembly designs.

The research efforts of this thesis are the first to consider the effects of burnup on AMOX fuel assembly performance and thermal safety margin over the 62 GWd/tHM expected operational assembly lifetime. In order to accomplish the objectives of this thesis, current design procedures for conventional and advanced fuel assemblies were surveyed. Recommendations from the literature and regulatory guides were used to formulate an appropriate design methodology tailored for burnup-dependent analysis. The new thermal-hydraulic analysis methodology includes steady-state scoping and transient analyses, and attempts to model the following: burnup-dependence of fuel rod neutronic relative power factors, effects of fuel assembly reshuffling from higher to lower power regions of the core as burnup increases, and the deleterious effects of burnup on fuel material thermal conductivity.

A comprehensive literature survey on thermal conductivity of the posed fuel materials with burnup-dependence was carried out. Where documented conductivity values were not available, a simplified method for estimating the thermal conductivity was developed. The new thermal conductivity models are based on the established

FRAPCON-3 fuel property models used in the nuclear industry, and small adjustments have been made to account for actinide additions.

A text-based coupling method was developed using PERL scripts to facilitate the exchange of information between the neutronic code DRAGON and thermal-hydraulic code VIPRE-01. Automation of data exchange and input deck formulation was utilized as much as possible to reduce the potential for human error and to expedite the analysis process. Results from neutronic calculations are directed to a text file. This text file is parsed by the coupling program, and the appropriate data is sent to additional programs that formulate the necessary thermal-hydraulic input decks and call VIPRE to execution.

MELCOR, a LWR severe accident code, was used as a systems code to model the entire primary side of the reference power plant during induced partial and complete LOFA transients. Results from MELCOR were used to generate the reactor core flow boundary conditions for VIPRE. An existing MELCOR input deck that models a PWR plant similar to the selected reference core design was modified to induce partial and complete LOFAs for transient analysis. Reactor core results from MELCOR for core pressure, coolant inlet temperature, coolant mass flow rate, and core power were applied as temporal forcing functions in VIPRE to induce changes in reactor operating conditions with time so that detailed assembly thermal performance could be analyzed.

VIPRE input decks were created to model the reference UO_2 fuel assembly design, as well as two AMOX assembly designs that utilize a thin outer layer of $(Am,Zr)O_2$ on a UO_2 and $(U,Pu)O_2$ central pellet to burn the americium. The input decks consist of reactor core boundary conditions, fuel and cladding material description, axial and radial power profiles, geometrical descriptions of fuel pins and assemblies, and instructions for running VIPRE cases, such as flow-field and heat transfer correlations, solution method, and convergence criteria. The reference plant is Luminant's Comanche Peak Steam Electric Station Nuclear Unit 1.

Using VIPRE, steady-state, single-pass hot channel analyses were conducted with

1/8th core symmetry at 18% core overpower to confirm that safety criteria are maintained by the new assembly designs under ANS Condition I and II events. The W-3L critical heat flux correlation was used for assessing the DNBR performance of assembly designs. The steady-state scoping analysis was used to analyze each fuel assembly design over its entire expected burnup lifetime. ANS Condition II and III partial and complete LOFA transient analyses were conducted at 12% core overpower using boundary conditions supplied from MELCOR results.

7.1 Conclusions

Steady-state and transient thermal-hydraulic analyses were performed with VIPRE for the reference UO_2 assembly design, and two AMOX fuel assembly designs using the new burnup-dependent thermal-hydraulic analysis methodology. All three designs maintained a sufficiently large thermal margin with respect to the MDNBR, and maximum cladding and fuel temperatures during the investigated ANS Conditions I, II, and III transient events. The most limiting results came from the complete LOFA analysis, though the lowest MDNBR was 1.7 and the maximum cladding and fuel temperature thermal margins are on the order of hundreds-of-degrees Celsius. The net effects of the thin $(Am,Zr)O_2$ outer layer on the fuel pellet are an increase in fuel centerline temperatures and a lower heat removal rate from the fuel pellet following reactor shutdown. This reduced heat removal rate is believed to be responsible for the small reductions in the MDNBR values for the AMOX fuel assembly designs during complete LOFA transient analysis since the fuel pin heat fluxes decrease more slowly than that of the reference UO_2 design due to cladding temperatures remaining hotter for a longer period of time.

Results from the steady-state scoping analysis for the three examined designs reveal that burnup has negligible effect on the MDNBR and cladding temperature thermal margins. The parameter of interest that is most affected by burnup is the maximum fuel temperature. The net effect of burnup is to reduce the fuel temperature thermal margin by increasing fuel temperature and reducing the fuel melting temperature.

There are many uncertainties associated with the modeling and analysis of new AMOX fuel assemblies. Uncertainties are primarily related to the VIPRE model and boundary conditions for each design, and include core-wide flow and temperature distribution, core power distribution, and the magnitude of the gap conductance. Other uncertainties associated with phenomena which are not modeled in the current research, or are not fully understood, include: the formation of a central void in the fuel pellet after the first rise to power, the magnitude of turbulent mixing in the core, effects of fission gas buildup in the fuel pins, and the effect of actinide additions to fuel material properties. Where large uncertainties exist, conservative assumptions have been applied to provide reasonable assurances that safe operation of an assembly design may be maintained under expected operational conditions.

Finally, the degree of conservatism employed within the new thermal-hydraulic methodology and its merit as an analysis tool for future fuel assembly designs has not been validated. While fuel assembly thermal performance results from analyses employing the new thermal-hydraulic methodology are believed to be conservative with respect to the three investigated primary parameters of interest, the validity of the burnup-dependent methodology can only be ascertained by further experimental studies with fabricated and irradiated AMOX fuel assembly designs. Therefore, caution must be exercised in applying the new burnup-dependent thermal-hydraulic methodology to additional fuel assembly analyses until results within this thesis can be confirmed with those from relevant experimental work.

7.2 Future Work

Suggestions for future work stemming from this thesis are:

1. To perform thermal-hydraulic analysis of future proposed AMOX fuel assembly designs using the new thermal-hydraulic methodology

2. To investigate the applicability of the new thermal-hydraulic methodology to inert matrix fuel assembly designs
3. To integrate a new thermal conductivity model for UO_2 and $(U,Pu)O_2$ being developed by Williford and Beyer [55] at Pacific Northwest National Laboratory for actinide additions up to 10%

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APPENDIX A

VIPRE INPUT CALCULATION NOTEBOOK

The following is a comprehensive calculation notebook describing the input deck presented in Appendix B. Unless otherwise noted, design specifications are based on reference [34] and the models discussed in Section 5. If the value for a card or record is not written, the default value is assumed. Some default values are utilized when the input parameters are irrelevant. The 9 input `GROUPS` used in the input decks are:

VIPRE Title and number of cases to be executed

GEOM Geometrical description of fluid subchannels

RODS Description of rod types, fuel material properties, and power profiles

PROP Contains options governing fluid properties

DRAG Governs lateral and axial friction factors

GRID Contains options for modeling axial pressure losses due to grid-spacers and other structural obstructions

CORR Contains options for two-phase flow, CHF, heat transfer, and void / quality correlations

OPER Core boundary conditions and implementation method

CONT Governs numerical solution method and convergence criteria

Unless otherwise noted, all dimensions and property input values are expressed in VIPRE's default English Engineering units.

A.1 VIPRE

CARD	*RECORD*	*VALUE*	*BASIS*
VIPRE.1	KASE	1	case number
	IRSTRT	0	0 indicates a new start, not a restart or continuation from a previous calculation
	IRSTEP	0	0 if IRSTRT is 0
	NUNITS	-1	input units are English Engineering units and output is SI units
	ISUPP	0	default value for input reflection, channel exit summary, and bundle summary output options
VIPRE.2	TEXT	see *BASIS*	case title: 1/8 PWR Core Hot Bundle Analysis (uox1 - 02/14/09)

A.2 GEOM

The two subchannel geometries encountered in these calculations are triangular and square channels. Triangular geometries occur when using core or assembly symmetry to reduce the computational cost of the analysis and a standard square channel is divided in half. Subchannels are defined by a flow area, heated perimeter, wetted perimeter, and gap connections. A gap is an imaginary plane existing between two adjacent subchannels that is perpendicular to the direction of cross-flow. The gap width is defined as the distance between the surfaces of rods through which cross-flow between two channels occurs. The centroid distance between subchannels is automatically calculated by VIPRE using the gap-to-length ratio on card `GEOM.2` if 0 is entered for record DIST on card `GEOM.4`. Figure A.1 shows the two subchannel geometries.

For the square subchannel geometry, the flow area, wetted perimeter, and heated perimeter are calculated using the following equations:

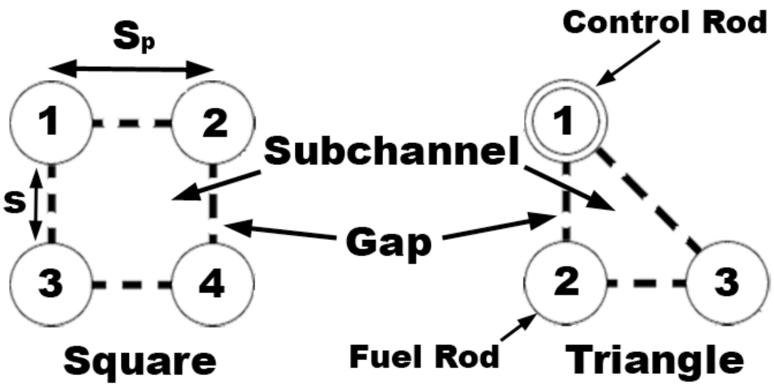

Figure A.1. Subchannel geometry type

$$A_{\text{sq}} = {S_p}^2 - \frac{\pi}{4}\left(\frac{{d_1}^2}{4} + \frac{{d_2}^2}{4} + \frac{{d_3}^2}{4} + \frac{{d_4}^2}{4}\right) \tag{A.1}$$

$$WP_{\text{sq}} = \frac{\pi}{4}\left(d_1 + d_2 + d_3 + d_4\right) \tag{A.2}$$

$$HP_{\text{sq}} = WP_{\text{sq}} - \sum_{CR_4} \frac{\pi}{4} d_i \tag{A.3}$$

where the summation is for all control rods with a quarter of their perimeter facing the square channel.

For the triangle subchannel geometry, the flow area, wetted perimeter, and heated perimeter are calculated using the following equations:

$$A_{\text{tr}} = \frac{{S_p}^2}{2} - \frac{\pi}{8}\left(\frac{{d_1}^2}{4} + \frac{{d_3}^2}{4}\right) - \frac{\pi}{4}\left(\frac{{d_2}^2}{4}\right) \tag{A.4}$$

$$WP_{\text{tr}} = \frac{\pi}{8}\left(d_1 + d_3\right) + \frac{\pi}{4}\left(d_2\right) \tag{A.5}$$

$$HP_{\text{tr}} = WP_{\text{tr}} - \sum_{CR_8} \frac{\pi}{8} d_i - \sum_{CR_4} \frac{\pi}{4} d_i \tag{A.6}$$

where CR_8 and CR_4 represent those control rods with $1/8^{\text{th}}$ and $1/4^{\text{th}}$ of their surface area connected to channel i, respectively.

For a fuel assembly with pitch P_{As} and 264 fuel rods with diameter d_{fr}, 24 control rods with diameter d_{cr}, and 1 instrument tube with diameter d_{it}, the total assembly flow area, wetted perimeter, and heated perimeter are calculated using the following equations:

$$A_{\text{As}} = {P_{As}}^2 - 264\left(\frac{\pi {d_{fr}}^2}{4}\right) - 24\left(\frac{\pi {d_{cr}}^2}{4}\right) - \frac{\pi {d_{it}}^2}{4} \tag{A.7}$$

$$WP_{\text{As}} = 264\pi d_{fr} + 25\pi d_{cr} + \pi d_{it} \tag{A.8}$$

$$HP_{\text{As}} = 264\pi d_{fr} \tag{A.9}$$

There are two types of gaps within the assembly designs discussed in this thesis. The first occurs between two fuel rods with diameter d_{fr}, and the width can be calculated using the following equation:

$$s_{fr} = S_p - \frac{d_{fr}}{2} - \frac{d_{fr}}{2} = S_p - d_{fr} \tag{A.10}$$

The second gap type occurs between a fuel rod with diameter d_{fr} and a control rod with diameter d_{cr}, and the width can be calculated using the following equation:

$$s_{cr} = S_p - \frac{d_{fr}}{2} - \frac{d_{cr}}{2} \tag{A.11}$$

The gap width connecting two whole 17 × 17 assemblies is given by

$$s_{As} = P_{As} - 17 d_{fr} \tag{A.12}$$

Using data from Table 5.1 for the UO_2 reference core, the following flow area, wetted perimeter, heated perimeter, and gap distance values are calculated for several subchannels and an assembly. The fuel pin dimensions are converted to English Engineering units with 3 significant digits after the decimal point, in accordance with standard manufacturing tolerances (e.g. 9.5mm = 0.374 inches):

	Flow area ($in.^2$)	Wetted perimeter (in.)	Heated perimeter (in.)	Gap width (in.)
Square subchannel with 4 fuel rods	0.1362	1.1750	1.1750	0.1220
Square subchannel with 3 fuel rods and 1 control rod	0.1180	1.2598	0.8812	0.0680
Triangle subchannel with 3 fuel rods	0.0681	0.5875	0.5875	0.1220
Triangle subchannel with 2 fuel rods and 1 control rod with 1/8th of its perimeter facing the channel	0.0590	0.6299	0.4406	0.0680
17 × 17 Fuel Assembly	38.11	348.04	310.19	2.108

A.2.1 Steady-State Scoping Analysis

The following is a list of the `GEOM` group input for the steady-state scoping analysis.

CARD	*RECORD*	*VALUE*	*BASIS*
GEOM.1	INFLAG	geom	group identification flag
	NCHANL	45	total number of channel, see Figure 5.1
	NCARD	45	number of channels for which data will be entered, equal to NCHANL
	NDX	31	number of axial nodes
	NAZONE	0	0 for uniform axial node height
	NCTYP	0	default value, 0 for normal geometry input
	MBWR	0	default value, 0 if optional BWR core geometry input is not required
GEOM.2	ZZ	152	fuel assembly height, from [34]
	THETA	0	fuel assembly relative vertical orientation
	SL	0.5	default value; gap-to-length ratio

In the steady-state scoping analysis, channels 37 and 38 from Figure 5.2 contain flow area from the hot assembly and the adjacent assembly, as shown in Figure A.2. The additional flow area occupied by channels 37 and 38 can be approximated by adding 2 and 2.5 standard square subchannel flow areas, respectively, to the lumped channels 37 and 38. Therefore, the number of fuel assemblies modeled by lumped channels 37 through 45 in Figure 5.2 are listed in Table A.1.

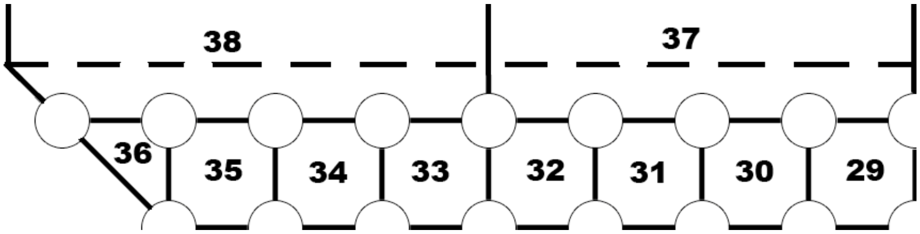

Figure A.2. Channels 37 and 38 hot assembly connection

Table A.1
Number of fuel assemblies modeled by lumped channels

Channel	Number of assemblies
37	0.1326
38	0.1330
39	0.2500
40	0.5000
41	0.5000
42	1.0000
43	0.5000
44	7.0000
45	14.0000

The area of each subchannel is dependent on the number and type of rods connected to it. The gap width between two adjacent channels is also dependent on what type of rods lie between the two channels. For the steady-state scoping analysis, 54 rods are modeled in VIPRE: 45 are modeled as individual rods, while the remaining 9 model lumped rods which represent the number of fuel assemblies associated with the channel the rod is connected to. Table A.2 shows how many fuel assemblies are modeled by lumped rods 46 through 54. Table A.4 lists the rod type and associated diameter for each rod modeled in VIPRE. Rod diameters are taken from Table 5.1. Figure A.3 shows channel connections for each rod in the hot assembly, and Tables A.5 and A.6 list rod channel connections and and the fraction of rod surface area connected to those channels, where the subchannels *i, j, k*, and *h* are shown in Figure A.4. A single rod can a have a maximum of four channel connections in a square lattice. However, some rods in Figures A.3 and 3.16 have fewer than four rod connections, and a '-' in the *j, k* and *h* columns of Tables A.5 and A.6 denote such rods. Surface area fractions larger than 1 for the lumped rods represent the equivalent number of actual fuel rods connected to an adjoining channel. For example, lumped fuel rod 54 from Table A.2 models 14 equivalent fuel assemblies, and each fuel assembly contains 264 fuel rods. Therefore, lumped rod 54 models 3696 rods, and the fractional surface area connected to channel 45 is 3696.

Using the data from Tables A.1, A.2, A.4, A.5, and A.6, the hot assembly and core subchannel nodalizations in Figures A.3 and 5.2, and Equations A.1 through A.12 the flow area, wetted perimeter, heated perimeter, channel connections, and gap widths are calculated for each channel. The flow area, wetted perimeter, heated perimeter, and number of channel connections for each channel are listed in Table A.7. The flow area, wetted perimeter, and heated perimeter for lumped channels are determined by multiplying the flow area of a standard fuel assembly by the number of fuel assemblies each lumped channel models form Table A.1. Gap connections and gap widths are detailed in Table A.8. The gap width for lumped channels is calculated by multiplying the standard assembly-to-assembly gap width (2.108 in.) by the number of adjacent

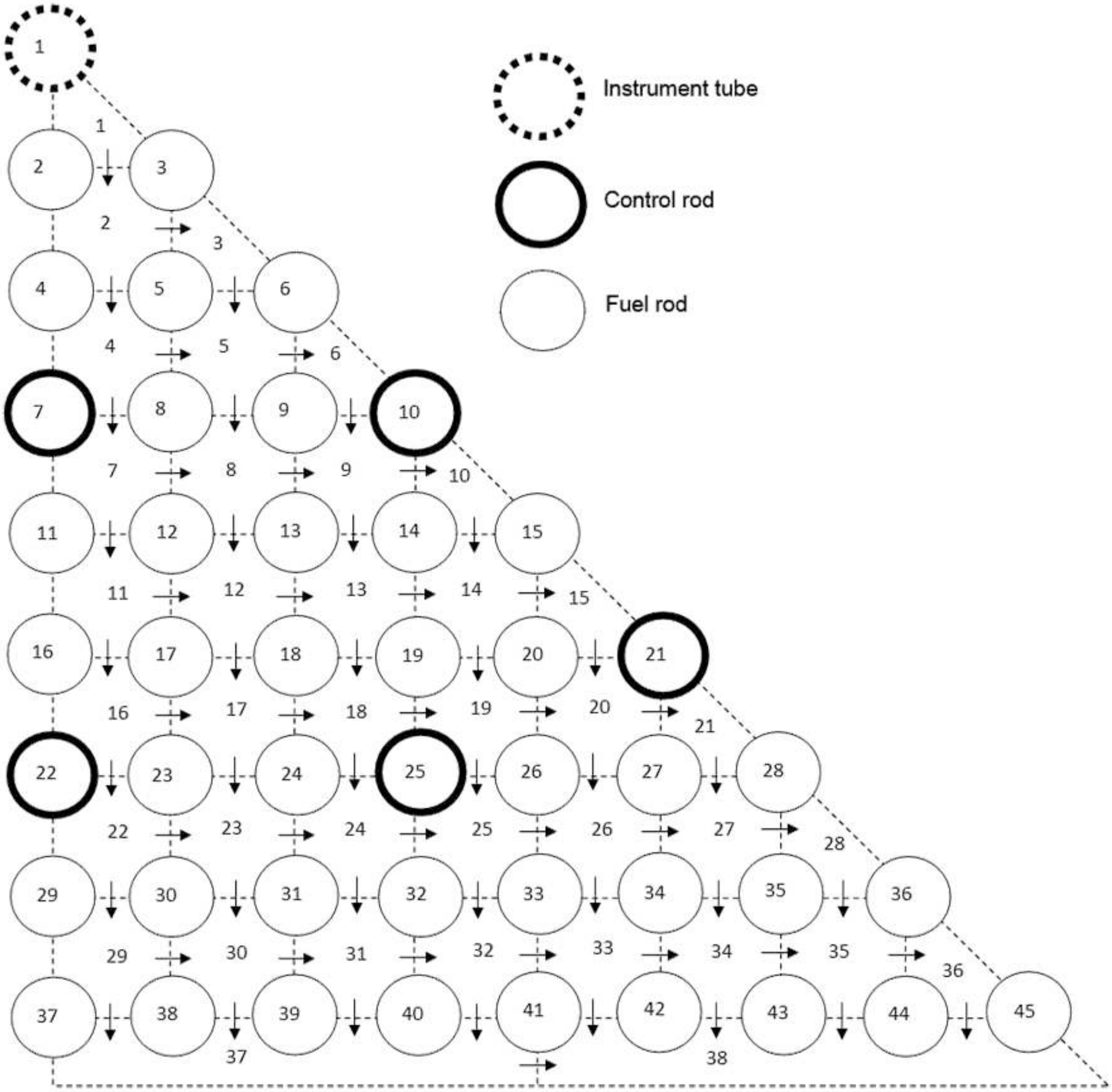

Figure A.3. Fuel rod and gap channel connections

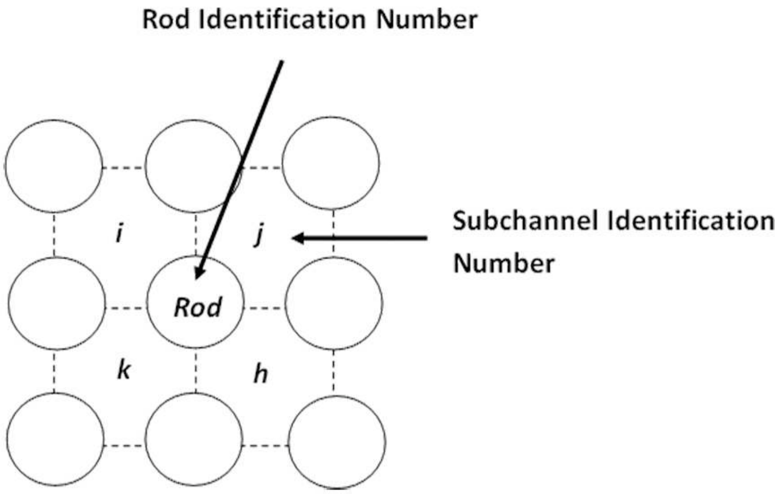

Figure A.4. Single rod channel connections

Table A.2
Number of fuel assemblies modeled by lumped rods

Rod	Number of assemblies
46	0.1326
47	0.1330
48	0.2500
49	0.5000
50	0.5000
51	1.0000
52	0.5000
53	7.0000
54	14.0000

assemblies in contact with a selected lumped channel. For example, 4.5 assemblies from channel 45 in Figure 5.2 are in contact with channel 44. Therefore, the gap width between channels 44 and 45 is .5 times the standard assembly-to-assembly gap width, or 9.486 inches. Data from Tables A.7 and A.8 are used to create the sub-channel geometry description for VIPRE on card `GEOM.4`. Card `GEOM.4` is repeated 45 times in order to supply VIPRE with all the necessary geometry information, once for each channel.

CARD	*RECORD*	*VALUE*	*BASIS*
GEOM.4	I	1	channel identification number from Figure 5.1
	AC	0.0590	channel flow area from Table A.7
	PW	0.6299	channel wetted perimeter from Table A.7
	PH	0.4406	channel heated perimeter from Table A.7
	N	1	number of gaps connected to channel i from Table A.7
	LC	2	identification number of channel connected to channel i, from Figure 5.1 and Table A.8
	GAPS	0.1220	gap width from channel i to adjacent channel, from Table A.8
	DIST	0	when 0 is entered the centroid distance is calculated by VIPRE using gap-to-length ratio in *RECORD* SL on *CARD* GEOM.2
	I	2	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	3	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	4	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	3	“ ”
	AC	0.0681	“ ”
	PW	0.5875	“ ”
	PH	0.5875	“ ”
	N	1	“ ”
	LC	5	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	4	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	5	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	7	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	I	5	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	6	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	8	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	6	“ ”
	AC	0.0590	“ ”
	PW	0.6299	“ ”
	PH	0.4406	“ ”
	N	1	“ ”
	LC	9	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	I	7	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	8	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	11	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	8	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	PH	1.1750	“ ”
	N	2	“ ”
	LC	9	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	12	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	9	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	10	“ ”
	GAPS	0.068	“ ”
	DIST	0	“ ”
	LC	13	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”
	I	10	“ ”
	AC	0.0590	“ ”
	PW	0.6299	“ ”
	PH	0.4406	“ ”
	N	1	“ ”
	LC	14	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	I	11	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	12	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”
	LC	16	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”
	I	12	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	13	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”
	LC	17	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”
	I	13	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	LC	14	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”
	LC	18	“ ”
	GAPS	0.122	“ ”
	DIST	0	“ ”
	I	14	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	15	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	19	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	15	“ ”
	AC	0.0590	“ ”
	PW	0.6299	“ ”
	PH	0.4406	“ ”
	N	1	“ ”
	LC	20	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	I	16	“ ”
	AC	0.1180	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	17	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	22	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	I	17	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	18	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	23	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	18	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	19	“ ”
	GAPS	0.0680	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	DIST	0	“ ”
	LC	24	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	I	19	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	20	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	25	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	I	20	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	21	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	LC	26	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	21	“ ”

Continued on next page...

CARD	*RECORD*	*VALUE*	*BASIS*
	AC	0.0590	“ ”
	PW	0.6299	“ ”
	PH	0.4406	“ ”
	N	1	“ ”
	LC	27	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	22	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	23	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	29	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	23	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	24	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	30	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	24	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	25	“ ”
	GAPS	0.0680	“ ”
	DIST	0	“ ”
	LC	31	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	25	“ ”
	AC	0.1180	“ ”
	PW	1.2598	“ ”
	PH	0.8812	“ ”
	N	2	“ ”
	LC	26	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	32	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	26	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	PH	1.1750	“ ”
	N	2	“ ”
	LC	27	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	33	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	27	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	28	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	34	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	28	“ ”
	AC	0.0681	“ ”
	PW	0.5875	“ ”
	PH	0.5875	“ ”
	N	1	“ ”
	LC	35	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	I	29	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	30	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	37	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	30	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	31	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	37	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	31	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	LC	32	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	37	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	32	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	33	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	37	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	33	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	34	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	38	“ ”
	GAPS	0.1220	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	DIST	0	“ ”
	I	34	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	35	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	38	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	35	“ ”
	AC	0.1362	“ ”
	PW	1.1750	“ ”
	PH	1.1750	“ ”
	N	2	“ ”
	LC	36	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	LC	38	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	36	“ ”
	AC	0.0681	“ ”
	PW	0.5875	“ ”
	PH	0.5875	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	N	1	“ ”
	LC	38	“ ”
	GAPS	0.1220	“ ”
	DIST	0	“ ”
	I	37	“ ”
	AC	5.3584	“ ”
	PW	48.4922	“ ”
	PH	43.4734	“ ”
	N	2	“ ”
	LC	38	“ ”
	GAPS	1.0540	“ ”
	DIST	0	“ ”
	LC	39	“ ”
	GAPS	0.4880	“ ”
	DIST	3.9680	“ ”
	I	38	“ ”
	AC	5.3764	“ ”
	PW	48.657	“ ”
	PH	43.620	“ ”
	N	2	“ ”
	LC	39	“ ”
	GAPS	0.5660	“ ”
	DIST	0	“ ”
	LC	40	“ ”
	GAPS	1.0540	“ ”
	DIST	0	“ ”
	I	39	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	AC	9.8333	" "
	PW	87.011	" "
	PH	77.547	" "
	N	2	" "
	LC	40	" "
	GAPS	1.0540	" "
	DIST	0	" "
	LC	41	" "
	GAPS	1.0540	" "
	DIST	0	" "
	I	40	" "
	AC	19.360	" "
	PW	174.02	" "
	PH	155.09	" "
	N	1	" "
	LC	42	" "
	GAPS	2.1080	" "
	DIST	0	" "
	I	41	" "
	AC	19.360	" "
	PW	174.02	" "
	PH	155.09	" "
	N	2	" "
	LC	42	" "
	GAPS	2.1080	" "
	DIST	0	" "
	LC	44	" "

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	GAPS	1.0540	“ ”
	DIST	12.434	“ ”
	I	42	“ ”
	AC	38.415	“ ”
	PW	348.04	“ ”
	PH	310.19	“ ”
	N	2	“ ”
	LC	43	“ ”
	GAPS	2.1080	“ ”
	DIST	0	“ ”
	LC	44	“ ”
	GAPS	2.1080	“ ”
	DIST	12.434	“ ”
	I	43	“ ”
	AC	19.360	“ ”
	PW	174.02	“ ”
	PH	155.09	“ ”
	N	1	“ ”
	LC	44	“ ”
	GAPS	2.1080	“ ”
	DIST	0	“ ”
	I	44	“ ”
	AC	267.07	“ ”
	PW	2436.3	“ ”
	PH	2171.3	“ ”
	N	1	“ ”
	LC	45	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	GAPS	9.4860	“ ”
	DIST	0	“ ”
	I	45	“ ”
	AC	533.52	“ ”
	PW	4872.6	“ ”
	PH	4342.6	“ ”

Table A.4: VIPRE Rod type

Rod	Rod type	Rod diameter (in.)
1	Instrument	0.482
2	Fuel	0.374
3	Fuel	0.374
4	Fuel	0.374
5	Fuel	0.374
6	Fuel	0.374
7	Control	0.482
8	Fuel	0.374
9	Fuel	0.374
10	Control	0.482
11	Fuel	0.374
12	Fuel	0.374
13	Fuel	0.374
14	Fuel	0.374
15	Fuel	0.374
16	Fuel	0.374
17	Fuel	0.374
18	Fuel	0.374
19	Fuel	0.374
20	Fuel	0.374
21	Control	0.482
22	Control	0.482
23	Fuel	0.374
24	Fuel	0.374

Continued on next page. . .

Rod	Rod type	Rod diameter (in.)
25	Control	0.482
26	Fuel	0.374
27	Fuel	0.374
28	Fuel	0.374
29	Fuel	0.374
30	Fuel	0.374
31	Fuel	0.374
32	Fuel	0.374
33	Fuel	0.374
34	Fuel	0.374
35	Fuel	0.374
36	Fuel	0.374
37	Fuel	0.374
38	Fuel	0.374
39	Fuel	0.374
40	Fuel	0.374
41	Fuel	0.374
42	Fuel	0.374
43	Fuel	0.374
44	Fuel	0.374
45	Fuel	0.374
46	Fuel	Lumped
47	Fuel	Lumped
48	Fuel	Lumped
49	Fuel	Lumped
50	Fuel	Lumped

Continued on next page…

Rod	Rod type	Rod diameter (in.)
51	Fuel	Lumped
52	Fuel	Lumped
53	Fuel	Lumped
54	Fuel	Lumped

Table A.5: Fuel rod connections

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
1	1	0.125	—	—	—	—
2	1	0.25	2	0.25	—	—
3	1	0.125	2	0.25	3	0.125
4	2	0.25	4	0.25	—	—
5	2	0.25	3	0.25	4	0.25
6	3	0.125	5	0.25	6	0.125
7	4	0.25	7	0.25	—	—
8	4	0.25	5	0.25	7	0.25
9	5	0.25	6	0.25	8	0.25
10	6	0.125	9	0.25	10	0.125
11	7	0.25	11	0.25	—	—
12	7	0.25	8	0.25	11	0.25
13	8	0.25	9	0.25	12	0.25
14	9	0.25	10	0.25	13	0.25
15	10	0.125	14	0.25	15	0.125
16	11	0.25	16	0.25	—	—
17	11	0.25	12	0.25	16	0.25
18	12	0.25	13	0.25	17	0.25
19	13	0.25	14	0.25	18	0.25
20	14	0.25	15	0.25	19	0.25
21	15	0.125	20	0.25	21	0.125

Continued on next page. . .

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
22	16	0.25	22	0.25	—	—
23	16	0.25	17	0.25	22	0.25
24	17	0.25	18	0.25	23	0.25
25	18	0.25	19	0.25	24	0.25
26	19	0.25	20	0.25	25	0.25
27	20	0.25	21	0.25	26	0.25
28	21	0.125	27	0.25	28	0.125
29	22	0.25	29	0.25	—	—
30	22	0.25	23	0.25	29	0.25
31	23	0.25	24	0.25	30	0.25
32	24	0.25	25	0.25	31	0.25
33	25	0.25	26	0.25	32	0.25
34	26	0.25	27	0.25	33	0.25
35	27	0.25	28	0.25	34	0.25
36	28	0.125	35	0.25	36	0.125
37	29	0.25	37	0.25	—	—
38	29	0.25	30	0.25	37	0.5
39	30	0.25	31	0.25	37	0.5
40	31	0.25	32	0.25	37	0.5
41	32	0.25	33	0.25	37	0.25
42	33	0.25	34	0.25	38	0.5
43	34	0.25	35	0.25	38	0.5
44	35	0.25	36	0.25	38	0.5

Continued on next page. . .

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
45	36	0.125	38	0.375	—	—
46	37	35	—	—	—	—
47	38	35.125	—	—	—	—
48	39	66	—	—	—	—
49	40	132	—	—	—	—
50	41	132	—	—	—	—
51	42	264	—	—	—	—
52	43	132	—	—	—	—
53	44	1848	—	—	—	—
54	45	3696	—	—	—	—

Table A.6: Additional fuel rod connections

Rod	Channel h	Fraction of rod facing channel h
5	5	0.25
8	8	0.25
9	9	0.25
12	12	0.25
13	13	0.25
14	14	0.25
17	17	0.25
18	18	0.25
19	19	0.25
20	20	0.25
23	23	0.25
24	24	0.25
25	25	0.25
26	26	0.25
27	27	0.25
30	30	0.25
31	31	0.25
32	32	0.25
33	33	0.25
34	34	0.25
35	35	0.25

Continued on next page...

Rod	Channel h	Fraction of rod facing channel h
41	38	0.25

Table A.7: Subchannel data

Channel	Area ($in.^2$)	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
1	0.0590	0.6299	0.4406	1
2	0.1362	1.1750	1.1750	2
3	0.0681	0.5875	0.5875	1
4	0.1180	1.2598	0.8812	2
5	0.1362	1.1750	1.1750	2
6	0.0590	0.6299	0.4406	1
7	0.1180	1.2598	0.8812	2
8	0.1362	1.1750	1.1750	2
9	0.1180	1.2598	0.8812	2
10	0.0590	0.6299	0.4406	1
11	0.1362	1.1750	1.1750	2
12	0.1362	1.1750	1.1750	2
13	0.1362	1.1750	1.1750	2
14	0.1362	1.1750	1.1750	2
15	0.0590	0.6299	0.4406	1
16	0.1180	1.2598	0.8812	2
17	0.1362	1.1750	1.1750	2
18	0.1180	1.2598	0.8812	2
19	0.1180	1.2598	0.8812	2
20	0.1180	1.2598	0.8812	2
21	0.0590	0.6299	0.4406	1
22	0.1180	1.2598	0.8812	2
23	0.1362	1.1750	1.1750	2

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Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
24	0.1180	1.2598	0.8812	2
25	0.1180	1.2598	0.8812	2
26	0.1362	1.1750	1.1750	2
27	0.1362	1.1750	1.1750	2
28	0.0681	0.5875	0.5875	1
29	0.1362	1.1750	1.1750	2
30	0.1362	1.1750	1.1750	2
31	0.1362	1.1750	1.1750	2
32	0.1362	1.1750	1.1750	2
33	0.1362	1.1750	1.1750	2
34	0.1362	1.1750	1.1750	2
35	0.1362	1.1750	1.1750	2
36	0.0681	0.5875	0.5875	1
37	5.3584	48.4922	43.4734	2
38	5.3764	48.6570	43.6202	2
39	9.8333	87.0111	77.5471	2
40	19.3605	174.0222	155.0941	1
41	19.3605	174.0222	155.0941	2
42	38.4149	348.0445	310.1883	2
43	19.3605	174.0222	155.0941	1
44	267.0682	2436.3114	2171.3180	1
45	533.5243	4872.6228	4342.6361	—

Table A.8: Subchannel connections

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
1	2	0.122	0	—	—	—
2	3	0.122	0	4	0.122	0
3	5	0.122	0	—	—	—
4	5	0.122	0	7	0.068	0
5	6	0.122	0	8	0.122	0
6	9	0.068	0	—	—	—
7	8	0.122	0	11	0.122	0
8	9	0.122	0	12	0.122	0
9	10	0.068	0	13	0.122	0
10	14	0.122	0	—	—	—
11	12	0.122	0	16	0.122	0
12	13	0.122	0	17	0.122	0
13	14	0.122	0	18	0.122	0
14	15	0.122	0	19	0.122	0
15	20	0.068	0	—	—	—
16	17	0.122	0	22	0.068	0
17	18	0.122	0	23	0.122	0
18	19	0.068	0	24	0.068	0
19	20	0.122	0	25	0.068	0
20	21	0.068	0	26	0.122	0
21	27	0.122	0	—	—	—
22	23	0.122	0	29	0.122	0

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	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
23	24	0.122	0	30	0.122	0
24	25	0.068	0	31	0.122	0
25	26	0.122	0	32	0.122	0
26	27	0.122	0	33	0.122	0
27	28	0.122	0	34	0.122	0
28	35	0.122	0	—	—	—
29	30	0.122	0	37	0.122	0
30	31	0.122	0	37	0.122	0
31	32	0.122	0	37	0.122	0
32	33	0.122	0	37	0.122	0
33	34	0.122	0	38	0.122	0
34	35	0.122	0	38	0.122	0
35	36	0.122	0	38	0.122	0
36	38	0.122	0	—	—	—
37	38	1.054	0	39	0.488	0
38	39	0.566	0	40	1.054	0
39	40	1.054	0	41	1.054	0
40	42	2.108	0	—	—	—
41	42	2.108	0	44	1.054	0
42	43	2.108	0	44	2.108	0
43	44	2.108	0	—	—	—
44	45	9.486	0	—	—	—
45	—	—	—	—	—	—

A.2.2 Transient Analysis

For transient analysis, the subchannel nodalization is taken from Figure 5.3 and 292 channels and 325 rods are modeled. Therefore, the input for cards `GEOM.1` and `GEOM.4` are different than those from the steady-state scoping analysis. Fuel rod type and channel connection information for transient analyses are listed in Tables A.10, A.11, and A.12. The number of fuel assemblies model by lumped channels and rods for transient analyses are taken from Figure 5.3 and listed in Table A.9. Using the new rod and channel information for transient analyses, and Equations A.1 through A.12, the flow area, wetted perimeter, heated perimeter, channel connection, and gap width for each channel are listed in Tables A.13 and A.14. The data in these tables is used in the same manner for the transient analysis input deck formulation for card `GEOM.4` as in the steady-state scoping analysis. This table has been left out due to length restrictions.

CARD	*RECORD*	*VALUE*	*BASIS*
GEOM.1	INFLAG	geom	group identification flag
	NCHANL	292	total number of channel, see Figure 5.1
	NCARD	292	number of channels for which data will be entered, equal to NCHANL
	NDX	31	number of axial nodes
	NAZONE	0	0 for uniform axial nodal height
	NCTYP	0	default value, 0 for normal geometry input
	MBWR	0	default value, 0 if optional BWR core geometry input is not required

Table A.9: Number of fuel assemblies modeled by lumped channels and rods for transient analysis

Channel	Number of assemblies	Rod	Number of assemblies
1	3.125	1	3.125
2	1.000	2	1.000
3	1.000	3	1.000
4	1.000	4	1.000
5	0.500	5	0.500
6	1.000	6	1.000
7	1.000	7	1.000
8	1.000	8	1.000
9	0.500	9	0.500
10	0.500	10	0.500
11	1.000	11	1.000
12	1.000	12	1.000
13	0.250	13	0.250
14	0.250	14	0.250
15	0.250	15	0.250
16	0.250	16	0.250
17	1.000	17	1.000
18	0.500	18	0.500
19	0.500	19	0.500
20	1.000	20	1.000
21	0.250	21	0.250
22	0.250	22	0.250

Continued on next page. . .

Channel	Number of assemblies	Rod	Number of assemblies
23	0.250	23	0.250
24	0.250	24	0.250
281	0.250	314	0.250
282	0.250	315	0.250
283	0.250	316	0.250
284	0.250	317	0.250
285	1.000	318	1.000
286	0.500	319	0.500
287	1.000	320	1.000
288	1.000	321	1.000
289	0.250	322	0.250
290	0.250	323	0.250
291	0.250	324	0.250
292	0.250	325	0.250

Table A.10: VIPRE Rod type for transient analysis

Rod	Rod type	Rod diameter (in.)	Rod	Rod type	Rod diameter (in.)
1	Fuel	Lumped	25	Fuel	0.374
2	Fuel	Lumped	26	Fuel	0.374
3	Fuel	Lumped	27	Fuel	0.374
4	Fuel	Lumped	28	Fuel	0.374
5	Fuel	Lumped	29	Fuel	0.374
6	Fuel	Lumped	30	Fuel	0.374
7	Fuel	Lumped	31	Fuel	0.374
8	Fuel	Lumped	32	Fuel	0.374
9	Fuel	Lumped	33	Fuel	0.374
10	Fuel	Lumped	34	Fuel	0.374
11	Fuel	Lumped	35	Fuel	0.374
12	Fuel	Lumped	36	Fuel	0.374
13	Fuel	Lumped	37	Fuel	0.374
14	Fuel	Lumped	38	Fuel	0.374
15	Fuel	Lumped	39	Fuel	0.374
16	Fuel	Lumped	40	Fuel	0.374
17	Fuel	Lumped	41	Fuel	0.374
18	Fuel	Lumped	42	Fuel	0.374
19	Fuel	Lumped	43	Fuel	0.374
20	Fuel	Lumped	44	Fuel	0.374
21	Fuel	Lumped	45	Fuel	0.374
22	Fuel	Lumped	46	Fuel	0.374
23	Fuel	Lumped	47	Fuel	0.374
24	Fuel	Lumped	48	Fuel	0.374

Continued on next page…

Rod	Rod type	Rod diameter (in.)	Rod	Rod type	Rod diameter (in.)
49	Fuel	0.374	75	Fuel	0.374
50	Fuel	0.374	76	Fuel	0.374
51	Fuel	0.374	77	Fuel	0.374
52	Fuel	0.374	78	Fuel	0.374
53	Fuel	0.374	79	Control	0.482
54	Fuel	0.374	80	Fuel	0.374
55	Fuel	0.374	81	Fuel	0.374
56	Fuel	0.374	82	Fuel	0.374
57	Fuel	0.374	83	Fuel	0.374
58	Fuel	0.374	84	Fuel	0.374
59	Fuel	0.374	85	Fuel	0.374
60	Fuel	0.374	86	Fuel	0.374
61	Fuel	0.374	87	Fuel	0.374
62	Fuel	0.374	88	Fuel	0.374
63	Fuel	0.374	89	Control	0.482
64	Control	0.482	90	Fuel	0.374
65	Fuel	0.374	91	Fuel	0.374
66	Fuel	0.374	92	Fuel	0.374
67	Control	0.482	93	Fuel	0.374
68	Fuel	0.374	94	Fuel	0.374
69	Fuel	0.374	95	Fuel	0.374
70	Control	0.482	96	Fuel	0.374
71	Fuel	0.374	97	Fuel	0.374
72	Fuel	0.374	98	Fuel	0.374
73	Fuel	0.374	99	Fuel	0.374
74	Fuel	0.374	100	Fuel	0.374

Continued on next page. . .

Rod	Rod type	Rod diameter (in.)	Rod	Rod type	Rod diameter (in.)
101	Fuel	0.374	127	Fuel	0.374
102	Fuel	0.374	128	Fuel	0.374
103	Fuel	0.374	129	Fuel	0.374
104	Fuel	0.374	130	Fuel	0.374
105	Fuel	0.374	131	Fuel	0.374
106	Fuel	0.374	132	Fuel	0.374
107	Fuel	0.374	133	Fuel	0.374
108	Fuel	0.374	134	Fuel	0.374
109	Fuel	0.374	135	Fuel	0.374
110	Fuel	0.374	136	Fuel	0.374
111	Fuel	0.374	137	Fuel	0.374
112	Control	0.482	138	Fuel	0.374
113	Fuel	0.374	139	Fuel	0.374
114	Fuel	0.374	140	Fuel	0.374
115	Control	0.482	141	Fuel	0.374
116	Fuel	0.374	142	Fuel	0.374
117	Fuel	0.374	143	Fuel	0.374
118	Control	0.482	144	Fuel	0.374
119	Fuel	0.374	145	Fuel	0.374
120	Fuel	0.374	146	Fuel	0.374
121	Control	0.482	147	Fuel	0.374
122	Fuel	0.374	148	Fuel	0.374
123	Fuel	0.374	149	Fuel	0.374
124	Control	0.482	150	Fuel	0.374
125	Fuel	0.374	151	Fuel	0.374
126	Fuel	0.374	152	Fuel	0.374

Continued on next page. . .

Rod	Rod type	Rod diameter (in.)	Rod	Rod type	Rod diameter (in.)
153	Fuel	0.374	179	Fuel	0.374
154	Fuel	0.374	180	Fuel	0.374
155	Fuel	0.374	181	Fuel	0.374
156	Fuel	0.374	182	Fuel	0.374
157	Fuel	0.374	183	Fuel	0.374
158	Fuel	0.374	184	Fuel	0.374
159	Fuel	0.374	185	Fuel	0.374
160	Fuel	0.374	186	Fuel	0.374
161	Fuel	0.374	187	Fuel	0.374
162	Fuel	0.374	188	Fuel	0.374
163	Control	0.482	189	Fuel	0.374
164	Fuel	0.374	190	Fuel	0.374
165	Fuel	0.374	191	Fuel	0.374
166	Control	0.482	192	Fuel	0.374
167	Fuel	0.374	193	Fuel	0.374
168	Fuel	0.374	194	Fuel	0.374
169	Instrument	0.482	195	Fuel	0.374
170	Fuel	0.374	196	Fuel	0.374
171	Fuel	0.374	197	Fuel	0.374
172	Control	0.482	198	Fuel	0.374
173	Fuel	0.374	199	Fuel	0.374
174	Fuel	0.374	200	Fuel	0.374
175	Control	0.482	201	Fuel	0.374
176	Fuel	0.374	202	Fuel	0.374
177	Fuel	0.374	203	Fuel	0.374
178	Fuel	0.374	204	Fuel	0.374

Continued on next page. . .

Rod	Rod type	Rod diameter (in.)	Rod	Rod type	Rod diameter (in.)
205	Fuel	0.374	231	Fuel	0.374
206	Fuel	0.374	232	Fuel	0.374
207	Fuel	0.374	233	Fuel	0.374
208	Fuel	0.374	234	Fuel	0.374
209	Fuel	0.374	235	Fuel	0.374
210	Fuel	0.374	236	Fuel	0.374
211	Fuel	0.374	237	Fuel	0.374
212	Fuel	0.374	238	Fuel	0.374
213	Fuel	0.374	239	Fuel	0.374
214	Control	0.482	240	Fuel	0.374
215	Fuel	0.374	241	Fuel	0.374
216	Fuel	0.374	242	Fuel	0.374
217	Control	0.482	243	Fuel	0.374
218	Fuel	0.374	244	Fuel	0.374
219	Fuel	0.374	245	Fuel	0.374
220	Control	0.482	246	Fuel	0.374
221	Fuel	0.374	247	Fuel	0.374
222	Fuel	0.374	248	Fuel	0.374
223	Control	0.482	249	Control	0.482
224	Fuel	0.374	250	Fuel	0.374
225	Fuel	0.374	251	Fuel	0.374
226	Control	0.482	252	Fuel	0.374
227	Fuel	0.374	253	Fuel	0.374
228	Fuel	0.374	254	Fuel	0.374
229	Fuel	0.374	255	Fuel	0.374
230	Fuel	0.374	256	Fuel	0.374

Continued on next page. . .

Rod	Rod type	Rod diameter (in.)	Rod	Rod type	Rod diameter (in.)
257	Fuel	0.374	283	Fuel	0.374
258	Fuel	0.374	284	Fuel	0.374
259	Control	0.482	285	Fuel	0.374
260	Fuel	0.374	286	Fuel	0.374
261	Fuel	0.374	287	Fuel	0.374
262	Fuel	0.374	288	Fuel	0.374
263	Fuel	0.374	289	Fuel	0.374
264	Fuel	0.374	290	Fuel	0.374
265	Fuel	0.374	291	Fuel	0.374
266	Fuel	0.374	292	Fuel	0.374
267	Fuel	0.374	293	Fuel	0.374
268	Control	0.482	294	Fuel	0.374
269	Fuel	0.374	295	Fuel	0.374
270	Fuel	0.374	296	Fuel	0.374
271	Control	0.482	297	Fuel	0.374
272	Fuel	0.374	298	Fuel	0.374
273	Fuel	0.374	299	Fuel	0.374
274	Control	0.482	300	Fuel	0.374
275	Fuel	0.374	301	Fuel	0.374
276	Fuel	0.374	302	Fuel	0.374
277	Fuel	0.374	303	Fuel	0.374
278	Fuel	0.374	304	Fuel	0.374
279	Fuel	0.374	305	Fuel	0.374
280	Fuel	0.374	306	Fuel	0.374
281	Fuel	0.374	307	Fuel	0.374
282	Fuel	0.374	308	Fuel	0.374

Continued on next page. . .

Rod	Rod type	Rod diameter (in.)	Rod	Rod type	Rod diameter (in.)
309	Fuel	0.374	—	—	—
310	Fuel	0.374	—	—	—
311	Fuel	0.374	—	—	—
312	Fuel	0.374	—	—	—
313	Fuel	0.374	—	—	—
314	Fuel	Lumped	—	—	—
315	Fuel	Lumped	—	—	—
316	Fuel	Lumped	—	—	—
317	Fuel	Lumped	—	—	—
318	Fuel	Lumped	—	—	—
319	Fuel	Lumped	—	—	—
320	Fuel	Lumped	—	—	—
321	Fuel	Lumped	—	—	—
322	Fuel	Lumped	—	—	—
323	Fuel	Lumped	—	—	—
324	Fuel	Lumped	—	—	—
325	Fuel	Lumped	—	—	—

Table A.11: Fuel rod connections for transient analysis

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
1	1	825	—	—	—	—
2	2	528	—	—	—	—
3	3	264	—	—	—	—
4	4	264	—	—	—	—
5	5	132	—	—	—	—
6	6	264	—	—	—	—
7	7	264	—	—	—	—
8	8	264	—	—	—	—
9	9	132	—	—	—	—
10	10	132	—	—	—	—
11	11	264	—	—	—	—
12	12	264	—	—	—	—
13	13	66	—	—	—	—
14	14	66	—	—	—	—
15	15	66	—	—	—	—
16	16	66	—	—	—	—
17	17	264	—	—	—	—
18	18	132	—	—	—	—
19	19	132	—	—	—	—
20	20	264	—	—	—	—
21	21	66	—	—	—	—

Continued on next page...

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
22	22	66	—	—	—	—
23	23	66	—	—	—	—
24	24	66	—	—	—	—
25	13	0.375	21	0.375	25	0.25
26	13	0.5	25	0.25	26	0.25
27	13	0.5	26	0.25	27	0.25
28	13	0.5	27	0.25	28	0.25
29	13	0.25	14	0.25	28	0.25
30	14	0.5	29	0.25	30	0.25
31	14	0.5	30	0.25	31	0.25
32	14	0.5	31	0.25	32	0.25
33	14	0.25	15	0.25	32	0.25
34	15	0.5	33	0.25	34	0.25
35	15	0.5	34	0.25	35	0.25
36	15	0.5	35	0.25	36	0.25
37	15	0.25	16	0.25	36	0.25
38	16	0.5	37	0.25	38	0.25
39	16	0.5	38	0.25	39	0.25
40	16	0.5	39	0.25	40	0.25
41	16	0.375	40	0.25	281	0.375
42	21	0.5	25	0.25	41	0.25
43	25	0.25	26	0.25	41	0.25
44	26	0.25	27	0.25	42	0.25

Continued on next page...

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
45	27	0.25	28	0.25	43	0.25
46	28	0.25	29	0.25	44	0.25
47	29	0.25	30	0.25	45	0.25
48	30	0.25	31	0.25	46	0.25
49	31	0.25	32	0.25	47	0.25
50	32	0.25	33	0.25	48	0.25
51	33	0.25	34	0.25	49	0.25
52	34	0.25	35	0.25	50	0.25
53	35	0.25	36	0.25	51	0.25
54	36	0.25	37	0.25	52	0.25
55	37	0.25	38	0.25	53	0.25
56	38	0.25	39	0.25	54	0.25
57	39	0.25	40	0.25	55	0.25
58	40	0.25	56	0.25	281	0.5
59	21	0.5	41	0.25	57	0.25
60	41	0.25	42	0.25	57	0.25
61	42	0.25	43	0.25	58	0.25
62	43	0.25	44	0.25	59	0.25
63	44	0.25	45	0.25	60	0.25
64	45	0.25	46	0.25	61	0.25
65	46	0.25	47	0.25	62	0.25
66	47	0.25	48	0.25	63	0.25
67	48	0.25	49	0.25	64	0.25

Continued on next page. . .

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
68	49	0.25	50	0.25	65	0.25
69	50	0.25	51	0.25	66	0.25
70	51	0.25	52	0.25	67	0.25
71	52	0.25	53	0.25	68	0.25
72	53	0.25	54	0.25	69	0.25
73	54	0.25	55	0.25	70	0.25
74	55	0.25	56	0.25	71	0.25
75	56	0.25	72	0.25	281	0.5
76	21	0.5	57	0.25	73	0.25
77	57	0.25	58	0.25	73	0.25
78	58	0.25	59	0.25	74	0.25
79	59	0.25	60	0.25	75	0.25
80	60	0.25	61	0.25	76	0.25
81	61	0.25	62	0.25	77	0.25
82	62	0.25	63	0.25	78	0.25
83	63	0.25	64	0.25	79	0.25
84	64	0.25	65	0.25	80	0.25
85	65	0.25	66	0.25	81	0.25
86	66	0.25	67	0.25	82	0.25
87	67	0.25	68	0.25	83	0.25
88	68	0.25	69	0.25	84	0.25
89	69	0.25	70	0.25	85	0.25
90	70	0.25	71	0.25	86	0.25

Continued on next page...

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
91	71	0.25	72	0.25	87	0.25
92	72	0.25	88	0.25	281	0.5
93	21	0.25	22	0.25	73	0.25
94	73	0.25	74	0.25	89	0.25
95	74	0.25	75	0.25	90	0.25
96	75	0.25	76	0.25	91	0.25
97	76	0.25	77	0.25	92	0.25
98	77	0.25	78	0.25	93	0.25
99	78	0.25	79	0.25	94	0.25
100	79	0.25	80	0.25	95	0.25
101	80	0.25	81	0.25	96	0.25
102	81	0.25	82	0.25	97	0.25
103	82	0.25	83	0.25	98	0.25
104	83	0.25	84	0.25	99	0.25
105	84	0.25	85	0.25	100	0.25
106	85	0.25	86	0.25	101	0.25
107	86	0.25	87	0.25	102	0.25
108	87	0.25	88	0.25	103	0.25
109	88	0.25	104	0.25	281	0.25
110	22	0.5	89	0.25	105	0.25
111	89	0.25	90	0.25	105	0.25
112	90	0.25	91	0.25	106	0.25
113	91	0.25	92	0.25	107	0.25

Continued on next page. . .

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
114	92	0.25	93	0.25	108	0.25
115	93	0.25	94	0.25	109	0.25
116	94	0.25	95	0.25	110	0.25
117	95	0.25	96	0.25	111	0.25
118	96	0.25	97	0.25	112	0.25
119	97	0.25	98	0.25	113	0.25
120	98	0.25	99	0.25	114	0.25
121	99	0.25	100	0.25	115	0.25
122	100	0.25	101	0.25	116	0.25
123	101	0.25	102	0.25	117	0.25
124	102	0.25	103	0.25	118	0.25
125	103	0.25	104	0.25	119	0.25
126	104	0.25	120	0.25	282	0.5
127	22	0.5	105	0.25	121	0.25
128	105	0.25	106	0.25	121	0.25
129	106	0.25	107	0.25	122	0.25
130	107	0.25	108	0.25	123	0.25
131	108	0.25	109	0.25	124	0.25
132	109	0.25	110	0.25	125	0.25
133	110	0.25	111	0.25	126	0.25
134	111	0.25	112	0.25	127	0.25
135	112	0.25	113	0.25	128	0.25
136	113	0.25	114	0.25	129	0.25

Continued on next page. . .

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
137	114	0.25	115	0.25	130	0.25
138	115	0.25	116	0.25	131	0.25
139	116	0.25	117	0.25	132	0.25
140	117	0.25	118	0.25	133	0.25
141	118	0.25	119	0.25	134	0.25
142	119	0.25	120	0.25	135	0.25
143	120	0.25	136	0.25	282	0.5
144	22	0.5	121	0.25	137	0.25
145	121	0.25	122	0.25	137	0.25
146	122	0.25	123	0.25	138	0.25
147	123	0.25	124	0.25	139	0.25
148	124	0.25	125	0.25	140	0.25
149	125	0.25	126	0.25	141	0.25
150	126	0.25	127	0.25	142	0.25
151	127	0.25	128	0.25	143	0.25
152	128	0.25	129	0.25	144	0.25
153	129	0.25	130	0.25	145	0.25
154	130	0.25	131	0.25	146	0.25
155	131	0.25	132	0.25	147	0.25
156	132	0.25	133	0.25	148	0.25
157	133	0.25	134	0.25	149	0.25
158	134	0.25	135	0.25	150	0.25
159	135	0.25	136	0.25	151	0.25

Continued on next page...

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
160	136	0.25	152	0.25	282	0.5
161	22	0.25	23	0.25	137	0.25
162	137	0.25	138	0.25	153	0.25
163	138	0.25	139	0.25	154	0.25
164	139	0.25	140	0.25	155	0.25
165	140	0.25	141	0.25	156	0.25
166	141	0.25	142	0.25	157	0.25
167	142	0.25	143	0.25	158	0.25
168	143	0.25	144	0.25	159	0.25
169	144	0.25	145	0.25	160	0.25
170	145	0.25	146	0.25	161	0.25
171	146	0.25	147	0.25	162	0.25
172	147	0.25	148	0.25	163	0.25
173	148	0.25	149	0.25	164	0.25
174	149	0.25	150	0.25	165	0.25
175	150	0.25	151	0.25	166	0.25
176	151	0.25	152	0.25	167	0.25
177	152	0.25	168	0.25	282	0.25
178	23	0.5	153	0.25	169	0.25
179	153	0.25	154	0.25	169	0.25
180	154	0.25	155	0.25	170	0.25
181	155	0.25	156	0.25	171	0.25
182	156	0.25	157	0.25	172	0.25

Continued on next page. . .

Rod	Channel *i*	Fraction of rod facing channel *i*	Channel *j*	Fraction of rod facing channel *j*	Channel *k*	Fraction of rod facing channel *k*
183	157	0.25	158	0.25	173	0.25
184	158	0.25	159	0.25	174	0.25
185	159	0.25	160	0.25	175	0.25
186	160	0.25	161	0.25	176	0.25
187	161	0.25	162	0.25	177	0.25
188	162	0.25	163	0.25	178	0.25
189	163	0.25	164	0.25	179	0.25
190	164	0.25	165	0.25	180	0.25
191	165	0.25	166	0.25	181	0.25
192	166	0.25	167	0.25	182	0.25
193	167	0.25	168	0.25	183	0.25
194	168	0.25	184	0.25	283	0.5
195	23	0.5	169	0.25	185	0.25
196	169	0.25	170	0.25	185	0.25
197	170	0.25	171	0.25	186	0.25
198	171	0.25	172	0.25	187	0.25
199	172	0.25	173	0.25	188	0.25
200	173	0.25	174	0.25	189	0.25
201	174	0.25	175	0.25	190	0.25
202	175	0.25	176	0.25	191	0.25
203	176	0.25	177	0.25	192	0.25
204	177	0.25	178	0.25	193	0.25
205	178	0.25	179	0.25	194	0.25

Continued on next page…

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
206	179	0.25	180	0.25	195	0.25
207	180	0.25	181	0.25	196	0.25
208	181	0.25	182	0.25	197	0.25
209	182	0.25	183	0.25	198	0.25
210	183	0.25	184	0.25	199	0.25
211	184	0.25	200	0.25	283	0.5
212	23	0.5	185	0.25	201	0.25
213	185	0.25	186	0.25	201	0.25
214	186	0.25	187	0.25	202	0.25
215	187	0.25	188	0.25	203	0.25
216	188	0.25	189	0.25	204	0.25
217	189	0.25	190	0.25	205	0.25
218	190	0.25	191	0.25	206	0.25
219	191	0.25	192	0.25	207	0.25
220	192	0.25	193	0.25	208	0.25
221	193	0.25	194	0.25	209	0.25
222	194	0.25	195	0.25	210	0.25
223	195	0.25	196	0.25	211	0.25
224	196	0.25	197	0.25	212	0.25
225	197	0.25	198	0.25	213	0.25
226	198	0.25	199	0.25	214	0.25
227	199	0.25	200	0.25	215	0.25
228	200	0.25	216	0.25	283	0.5

Continued on next page…

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
229	23	0.25	24	0.25	201	0.25
230	201	0.25	202	0.25	217	0.25
231	202	0.25	203	0.25	218	0.25
232	203	0.25	204	0.25	219	0.25
233	204	0.25	205	0.25	220	0.25
234	205	0.25	206	0.25	221	0.25
235	206	0.25	207	0.25	222	0.25
236	207	0.25	208	0.25	223	0.25
237	208	0.25	209	0.25	224	0.25
238	209	0.25	210	0.25	225	0.25
239	210	0.25	211	0.25	226	0.25
240	211	0.25	212	0.25	227	0.25
241	212	0.25	213	0.25	228	0.25
242	213	0.25	214	0.25	229	0.25
243	214	0.25	215	0.25	230	0.25
244	215	0.25	216	0.25	231	0.25
245	216	0.25	232	0.25	283	0.25
246	24	0.5	217	0.25	233	0.25
247	217	0.25	218	0.25	233	0.25
248	218	0.25	219	0.25	234	0.25
249	219	0.25	220	0.25	235	0.25
250	220	0.25	221	0.25	236	0.25
251	221	0.25	222	0.25	237	0.25

Continued on next page…

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
252	222	0.25	223	0.25	238	0.25
253	223	0.25	224	0.25	239	0.25
254	224	0.25	225	0.25	240	0.25
255	225	0.25	226	0.25	241	0.25
256	226	0.25	227	0.25	242	0.25
257	227	0.25	228	0.25	243	0.25
258	228	0.25	229	0.25	244	0.25
259	229	0.25	230	0.25	245	0.25
260	230	0.25	231	0.25	246	0.25
261	231	0.25	232	0.25	247	0.25
262	232	0.25	248	0.25	284	0.5
263	24	0.5	233	0.25	249	0.25
264	233	0.25	234	0.25	249	0.25
265	234	0.25	235	0.25	250	0.25
266	235	0.25	236	0.25	251	0.25
267	236	0.25	237	0.25	252	0.25
268	237	0.25	238	0.25	253	0.25
269	238	0.25	239	0.25	254	0.25
270	239	0.25	240	0.25	255	0.25
271	240	0.25	241	0.25	256	0.25
272	241	0.25	242	0.25	257	0.25
273	242	0.25	243	0.25	258	0.25
274	243	0.25	244	0.25	259	0.25

Continued on next page. . .

Rod	Channel *i*	Fraction of rod facing channel *i*	Channel *j*	Fraction of rod facing channel *j*	Channel *k*	Fraction of rod facing channel *k*
275	244	0.25	245	0.25	260	0.25
276	245	0.25	246	0.25	261	0.25
277	246	0.25	247	0.25	262	0.25
278	247	0.25	248	0.25	263	0.25
279	248	0.25	264	0.25	284	0.5
280	24	0.5	249	0.25	265	0.25
281	249	0.25	250	0.25	265	0.25
282	250	0.25	251	0.25	266	0.25
283	251	0.25	252	0.25	267	0.25
284	252	0.25	253	0.25	268	0.25
285	253	0.25	254	0.25	269	0.25
286	254	0.25	255	0.25	270	0.25
287	255	0.25	256	0.25	271	0.25
288	256	0.25	257	0.25	272	0.25
289	257	0.25	258	0.25	273	0.25
290	258	0.25	259	0.25	274	0.25
291	259	0.25	260	0.25	275	0.25
292	260	0.25	261	0.25	276	0.25
293	261	0.25	262	0.25	277	0.25
294	262	0.25	263	0.25	278	0.25
295	263	0.25	264	0.25	279	0.25
296	264	0.25	280	0.25	284	0.5
297	24	0.375	265	0.25	289	0.375

Continued on next page. . .

Rod	Channel *i*	Fraction of rod facing channel *i*	Channel *j*	Fraction of rod facing channel *j*	Channel *k*	Fraction of rod facing channel *k*
298	265	0.25	266	0.25	289	0.5
299	266	0.25	267	0.25	289	0.5
300	267	0.25	268	0.25	289	0.5
301	268	0.25	269	0.25	289	0.25
302	269	0.25	270	0.25	290	0.5
303	270	0.25	271	0.25	290	0.5
304	271	0.25	272	0.25	290	0.5
305	272	0.25	273	0.25	290	0.25
306	273	0.25	274	0.25	291	0.5
307	274	0.25	275	0.25	291	0.5
308	275	0.25	276	0.25	291	0.5
309	276	0.25	277	0.25	291	0.25
310	277	0.25	278	0.25	292	0.5
311	278	0.25	279	0.25	292	0.5
312	279	0.25	280	0.25	292	0.5
313	280	0.25	284	0.375	292	0.375
314	281	66	—	—	—	—
315	282	66	—	—	—	—
316	283	66	—	—	—	—
317	284	66	—	—	—	—
318	285	264	—	—	—	—
319	286	132	—	—	—	—
320	287	264	—	—	—	—

Continued on next page...

Rod	Channel i	Fraction of rod facing channel i	Channel j	Fraction of rod facing channel j	Channel k	Fraction of rod facing channel k
321	288	264	—	—	—	—
322	289	66	—	—	—	—
323	290	66	—	—	—	—
324	291	66	—	—	—	—
325	292	66	—	—	—	—

Table A.12: Additional fuel rod connections for transient analysis

Rod	Channel h	Fraction of rod facing channel h
29	29	0.25
33	33	0.25
37	37	0.25
43	42	0.25
44	43	0.25
45	44	0.25
46	45	0.25
47	46	0.25
48	47	0.25
49	48	0.25
50	49	0.25
51	50	0.25
52	51	0.25
53	52	0.25
54	53	0.25
55	54	0.25
56	55	0.25
57	56	0.25
62	60	0.25
63	61	0.25

Continued on next page. . .

Rod	Channel h	Fraction of rod facing channel h
64	62	0.25
65	63	0.25
66	64	0.25
67	65	0.25
68	66	0.25
69	67	0.25
70	68	0.25
71	69	0.25
72	70	0.25
73	71	0.25
74	72	0.25
77	74	0.25
78	75	0.25
81	78	0.25
82	79	0.25
83	80	0.25
84	81	0.25
85	82	0.25
86	83	0.25
87	84	0.25
88	85	0.25
89	86	0.25
90	87	0.25

Continued on next page. . .

Rod	Channel h	Fraction of rod facing channel h
91	88	0.25
93	89	0.25
94	90	0.25
95	91	0.25
96	92	0.25
98	94	0.25
99	95	0.25
100	96	0.25
101	97	0.25
102	98	0.25
103	99	0.25
104	100	0.25
105	101	0.25
106	102	0.25
107	103	0.25
108	104	0.25
109	282	0.25
111	106	0.25
112	107	0.25
113	108	0.25
114	109	0.25
115	110	0.25
117	112	0.25

Continued on next page. . .

Rod	Channel h	Fraction of rod facing channel h
118	113	0.25
119	114	0.25
120	115	0.25
121	116	0.25
122	117	0.25
123	118	0.25
124	119	0.25
125	120	0.25
128	122	0.25
129	123	0.25
130	124	0.25
131	125	0.25
132	126	0.25
133	127	0.25
134	128	0.25
135	129	0.25
136	130	0.25
137	131	0.25
138	132	0.25
139	133	0.25
140	134	0.25
141	135	0.25
142	136	0.25

Continued on next page…

Rod	Channel h	Fraction of rod facing channel h
145	138	0.25
146	139	0.25
147	140	0.25
148	141	0.25
149	142	0.25
150	143	0.25
151	144	0.25
152	145	0.25
153	146	0.25
154	147	0.25
155	148	0.25
156	149	0.25
157	150	0.25
158	151	0.25
159	152	0.25
161	153	0.25
162	154	0.25
163	155	0.25
164	156	0.25
165	157	0.25
166	158	0.25
167	159	0.25
168	160	0.25

Continued on next page. . .

Rod	Channel h	Fraction of rod facing channel h
169	161	0.25
170	162	0.25
171	163	0.25
172	164	0.25
173	165	0.25
174	166	0.25
175	167	0.25
176	168	0.25
177	283	0.25
179	170	0.25
180	171	0.25
181	172	0.25
182	173	0.25
183	174	0.25
184	175	0.25
185	176	0.25
186	177	0.25
187	178	0.25
188	179	0.25
189	180	0.25
190	181	0.25
191	182	0.25
192	183	0.25

Continued on next page. . .

Rod	Channel h	Fraction of rod facing channel h
193	184	0.25
196	186	0.25
197	187	0.25
198	188	0.25
199	189	0.25
200	190	0.25
201	191	0.25
202	192	0.25
203	193	0.25
204	194	0.25
205	195	0.25
206	196	0.25
207	197	0.25
208	198	0.25
209	199	0.25
210	200	0.25
213	202	0.25
214	203	0.25
215	204	0.25
216	205	0.25
217	206	0.25
218	207	0.25
219	208	0.25

Continued on next page. . .

Rod	Channel h	Fraction of rod facing channel h
220	209	0.25
221	210	0.25
222	211	0.25
223	212	0.25
224	213	0.25
225	214	0.25
226	215	0.25
227	216	0.25
229	217	0.25
230	218	0.25
231	219	0.25
232	220	0.25
233	221	0.25
234	222	0.25
235	223	0.25
236	224	0.25
237	225	0.25
238	226	0.25
239	227	0.25
240	228	0.25
241	229	0.25
242	230	0.25
243	231	0.25

Continued on next page...

Rod	Channel h	Fraction of rod facing channel h
244	232	0.25
245	284	0.25
247	234	0.25
248	235	0.25
249	236	0.25
250	237	0.25
251	238	0.25
252	239	0.25
253	240	0.25
254	241	0.25
255	242	0.25
256	243	0.25
257	244	0.25
258	245	0.25
259	246	0.25
260	247	0.25
261	248	0.25
264	250	0.25
265	251	0.25
266	252	0.25
267	253	0.25
268	254	0.25
269	255	0.25

Continued on next page...

Rod	Channel h	Fraction of rod facing channel h
270	256	0.25
271	257	0.25
272	258	0.25
273	259	0.25
274	260	0.25
275	261	0.25
276	262	0.25
277	263	0.25
278	264	0.25
281	266	0.25
282	267	0.25
283	268	0.25
284	269	0.25
285	270	0.25
286	271	0.25
287	272	0.25
288	273	0.25
289	274	0.25
290	275	0.25
291	276	0.25
292	277	0.25
293	278	0.25
294	279	0.25

Continued on next page. . .

Rod	Channel h	Fraction of rod facing channel h
295	280	0.25
301	290	0.25
305	291	0.25
309	292	0.25

Table A.13: Subchannel data for transient analysis

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
1	119.0902	1087.6390	969.3384	3
2	38.1089	348.0445	310.1883	3
3	38.1089	348.0445	310.1883	2
4	38.1089	348.0445	310.1883	2
5	19.0544	174.0222	155.0941	1
6	38.1089	348.0445	310.1883	2
7	38.1089	348.0445	310.1883	2
8	38.1089	348.0445	310.1883	5
9	19.0544	174.0222	155.0941	1
10	19.0544	174.0222	155.0941	2
11	38.1089	348.0445	310.1883	2
12	38.1089	348.0445	310.1883	2
13	9.8440	89.4345	79.9704	5
14	9.8440	89.4345	79.9704	5
15	9.8440	89.4345	79.9704	5
16	9.8440	89.4345	79.9704	5
17	38.1089	348.0445	310.1883	2
18	19.0544	174.0222	155.0941	1
19	19.0544	174.0222	155.0941	2
20	38.1089	348.0445	310.1883	5
21	9.8440	89.4345	79.9704	5
22	9.8440	89.4345	79.9704	5
23	9.8440	89.4345	79.9704	5

Continued on next page…

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
24	9.8440	89.4345	79.9704	5
25	0.1362	1.1750	1.1750	2
26	0.1362	1.1750	1.1750	2
27	0.1362	1.1750	1.1750	2
28	0.1362	1.1750	1.1750	2
29	0.1362	1.1750	1.1750	2
30	0.1362	1.1750	1.1750	2
31	0.1362	1.1750	1.1750	2
32	0.1362	1.1750	1.1750	2
33	0.1362	1.1750	1.1750	2
34	0.1362	1.1750	1.1750	2
35	0.1362	1.1750	1.1750	2
36	0.1362	1.1750	1.1750	2
37	0.1362	1.1750	1.1750	2
38	0.1362	1.1750	1.1750	2
39	0.1362	1.1750	1.1750	2
40	0.1362	1.1750	1.1750	2
41	0.1362	1.1750	1.1750	2
42	0.1362	1.1750	1.1750	2
43	0.1362	1.1750	1.1750	2
44	0.1362	1.1750	1.1750	2
45	0.1180	1.2598	0.8812	2
46	0.1180	1.2598	0.8812	2
47	0.1362	1.1750	1.1750	2
48	0.1180	1.2598	0.8812	2

Continued on next page. . .

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
49	0.1180	1.2598	0.8812	2
50	0.1362	1.1750	1.1750	2
51	0.1180	1.2598	0.8812	2
52	0.1180	1.2598	0.8812	2
53	0.1362	1.1750	1.1750	2
54	0.1362	1.1750	1.1750	2
55	0.1362	1.1750	1.1750	2
56	0.1362	1.1750	1.1750	2
57	0.1362	1.1750	1.1750	2
58	0.1362	1.1750	1.1750	2
59	0.1180	1.2598	0.8812	2
60	0.1180	1.2598	0.8812	2
61	0.1180	1.2598	0.8812	2
62	0.1180	1.2598	0.8812	2
63	0.1362	1.1750	1.1750	2
64	0.1180	1.2598	0.8812	2
65	0.1180	1.2598	0.8812	2
66	0.1362	1.1750	1.1750	2
67	0.1180	1.2598	0.8812	2
68	0.1180	1.2598	0.8812	2
69	0.1180	1.2598	0.8812	2
70	0.1180	1.2598	0.8812	2
71	0.1362	1.1750	1.1750	2
72	0.1362	1.1750	1.1750	2
73	0.1362	1.1750	1.1750	2

Continued on next page. . .

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
74	0.1362	1.1750	1.1750	2
75	0.1180	1.2598	0.8812	2
76	0.1180	1.2598	0.8812	2
77	0.1362	1.1750	1.1750	2
78	0.1362	1.1750	1.1750	2
79	0.1362	1.1750	1.1750	2
80	0.1362	1.1750	1.1750	2
81	0.1362	1.1750	1.1750	2
82	0.1362	1.1750	1.1750	2
83	0.1362	1.1750	1.1750	2
84	0.1362	1.1750	1.1750	2
85	0.1180	1.2598	0.8812	2
86	0.1180	1.2598	0.8812	2
87	0.1362	1.1750	1.1750	2
88	0.1362	1.1750	1.1750	2
89	0.1362	1.1750	1.1750	2
90	0.1180	1.2598	0.8812	2
91	0.1180	1.2598	0.8812	2
92	0.1362	1.1750	1.1750	2
93	0.1180	1.2598	0.8812	2
94	0.1180	1.2598	0.8812	2
95	0.1362	1.1750	1.1750	2
96	0.1180	1.2598	0.8812	2
97	0.1180	1.2598	0.8812	2
98	0.1362	1.1750	1.1750	2

Continued on next page. . .

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
99	0.1180	1.2598	0.8812	2
100	0.1180	1.2598	0.8812	2
101	0.1362	1.1750	1.1750	2
102	0.1180	1.2598	0.8812	2
103	0.1180	1.2598	0.8812	2
104	0.1362	1.1750	1.1750	2
105	0.1362	1.1750	1.1750	2
106	0.1180	1.2598	0.8812	2
107	0.1180	1.2598	0.8812	2
108	0.1362	1.1750	1.1750	2
109	0.1180	1.2598	0.8812	2
110	0.1180	1.2598	0.8812	2
111	0.1362	1.1750	1.1750	2
112	0.1180	1.2598	0.8812	2
113	0.1180	1.2598	0.8812	2
114	0.1362	1.1750	1.1750	2
115	0.1180	1.2598	0.8812	2
116	0.1180	1.2598	0.8812	2
117	0.1362	1.1750	1.1750	2
118	0.1180	1.2598	0.8812	2
119	0.1180	1.2598	0.8812	2
120	0.1362	1.1750	1.1750	2
121	0.1362	1.1750	1.1750	2
122	0.1362	1.1750	1.1750	2
123	0.1362	1.1750	1.1750	2

Continued on next page. . .

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
124	0.1362	1.1750	1.1750	2
125	0.1362	1.1750	1.1750	2
126	0.1362	1.1750	1.1750	2
127	0.1362	1.1750	1.1750	2
128	0.1362	1.1750	1.1750	2
129	0.1362	1.1750	1.1750	2
130	0.1362	1.1750	1.1750	2
131	0.1362	1.1750	1.1750	2
132	0.1362	1.1750	1.1750	2
133	0.1362	1.1750	1.1750	2
134	0.1362	1.1750	1.1750	2
135	0.1362	1.1750	1.1750	2
136	0.1362	1.1750	1.1750	2
137	0.1362	1.1750	1.1750	2
138	0.1180	1.2598	0.8812	2
139	0.1180	1.2598	0.8812	2
140	0.1362	1.1750	1.1750	2
141	0.1180	1.2598	0.8812	2
142	0.1180	1.2598	0.8812	2
143	0.1362	1.1750	1.1750	2
144	0.1180	1.2598	0.8812	2
145	0.1180	1.2598	0.8812	2
146	0.1362	1.1750	1.1750	2
147	0.1180	1.2598	0.8812	2
148	0.1180	1.2598	0.8812	2

Continued on next page. . .

Channel	Area ($in.^2$)	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
149	0.1362	1.1750	1.1750	2
150	0.1180	1.2598	0.8812	2
151	0.1180	1.2598	0.8812	2
152	0.1362	1.1750	1.1750	2
153	0.1362	1.1750	1.1750	2
154	0.1180	1.2598	0.8812	2
155	0.1180	1.2598	0.8812	2
156	0.1362	1.1750	1.1750	2
157	0.1180	1.2598	0.8812	2
158	0.1180	1.2598	0.8812	2
159	0.1362	1.1750	1.1750	2
160	0.1180	1.2598	0.8812	2
161	0.1180	1.2598	0.8812	2
162	0.1362	1.1750	1.1750	2
163	0.1180	1.2598	0.8812	2
164	0.1180	1.2598	0.8812	2
165	0.1362	1.1750	1.1750	2
166	0.1180	1.2598	0.8812	2
167	0.1180	1.2598	0.8812	2
168	0.1362	1.1750	1.1750	2
169	0.1362	1.1750	1.1750	2
170	0.1362	1.1750	1.1750	2
171	0.1362	1.1750	1.1750	2
172	0.1362	1.1750	1.1750	2
173	0.1362	1.1750	1.1750	2

Continued on next page. . .

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
174	0.1362	1.1750	1.1750	2
175	0.1362	1.1750	1.1750	2
176	0.1362	1.1750	1.1750	2
177	0.1362	1.1750	1.1750	2
178	0.1362	1.1750	1.1750	2
179	0.1362	1.1750	1.1750	2
180	0.1362	1.1750	1.1750	2
181	0.1362	1.1750	1.1750	2
182	0.1362	1.1750	1.1750	2
183	0.1362	1.1750	1.1750	2
184	0.1362	1.1750	1.1750	2
185	0.1362	1.1750	1.1750	2
186	0.1180	1.2598	0.8812	2
187	0.1180	1.2598	0.8812	2
188	0.1362	1.1750	1.1750	2
189	0.1180	1.2598	0.8812	2
190	0.1180	1.2598	0.8812	2
191	0.1362	1.1750	1.1750	2
192	0.1180	1.2598	0.8812	2
193	0.1180	1.2598	0.8812	2
194	0.1362	1.1750	1.1750	2
195	0.1180	1.2598	0.8812	2
196	0.1180	1.2598	0.8812	2
197	0.1362	1.1750	1.1750	2
198	0.1180	1.2598	0.8812	2

Continued on next page…

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
199	0.1180	1.2598	0.8812	2
200	0.1362	1.1750	1.1750	2
201	0.1362	1.1750	1.1750	2
202	0.1180	1.2598	0.8812	2
203	0.1180	1.2598	0.8812	2
204	0.1362	1.1750	1.1750	2
205	0.1180	1.2598	0.8812	2
206	0.1180	1.2598	0.8812	2
207	0.1362	1.1750	1.1750	2
208	0.1180	1.2598	0.8812	2
209	0.1180	1.2598	0.8812	2
210	0.1362	1.1750	1.1750	2
211	0.1180	1.2598	0.8812	2
212	0.1180	1.2598	0.8812	2
213	0.1362	1.1750	1.1750	2
214	0.1180	1.2598	0.8812	2
215	0.1180	1.2598	0.8812	2
216	0.1362	1.1750	1.1750	2
217	0.1362	1.1750	1.1750	2
218	0.1362	1.1750	1.1750	2
219	0.1180	1.2598	0.8812	2
220	0.1180	1.2598	0.8812	2
221	0.1362	1.1750	1.1750	2
222	0.1362	1.1750	1.1750	2
223	0.1362	1.1750	1.1750	2

Continued on next page. . .

Channel	Area ($in.^2$)	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
224	0.1362	1.1750	1.1750	2
225	0.1362	1.1750	1.1750	2
226	0.1362	1.1750	1.1750	2
227	0.1362	1.1750	1.1750	2
228	0.1362	1.1750	1.1750	2
229	0.1180	1.2598	0.8812	2
230	0.1180	1.2598	0.8812	2
231	0.1362	1.1750	1.1750	2
232	0.1362	1.1750	1.1750	2
233	0.1362	1.1750	1.1750	2
234	0.1362	1.1750	1.1750	2
235	0.1180	1.2598	0.8812	2
236	0.1180	1.2598	0.8812	2
237	0.1180	1.2598	0.8812	2
238	0.1180	1.2598	0.8812	2
239	0.1362	1.1750	1.1750	2
240	0.1180	1.2598	0.8812	2
241	0.1180	1.2598	0.8812	2
242	0.1362	1.1750	1.1750	2
243	0.1180	1.2598	0.8812	2
244	0.1180	1.2598	0.8812	2
245	0.1180	1.2598	0.8812	2
246	0.1180	1.2598	0.8812	2
247	0.1362	1.1750	1.1750	2
248	0.1362	1.1750	1.1750	2

Continued on next page…

Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
249	0.1362	1.1750	1.1750	2
250	0.1362	1.1750	1.1750	2
251	0.1362	1.1750	1.1750	2
252	0.1362	1.1750	1.1750	2
253	0.1180	1.2598	0.8812	2
254	0.1180	1.2598	0.8812	2
255	0.1362	1.1750	1.1750	2
256	0.1180	1.2598	0.8812	2
257	0.1180	1.2598	0.8812	2
258	0.1362	1.1750	1.1750	2
259	0.1180	1.2598	0.8812	2
260	0.1180	1.2598	0.8812	2
261	0.1362	1.1750	1.1750	2
262	0.1362	1.1750	1.1750	2
263	0.1362	1.1750	1.1750	2
264	0.1362	1.1750	1.1750	2
265	0.1362	1.1750	1.1750	2
266	0.1362	1.1750	1.1750	2
267	0.1362	1.1750	1.1750	2
268	0.1362	1.1750	1.1750	2
269	0.1362	1.1750	1.1750	2
270	0.1362	1.1750	1.1750	2
271	0.1362	1.1750	1.1750	2
272	0.1362	1.1750	1.1750	2
273	0.1362	1.1750	1.1750	2

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Channel	Area (in.^{2})	Wetted perimeter (in.)	Heated perimeter (in.)	Num. of connected gaps
274	0.1362	1.1750	1.1750	2
275	0.1362	1.1750	1.1750	2
276	0.1362	1.1750	1.1750	2
277	0.1362	1.1750	1.1750	2
278	0.1362	1.1750	1.1750	2
279	0.1362	1.1750	1.1750	2
280	0.1362	1.1750	1.1750	2
281	9.8440	89.4345	79.9704	2
282	9.8440	89.4345	79.9704	2
283	9.8440	89.4345	79.9704	2
284	9.8440	89.4345	79.9704	1
285	38.1089	348.0445	310.1883	—
286	19.0544	174.0222	155.0941	1
287	38.1089	348.0445	310.1883	1
288	38.1089	348.0445	310.1883	1
289	9.8440	89.4345	79.9704	1
290	9.8440	89.4345	79.9704	1
291	9.8440	89.4345	79.9704	1
292	9.8440	89.4345	79.9704	—

Table A.14: Subchannel connections for transient analysis

	Connected Channel					
Channel *i*	Channel *j*	Gap *i*,*j* width (in.)	Centroid distance *i*,*j* (in.)	Channel *k*	Gap *i*,*k* width (in.)	Centroid distance *i*,*k* (in.)
1	2	1.054	0	3	2.108	0
1	4	2.108	0	—	—	—
2	3	2.108	0	6	2.108	0
2	10	1.054	0	—	—	—
3	4	2.108	0	6	2.108	0
4	5	2.108	0	7	2.108	0
5	8	2.108	0	—	—	—
6	7	2.108	0	11	2.108	0
7	8	2.108	0	12	2.108	0
8	9	2.108	0	13	0.527	0
8	14	0.527	0	—	—	—
8	15	0.527	0	16	0.527	0
9	17	2.108	0	—	—	—
10	11	2.108	6.482	19	1.054	0
11	12	2.108	8.466	20	2.108	0
12	13	2.108	5.49	21	2.108	0
13	14	2.108	1.984	25	0.122	4.746
13	26	0.122	4.746	27	0.122	4.746
13	28	0.122	4.746	—	—	—
14	15	2.108	1.984	29	0.122	4.746
14	30	0.122	4.746	31	0.122	4.746

Continued on next page. . .

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
14	32	0.122	4.746	—	—	—
15	16	2.108	1.984	33	0.122	4.746
15	34	0.122	4.746	35	0.122	4.746
15	36	0.122	4.746	—	—	—
16	17	2.108	0	37	0.122	4.746
16	38	0.122	4.746	39	0.122	4.746
16	40	0.122	4.746	—	—	—
17	18	2.108	0	281	2.108	0
18	285	2.108	0	—	—	—
19	20	2.108	0	286	1.054	8.466
20	21	0.527	0	22	0.527	0
20	23	0.527	0	24	0.527	0
20	287	2.108	0	—	—	—
21	22	2.108	1.984	25	0.122	4.746
21	41	0.122	4.746	57	0.122	4.746
21	73	0.122	4.746	—	—	—
22	23	2.108	1.984	89	0.122	4.746
22	105	0.122	4.746	121	0.122	4.746
22	137	0.122	4.746	—	—	—
23	24	2.108	1.984	153	0.122	4.746
23	169	0.122	4.746	185	0.122	4.746
23	201	0.122	4.746	—	—	—
24	217	0.122	4.746	233	0.122	4.746
24	249	0.122	4.746	265	0.122	4.746

Continued on next page…

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
24	288	2.108	0	—	—	—
25	26	0.122	0	41	0.122	0
26	27	0.122	0	42	0.122	0
27	28	0.122	0	43	0.122	0
28	29	0.122	0	44	0.122	0
29	30	0.122	0	45	0.122	0
30	31	0.122	0	46	0.122	0
31	32	0.122	0	47	0.122	0
32	33	0.122	0	48	0.122	0
33	34	0.122	0	49	0.122	0
34	35	0.122	0	50	0.122	0
35	36	0.122	0	51	0.122	0
36	37	0.122	0	52	0.122	0
37	38	0.122	0	53	0.122	0
38	39	0.122	0	54	0.122	0
39	40	0.122	0	55	0.122	0
40	56	0.122	0	281	0.122	0
41	42	0.122	0	57	0.122	0
42	43	0.122	0	58	0.122	0
43	44	0.122	0	59	0.122	0
44	45	0.122	0	60	0.122	0
45	46	0.068	0	61	0.068	0
46	47	0.122	0	62	0.068	0
47	48	0.122	0	63	0.122	0

Continued on next page. . .

	Connected Channel					
Channel *i*	Channel *j*	Gap *i,j* width (in.)	Centroid distance *i,j* (in.)	Channel *k*	Gap *i,k* width (in.)	Centroid distance *i,k* (in.)
48	49	0.068	0	64	0.068	0
49	50	0.122	0	65	0.068	0
50	51	0.122	0	66	0.122	0
51	52	0.068	0	67	0.068	0
52	53	0.122	0	68	0.068	0
53	54	0.122	0	69	0.122	0
54	55	0.122	0	70	0.122	0
55	56	0.122	0	71	0.122	0
56	72	0.122	0	281	0.122	0
57	58	0.122	0	73	0.122	0
58	59	0.122	0	74	0.122	0
59	60	0.068	0	75	0.068	0
60	61	0.122	0	76	0.068	0
61	62	0.068	0	77	0.122	0
62	63	0.122	0	78	0.122	0
63	64	0.122	0	79	0.122	0
64	65	0.068	0	80	0.122	0
65	66	0.122	0	81	0.122	0
66	67	0.122	0	82	0.122	0
67	68	0.068	0	83	0.122	0
68	69	0.122	0	84	0.122	0
69	70	0.068	0	85	0.068	0
70	71	0.122	0	86	0.068	0
71	72	0.122	0	87	0.122	0

Continued on next page. . .

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
72	88	0.122	0	281	0.122	0
73	74	0.122	0	89	0.122	0
74	75	0.122	0	90	0.122	0
75	76	0.068	0	91	0.122	0
76	77	0.122	0	92	0.122	0
77	78	0.122	0	93	0.122	0
78	79	0.122	0	94	0.122	0
79	80	0.122	0	95	0.122	0
80	81	0.122	0	96	0.122	0
81	82	0.122	0	97	0.122	0
82	83	0.122	0	98	0.122	0
83	84	0.122	0	99	0.122	0
84	85	0.122	0	100	0.122	0
85	86	0.068	0	101	0.122	0
86	87	0.122	0	102	0.122	0
87	88	0.122	0	103	0.122	0
88	104	0.122	0	281	0.122	0
89	90	0.122	0	105	0.122	0
90	91	0.068	0	106	0.068	0
91	92	0.122	0	107	0.068	0
92	93	0.122	0	108	0.122	0
93	94	0.068	0	109	0.068	0
94	95	0.122	0	110	0.068	0
95	96	0.122	0	111	0.122	0

Continued on next page. . .

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
96	97	0.068	0	112	0.068	0
97	98	0.122	0	113	0.068	0
98	99	0.122	0	114	0.122	0
99	100	0.068	0	115	0.068	0
100	101	0.122	0	116	0.068	0
101	102	0.122	0	117	0.122	0
102	103	0.068	0	118	0.068	0
103	104	0.122	0	119	0.068	0
104	120	0.122	0	282	0.122	0
105	106	0.122	0	121	0.122	0
106	107	0.068	0	122	0.122	0
107	108	0.122	0	123	0.122	0
108	109	0.122	0	124	0.122	0
109	110	0.068	0	125	0.122	0
110	111	0.122	0	126	0.122	0
111	112	0.122	0	127	0.122	0
112	113	0.068	0	128	0.122	0
113	114	0.122	0	129	0.122	0
114	115	0.122	0	130	0.122	0
115	116	0.068	0	131	0.122	0
116	117	0.122	0	132	0.122	0
117	118	0.122	0	133	0.122	0
118	119	0.068	0	134	0.122	0
119	120	0.122	0	135	0.122	0

Continued on next page...

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
120	136	0.122	0	282	0.122	0
121	122	0.122	0	137	0.122	0
122	123	0.122	0	138	0.122	0
123	124	0.122	0	139	0.122	0
124	125	0.122	0	140	0.122	0
125	126	0.122	0	141	0.122	0
126	127	0.122	0	142	0.122	0
127	128	0.122	0	143	0.122	0
128	129	0.122	0	144	0.122	0
129	130	0.122	0	145	0.122	0
130	131	0.122	0	146	0.122	0
131	132	0.122	0	147	0.122	0
132	133	0.122	0	148	0.122	0
133	134	0.122	0	149	0.122	0
134	135	0.122	0	150	0.122	0
135	136	0.122	0	151	0.122	0
136	152	0.122	0	282	0.122	0
137	138	0.122	0	153	0.122	0
138	139	0.068	0	154	0.068	0
139	140	0.122	0	155	0.068	0
140	141	0.122	0	156	0.122	0
141	142	0.068	0	157	0.068	0
142	143	0.122	0	158	0.068	0
143	144	0.122	0	159	0.122	0

Continued on next page...

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
144	145	0.068	0	160	0.068	0
145	146	0.122	0	161	0.068	0
146	147	0.122	0	162	0.122	0
147	148	0.068	0	163	0.068	0
148	149	0.122	0	164	0.068	0
149	150	0.122	0	165	0.122	0
150	151	0.068	0	166	0.068	0
151	152	0.122	0	167	0.068	0
152	168	0.122	0	282	0.122	0
153	154	0.122	0	169	0.122	0
154	155	0.068	0	170	0.122	0
155	156	0.122	0	171	0.122	0
156	157	0.122	0	172	0.122	0
157	158	0.068	0	173	0.122	0
158	159	0.122	0	174	0.122	0
159	160	0.122	0	175	0.122	0
160	161	0.068	0	176	0.122	0
161	162	0.122	0	177	0.122	0
162	163	0.122	0	178	0.122	0
163	164	0.068	0	179	0.122	0
164	165	0.122	0	180	0.122	0
165	166	0.122	0	181	0.122	0
166	167	0.068	0	182	0.122	0
167	168	0.122	0	183	0.122	0

Continued on next page. . .

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
168	184	0.122	0	283	0.122	0
169	170	0.122	0	185	0.122	0
170	171	0.122	0	186	0.122	0
171	172	0.122	0	187	0.122	0
172	173	0.122	0	188	0.122	0
173	174	0.122	0	189	0.122	0
174	175	0.122	0	190	0.122	0
175	176	0.122	0	191	0.122	0
176	177	0.122	0	192	0.122	0
177	178	0.122	0	193	0.122	0
178	179	0.122	0	194	0.122	0
179	180	0.122	0	195	0.122	0
180	181	0.122	0	196	0.122	0
181	182	0.122	0	197	0.122	0
182	183	0.122	0	198	0.122	0
183	184	0.122	0	199	0.122	0
184	200	0.122	0	283	0.122	0
185	186	0.122	0	201	0.122	0
186	187	0.068	0	202	0.068	0
187	188	0.122	0	203	0.068	0
188	189	0.122	0	204	0.122	0
189	190	0.068	0	205	0.068	0
190	191	0.122	0	206	0.068	0
191	192	0.122	0	207	0.122	0

Continued on next page. . .

Channel i	Connected Channel Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
192	193	0.068	0	208	0.068	0
193	194	0.122	0	209	0.068	0
194	195	0.122	0	210	0.122	0
195	196	0.068	0	211	0.068	0
196	197	0.122	0	212	0.068	0
197	198	0.122	0	213	0.122	0
198	199	0.068	0	214	0.068	0
199	200	0.122	0	215	0.068	0
200	216	0.122	0	283	0.122	0
201	202	0.122	0	217	0.122	0
202	203	0.068	0	218	0.122	0
203	204	0.122	0	219	0.122	0
204	205	0.122	0	220	0.122	0
205	206	0.068	0	221	0.122	0
206	207	0.122	0	222	0.122	0
207	208	0.122	0	223	0.122	0
208	209	0.068	0	224	0.122	0
209	210	0.122	0	225	0.122	0
210	211	0.122	0	226	0.122	0
211	212	0.068	0	227	0.122	0
212	213	0.122	0	228	0.122	0
213	214	0.122	0	229	0.122	0
214	215	0.068	0	230	0.122	0
215	216	0.122	0	231	0.122	0

Continued on next page...

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
216	232	0.122	0	283	0.122	0
217	218	0.122	0	233	0.122	0
218	219	0.122	0	234	0.122	0
219	220	0.068	0	235	0.068	0
220	221	0.122	0	236	0.068	0
221	222	0.122	0	237	0.122	0
222	223	0.122	0	238	0.122	0
223	224	0.122	0	239	0.122	0
224	225	0.122	0	240	0.122	0
225	226	0.122	0	241	0.122	0
226	227	0.122	0	242	0.122	0
227	228	0.122	0	243	0.122	0
228	229	0.122	0	244	0.122	0
229	230	0.068	0	245	0.068	0
230	231	0.122	0	246	0.068	0
231	232	0.122	0	247	0.122	0
232	248	0.122	0	284	0.122	0
233	234	0.122	0	249	0.122	0
234	235	0.122	0	250	0.122	0
235	236	0.068	0	251	0.122	0
236	237	0.122	0	252	0.122	0
237	238	0.068	0	253	0.068	0
238	239	0.122	0	254	0.068	0
239	240	0.122	0	255	0.122	0

Continued on next page...

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
240	241	0.068	0	256	0.068	0
241	242	0.122	0	257	0.068	0
242	243	0.122	0	258	0.122	0
243	244	0.068	0	259	0.068	0
244	245	0.122	0	260	0.068	0
245	246	0.068	0	261	0.122	0
246	247	0.122	0	262	0.122	0
247	248	0.122	0	263	0.122	0
248	264	0.122	0	284	0.122	0
249	250	0.122	0	265	0.122	0
250	251	0.122	0	266	0.122	0
251	252	0.122	0	267	0.122	0
252	253	0.122	0	268	0.122	0
253	254	0.068	0	269	0.122	0
254	255	0.122	0	270	0.122	0
255	256	0.122	0	271	0.122	0
256	257	0.068	0	272	0.122	0
257	258	0.122	0	273	0.122	0
258	259	0.122	0	274	0.122	0
259	260	0.068	0	275	0.122	0
260	261	0.122	0	276	0.122	0
261	262	0.122	0	277	0.122	0
262	263	0.122	0	278	0.122	0
263	264	0.122	0	279	0.122	0

Continued on next page…

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
264	280	0.122	0	284	0.122	0
265	266	0.122	0	289	0.122	0
266	267	0.122	0	289	0.122	0
267	268	0.122	0	289	0.122	0
268	269	0.122	0	289	0.122	0
269	270	0.122	0	290	0.122	0
270	271	0.122	0	290	0.122	0
271	272	0.122	0	290	0.122	0
272	273	0.122	0	290	0.122	0
273	274	0.122	0	291	0.122	0
274	275	0.122	0	291	0.122	0
275	276	0.122	0	291	0.122	0
276	277	0.122	0	291	0.122	0
277	278	0.122	0	292	0.122	0
278	279	0.122	0	292	0.122	0
279	280	0.122	0	292	0.122	0
280	284	0.122	0	292	0.122	0
281	282	2.108	1.984	285	0.527	0
282	283	2.108	1.984	285	0.527	0
283	284	2.108	1.984	285	0.527	0
284	285	0.527	0	—	—	—
285	—	—	—	—	—	—
286	287	2.108	0	—	—	—
287	288	2.108	0	—	—	—

Continued on next page…

	Connected Channel					
Channel i	Channel j	Gap i,j width (in.)	Centroid distance i,j (in.)	Channel k	Gap i,k width (in.)	Centroid distance i,k (in.)
288	289	2.108	0	—	—	—
289	290	2.108	1.984	—	—	—
290	291	2.108	1.984	—	—	—
291	292	2.108	1.984	—	—	—
292	—	—	—	—	—	—

A.3 RODS

A.3.1 Steady-State Scoping Analysis

CARD	*RECORD*	*VALUE*	*BASIS*
RODS.1	INFLAG	rods	group identification flag
	NAXP	1	1 specified axial power profile, defined on *CARDS* RODS.3 and RODS.5
	NROD	54	54 rods modeled in steady-state scoping analysis
	NC	1	1 activates the rod internal conduction model
	NFUELT	2	2 types of rod geometries: fuel rods and control rods/ instrument tubes with outer diameters from Table 5.1
	NMAT	1	1 rod materials for which properties will be input on *CARDS* RODS.70 and RODS.71; rod materials are burnup-dependent thermal-physical properties for UO_2
	IGPFF	0	default value; no temporal gap conductance forcing functions are used
	NGPFF	0	default value; 0 if *RECORD* IGPFF is 0
	NOPT	0	default value; specifies normal rod layout input
	IPOWV	0	default value; specifies constant axial power profiles with time

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CARD	*RECORD*	*VALUE*	*BASIS*
	ICPR	0	default value; no critical power ratio calculations are required
	IRFF	0	default value; constant radial power factors with time
	NMATB	0	no built-in burnup-dependent fuel properties
RODS.2	ZZH	144	fuel assembly heated length is 144 inches, from Table 3.1
	ZSTRT	4	heated length begins 4 inches above channel inlet
	NODALS	0	default value; axial power profile is input as power factors versus distance
	NODALT	0	default value; no transient axial power profiles
	TREFF	0.0	default value; reference temperature for fuel enthalpy calculation
RODS.3	NAXN	-1	axial power profile is a symmetric chopped cosine
	NSPLN	3	a spline fit interpolation method with normalization is used to calculate values for the axial power profile versus distance
RODS.5	PSTAR	1.55	1.55 peak-to-average ratio for the axial power profile; from assumptions in Section 3

CARD	*RECORD*	*VALUE*	*BASIS*
RODS.9	I	1	rod identification number, from Table A.4
	IDFUEL	2	rod geometry type (control rod/ instrument tube), from Table A.4
	RADIAL	0.0000	rod radial power factor, from Table A.19
	IAXP	1	rod uses chopped cosine axial power profile defined on *CARDS* RODS.3 and RODS.5
	LRDUM	1	identification number of channel connected to rod I, from Tables A.5 and A.6
	PHIDUM	0.125	fraction of rod I outside perimeter facing channel LRDUM, from Tables A.5 and A.6
	I	2	rod identification number, from Table A.4
	IDFUEL	1	rod geometry type (fuel rod), from Table A.4
	RADIAL	1.5254	rod radial power factor, from Table A.19
	IAXP	1	rod uses chopped cosine axial power profile defined on *CARDS* RODS.3 and RODS.5
	LRDUM	1	identification number of channel connected to rod I, from Tables A.5 and A.6

Continued on next page...

CARD	*RECORD*	*VALUE*	*BASIS*
	PHIDUM	0.25	fraction of rod I outside perimeter facing channel LRDUM, from Tables A.5 and A.6
	LRDUM	2	identification number of channel connected to rod I, from Tables A.5 and A.6
	PHIDUM	0.25	fraction of rod I outside perimeter facing channel LRDUM, from Tables A.5 and A.6
	I	3	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4778	“ ”
	IAXP	1	“ ”
	LRDUM	1	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	2	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	3	“ ”
	PHIDUM	0.125	“ ”
	I	4	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5259	“ ”
	IAXP	1	“ ”
	LRDUM	2	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	4	“ ”
	PHIDUM	0.25	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	I	5	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4786	“ ”
	IAXP	1	“ ”
	LRDUM	2	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	3	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	4	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	5	“ ”
	PHIDUM	0.25	“ ”
	I	6	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4804	“ ”
	IAXP	1	“ ”
	LRDUM	3	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	5	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	6	“ ”
	PHIDUM	0.125	“ ”
	I	7	“ ”
	IDFUEL	2	“ ”
	RADIAL	0.0000	“ ”
	IAXP	1	“ ”
	LRDUM	4	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	PHIDUM	0.25	“ ”
	LRDUM	7	“ ”
	PHIDUM	0.25	“ ”
	I	8	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5274	“ ”
	IAXP	1	“ ”
	LRDUM	4	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	5	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	7	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	8	“ ”
	PHIDUM	0.25	“ ”
	I	9	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5311	“ ”
	IAXP	1	“ ”
	LRDUM	5	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	6	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	8	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	9	“ ”
	PHIDUM	0.25	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	I	10	“ ”
	IDFUEL	2	“ ”
	RADIAL	0.0000	“ ”
	IAXP	1	“ ”
	LRDUM	6	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	9	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	10	“ ”
	PHIDUM	0.125	“ ”
	I	11	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5259	“ ”
	IAXP	1	“ ”
	LRDUM	7	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	11	“ ”
	PHIDUM	0.25	“ ”
	I	12	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4795	“ ”
	IAXP	1	“ ”
	LRDUM	7	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	8	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	11	“ ”

Continued on next page…

CARD	*RECORD*	*VALUE*	*BASIS*
	PHIDUM	0.25	“ ”
	LRDUM	12	“ ”
	PHIDUM	0.25	“ ”
	I	13	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4852	“ ”
	IAXP	1	“ ”
	LRDUM	8	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	9	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	12	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	13	“ ”
	PHIDUM	0.25	“ ”
	I	14	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5466	“ ”
	IAXP	1	“ ”
	LRDUM	9	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	10	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	13	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	14	“ ”
	PHIDUM	0.25	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	I	15	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5256	“ ”
	IAXP	1	“ ”
	LRDUM	10	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	14	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	15	“ ”
	PHIDUM	0.125	“ ”
	I	16	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5229	“ ”
	IAXP	1	“ ”
	LRDUM	11	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	16	“ ”
	PHIDUM	0.25	“ ”
	I	17	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4769	“ ”
	IAXP	1	“ ”
	LRDUM	11	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	12	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	16	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	PHIDUM	0.25	“ ”
	LRDUM	17	“ ”
	PHIDUM	0.25	“ ”
	I	18	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4836	“ ”
	IAXP	1	“ ”
	LRDUM	12	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	13	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	17	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	18	“ ”
	PHIDUM	0.25	“ ”
	I	19	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5499	“ ”
	IAXP	1	“ ”
	LRDUM	13	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	14	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	18	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	19	“ ”
	PHIDUM	0.25	“ ”

Continued on next page…

CARD	*RECORD*	*VALUE*	*BASIS*
	I	20	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5611	“ ”
	IAXP	1	“ ”
	LRDUM	14	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	15	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	19	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	20	“ ”
	PHIDUM	0.25	“ ”
	I	21	“ ”
	IDFUEL	2	“ ”
	RADIAL	0.0000	“ ”
	IAXP	1	“ ”
	LRDUM	15	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	20	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	21	“ ”
	PHIDUM	0.125	“ ”
	I	22	“ ”
	IDFUEL	2	“ ”
	RADIAL	0.0000	“ ”
	IAXP	1	“ ”
	LRDUM	16	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	PHIDUM	0.25	“ ”
	LRDUM	22	“ ”
	PHIDUM	0.25	“ ”
	I	23	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5179	“ ”
	IAXP	1	“ ”
	LRDUM	16	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	17	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	22	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	23	“ ”
	PHIDUM	0.25	“ ”
	I	24	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5219	“ ”
	IAXP	1	“ ”
	LRDUM	17	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	18	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	23	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	24	“ ”
	PHIDUM	0.25	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	I	25	“ ”
	IDFUEL	2	“ ”
	RADIAL	0.0000	“ ”
	IAXP	1	“ ”
	LRDUM	18	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	19	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	24	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	25	“ ”
	PHIDUM	0.25	“ ”
	I	26	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5389	“ ”
	IAXP	1	“ ”
	LRDUM	19	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	20	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	25	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	26	“ ”
	PHIDUM	0.25	“ ”
	I	27	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5095	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	IAXP	1	“ ”
	LRDUM	20	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	21	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	26	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	27	“ ”
	PHIDUM	0.25	“ ”
	I	28	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4343	“ ”
	IAXP	1	“ ”
	LRDUM	21	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	27	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	28	“ ”
	PHIDUM	0.125	“ ”
	I	29	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5000	“ ”
	IAXP	1	“ ”
	LRDUM	22	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	29	“ ”
	PHIDUM	0.25	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	I	30	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4592	“ ”
	IAXP	1	“ ”
	LRDUM	22	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	23	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	29	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	30	“ ”
	PHIDUM	0.25	“ ”
	I	31	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4602	“ ”
	IAXP	1	“ ”
	LRDUM	23	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	24	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	30	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	31	“ ”
	PHIDUM	0.25	“ ”
	I	32	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.5019	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	IAXP	1	“ ”
	LRDUM	24	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	25	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	31	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	32	“ ”
	PHIDUM	0.25	“ ”
	I	33	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4543	“ ”
	IAXP	1	“ ”
	LRDUM	25	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	26	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	32	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	33	“ ”
	PHIDUM	0.25	“ ”
	I	34	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4249	“ ”
	IAXP	1	“ ”
	LRDUM	26	“ ”
	PHIDUM	0.25	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	LRDUM	27	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	33	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	34	“ ”
	PHIDUM	0.25	“ ”
	I	35	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.3984	“ ”
	IAXP	1	“ ”
	LRDUM	27	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	28	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	34	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	35	“ ”
	PHIDUM	0.25	“ ”
	I	36	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.3899	“ ”
	IAXP	1	“ ”
	LRDUM	28	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	35	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	36	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	PHIDUM	0.125	“ ”
	I	37	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4403	“ ”
	IAXP	1	“ ”
	LRDUM	29	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	37	“ ”
	PHIDUM	0.25	“ ”
	I	38	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4334	“ ”
	IAXP	1	“ ”
	LRDUM	29	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	30	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	37	“ ”
	PHIDUM	0.5	“ ”
	I	39	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4331	“ ”
	IAXP	1	“ ”
	LRDUM	30	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	31	“ ”
	PHIDUM	0.25	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	LRDUM	37	“ ”
	PHIDUM	0.5	“ ”
	I	40	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4378	“ ”
	IAXP	1	“ ”
	LRDUM	31	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	32	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	37	“ ”
	PHIDUM	0.5	“ ”
	I	41	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4237	“ ”
	IAXP	1	“ ”
	LRDUM	32	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	33	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	37	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	38	“ ”
	PHIDUM	0.25	“ ”
	I	42	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4078	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	IAXP	1	“ ”
	LRDUM	33	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	34	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	38	“ ”
	PHIDUM	0.5	“ ”
	I	43	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.3968	“ ”
	IAXP	1	“ ”
	LRDUM	34	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	35	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	38	“ ”
	PHIDUM	0.5	“ ”
	I	44	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.3991	“ ”
	IAXP	1	“ ”
	LRDUM	35	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	36	“ ”
	PHIDUM	0.25	“ ”
	LRDUM	38	“ ”
	PHIDUM	0.5	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	I	45	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4131	“ ”
	IAXP	1	“ ”
	LRDUM	36	“ ”
	PHIDUM	0.125	“ ”
	LRDUM	38	“ ”
	PHIDUM	0.375	“ ”
	I	46	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4764	“ ”
	IAXP	1	“ ”
	LRDUM	37	“ ”
	PHIDUM	35	“ ”
	I	47	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4764	“ ”
	IAXP	1	“ ”
	LRDUM	38	“ ”
	PHIDUM	35.125	“ ”
	I	48	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.4764	“ ”
	IAXP	1	“ ”
	LRDUM	39	“ ”
	PHIDUM	66	“ ”
	I	49	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	IDFUEL	1	“ ”
	RADIAL	1.4764	“ ”
	IAXP	1	“ ”
	LRDUM	40	“ ”
	PHIDUM	132	“ ”
	I	50	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.3820	“ ”
	IAXP	1	“ ”
	LRDUM	41	“ ”
	PHIDUM	132	“ ”
	I	51	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.2610	“ ”
	IAXP	1	“ ”
	LRDUM	42	“ ”
	PHIDUM	264	“ ”
	I	52	“ ”
	IDFUEL	1	“ ”
	RADIAL	1.2260	“ ”
	IAXP	1	“ ”
	LRDUM	43	“ ”
	PHIDUM	132	“ ”
	I	53	“ ”
	IDFUEL	1	“ ”
	RADIAL	0.9410	“ ”
	IAXP	1	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	LRDUM	44	“ ”
	PHIDUM	1848	“ ”
	I	54	“ ”
	IDFUEL	1	“ ”
	RADIAL	0.9420	“ ”
	IAXP	1	“ ”
	LRDUM	45	“ ”
	PHIDUM	3696	“ ”
	I	0	0 terminates the input for *CARD* RODS.9
	IDFUEL	—	—
	RADIAL	—	—
	IAXP	—	—
	LRDUM	—	—
	PHIDUM	—	—

CARD	*RECORD*	*VALUE*	*BASIS*
RODS.62	I	1	geometry type number
	FTYPE	nucl	nuclear rod geometry identifier
	DROD	0.374	fuel rod outside diameter, from Table 5.1
	DFUEL	0.3252	fuel pellet diameter, from Table 5.1
	NFUEL	6	default value; number of radial nodes in fuel pellet
	DCORE	0.0	default value; fuel pellet has no central void
	TCLAD	0.02244	cladding thickness, from Table 5.1
RODS.63	IRADP	0	default value; uniform radial power profile in pellet
	IMATF	1	fuel pellet material property index, references material 1 on *CARD* RODS.70
	IMATC	0	default value; VIPRE uses built-in material properties for zircaloy-4
	IGPC	0	fuel rods use a uniform gap conductance specified on *RECORD* HGAP
	IGFORC	0	gap conductance is constant in time
	HGAP	2000	fuel rods use a constant gap conductance of 2000 BTU/hr $\cdot$ ft^2 $\cdot$ °F from assumptions in Section 3
	FTDENS	0.95	fuel theoretical density; not used for current VIPRE calculations

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CARD	*RECORD*	*VALUE*	*BASIS*
	FCLAD	0	fraction of applied power generated in the cladding; calculations conservatively assume that all power is generated in the fuel
RODS.68	I	2	geometry type number
	FTYPE	dumy	dummy rod geometry identifier; dummy rods do not use the conduction model and model control rods and instrument tubes in the current calculations
	DROD	0.482	rod outside diameter, from Table 5.1
	DFUEL	0	dummy geometry is a solid rod instead of a tube
	NFUEL	0	default value; 0 for dummy rods
RODS.70	N	1	material type number
	NNTDP	61	number of entries in table of user defined material properties versus temperature for material N; 61 entries adequately represents the temperature dependent curve of oxide fuel thermal conductivity
	RCOLD	651.1861	UO_2 cold state density in lbm/ft^2; equivalent to 10.431g/m^3 from [29]
	ANAME	UOX	alphanumeric identifier for UO_2

CARD	*RECORD*	*VALUE*	*BASIS*
RODS.71	TROP	440.6	temperature I in °F, from Table A.20
	CPFF	0.0673	specific heat for temperature I in BTU/lbm · °F, from Table A.20
	THCF	3.4160	thermal conductivity for temperature I in BTU/hr · ft · °F, from Table A.20
	TROP	530.6	“ ”
	CPFF	0.0687	“ ”
	THCF	3.1845	“ ”
	TROP	620.6	“ ”
	CPFF	0.0698	“ ”
	THCF	2.9824	“ ”
	TROP	710.6	“ ”
	CPFF	0.0707	“ ”
	THCF	2.8045	“ ”
	TROP	800.6	“ ”
	CPFF	0.0715	“ ”
	THCF	2.6467	“ ”
	TROP	890.6	“ ”
	CPFF	0.0722	“ ”
	THCF	2.5059	“ ”
	TROP	980.6	“ ”
	CPFF	0.0729	“ ”
	THCF	2.3794	“ ”
	TROP	1070.6	“ ”
	CPFF	0.0735	“ ”
	THCF	2.2651	“ ”
	TROP	1160.6	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	CPFF	0.0740	“ ”
	THCF	2.1615	“ ”
	TROP	1250.6	“ ”
	CPFF	0.0745	“ ”
	THCF	2.0670	“ ”
	TROP	1340.6	“ ”
	CPFF	0.0750	“ ”
	THCF	1.9804	“ ”
	TROP	1430.6	“ ”
	CPFF	0.0754	“ ”
	THCF	1.9009	“ ”
	TROP	1520.6	“ ”
	CPFF	0.0758	“ ”
	THCF	1.8276	“ ”
	TROP	1610.6	“ ”
	CPFF	0.0762	“ ”
	THCF	1.7600	“ ”
	TROP	1700.6	“ ”
	CPFF	0.0767	“ ”
	THCF	1.6974	“ ”
	TROP	1790.6	“ ”
	CPFF	0.0771	“ ”
	THCF	1.6395	“ ”
	TROP	1880.6	“ ”
	CPFF	0.0775	“ ”
	THCF	1.5860	“ ”
	TROP	1970.6	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	CPFF	0.0779	“ ”
	THCF	1.5365	“ ”
	TROP	2060.6	“ ”
	CPFF	0.0783	“ ”
	THCF	1.4909	“ ”
	TROP	2150.6	“ ”
	CPFF	0.0788	“ ”
	THCF	1.4491	“ ”
	TROP	2240.6	“ ”
	CPFF	0.0793	“ ”
	THCF	1.4109	“ ”
	TROP	2330.6	“ ”
	CPFF	0.0799	“ ”
	THCF	1.3762	“ ”
	TROP	2420.6	“ ”
	CPFF	0.0805	“ ”
	THCF	1.3449	“ ”
	TROP	2510.6	“ ”
	CPFF	0.0813	“ ”
	THCF	1.3172	“ ”
	TROP	2600.6	“ ”
	CPFF	0.0821	“ ”
	THCF	1.2928	“ ”
	TROP	2690.6	“ ”
	CPFF	0.0830	“ ”
	THCF	1.2718	“ ”
	TROP	2780.6	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	CPFF	0.0840	“ ”
	THCF	1.2542	“ ”
	TROP	2870.6	“ ”
	CPFF	0.0851	“ ”
	THCF	1.2399	“ ”
	TROP	2960.6	“ ”
	CPFF	0.0864	“ ”
	THCF	1.2290	“ ”
	TROP	3050.6	“ ”
	CPFF	0.0879	“ ”
	THCF	1.2213	“ ”
	TROP	3140.6	“ ”
	CPFF	0.0895	“ ”
	THCF	1.2170	“ ”
	TROP	3230.6	“ ”
	CPFF	0.0914	“ ”
	THCF	1.2158	“ ”
	TROP	3320.6	“ ”
	CPFF	0.0934	“ ”
	THCF	1.2179	“ ”
	TROP	3410.6	“ ”
	CPFF	0.0956	“ ”
	THCF	1.2231	“ ”
	TROP	3500.6	“ ”
	CPFF	0.0980	“ ”
	THCF	1.2313	“ ”
	TROP	3590.6	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	CPFF	0.1006	“ ”
	THCF	1.2426	“ ”
	TROP	3680.6	“ ”
	CPFF	0.1035	“ ”
	THCF	1.2567	“ ”
	TROP	3770.6	“ ”
	CPFF	0.1066	“ ”
	THCF	1.2737	“ ”
	TROP	3860.6	“ ”
	CPFF	0.1099	“ ”
	THCF	1.2933	“ ”
	TROP	3950.6	“ ”
	CPFF	0.1134	“ ”
	THCF	1.3156	“ ”
	TROP	4040.6	“ ”
	CPFF	0.1172	“ ”
	THCF	1.3404	“ ”
	TROP	4130.6	“ ”
	CPFF	0.1212	“ ”
	THCF	1.3676	“ ”
	TROP	4220.6	“ ”
	CPFF	0.1254	“ ”
	THCF	1.3970	“ ”
	TROP	4310.6	“ ”
	CPFF	0.1299	“ ”
	THCF	1.4286	“ ”
	TROP	4400.6	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	CPFF	0.1346	“ ”
	THCF	1.4622	“ ”
	TROP	4490.6	“ ”
	CPFF	0.1395	“ ”
	THCF	1.4977	“ ”
	TROP	4580.6	“ ”
	CPFF	0.1446	“ ”
	THCF	1.5350	“ ”
	TROP	4670.6	“ ”
	CPFF	0.1499	“ ”
	THCF	1.5739	“ ”
	TROP	4760.6	“ ”
	CPFF	0.1555	“ ”
	THCF	1.6144	“ ”
	TROP	4850.6	“ ”
	CPFF	0.1612	“ ”
	THCF	1.6563	“ ”
	TROP	4940.6	“ ”
	CPFF	0.1671	“ ”
	THCF	1.6995	“ ”
	TROP	5030.6	“ ”
	CPFF	0.1732	“ ”
	THCF	1.7438	“ ”
	TROP	5120.6	“ ”
	CPFF	0.1794	“ ”
	THCF	1.7892	“ ”
	TROP	5210.6	“ ”

Continued on next page...

CARD	*RECORD*	*VALUE*	*BASIS*
	CPFF	0.1858	“ ”
	THCF	1.8356	“ ”
	TROP	5300.6	“ ”
	CPFF	0.1924	“ ”
	THCF	1.8827	“ ”
	TROP	5390.6	“ ”
	CPFF	0.1990	“ ”
	THCF	1.9307	“ ”
	TROP	5480.6	“ ”
	CPFF	0.2059	“ ”
	THCF	1.9792	“ ”
	TROP	5570.6	“ ”
	CPFF	0.2128	“ ”
	THCF	2.0282	“ ”
	TROP	5660.6	“ ”
	CPFF	0.2199	“ ”
	THCF	2.0777	“ ”
	TROP	5750.6	“ ”
	CPFF	0.2270	“ ”
	THCF	2.1276	“ ”
	TROP	5840.6	“ ”
	CPFF	0.2343	“ ”
	THCF	2.1777	“ ”

Table A.19: Rod relative power factors from neutronic calculations (fresh fuel)

Rod	Relative power factor	Rod	Relative power factor	Rod	Relative power factor
1	0.0000	23	1.5179	45	1.4131
2	1.5254	24	1.5219	46	1.47641
3	1.4778	25	0	47	1.47641
4	1.5259	26	1.5389	48	1.47641
5	1.4786	27	1.5095	49	1.4764
6	1.4804	28	1.4343	50	1.3820
7	0.0000	29	1.5	51	1.2610
8	1.5274	30	1.4592	52	1.2260
9	1.5311	31	1.4602	53	0.9410
10	0.0000	32	1.5019	54	0.9420
11	1.5259	33	1.4543	—	—
12	1.4795	34	1.4249	—	—
13	1.4852	35	1.3984	—	—
14	1.5466	36	1.3899	—	—
15	1.5256	37	1.4403	—	—
16	1.5229	38	1.4334	—	—
17	1.4769	39	1.4331	—	—
18	1.4836	40	1.4378	—	—
19	1.5499	41	1.4237	—	—
20	1.5611	42	1.4078	—	—
21	0.0000	43	1.3968	—	—
22	0.0000	44	1.3991	—	—

Table A.20: UO_2 Thermal-physical properties for UO_2 (fresh fuel)

Temperature (°F)	Specific heat (BTU/lbm · °F)	Thermal conductivity (BTU/hr · ft · °F)
440.6	0.0673	3.4160
530.6	0.0687	3.1845
620.6	0.0698	2.9824
710.6	0.0707	2.8045
800.6	0.0715	2.6467
890.6	0.0722	2.5059
980.6	0.0729	2.3794
1070.6	0.0735	2.2651
1160.6	0.0740	2.1615
1250.6	0.0745	2.0670
1340.6	0.0750	1.9804
1430.6	0.0754	1.9009
1520.6	0.0758	1.8276
1610.6	0.0762	1.7600
1700.6	0.0767	1.6974
1790.6	0.0771	1.6395
1880.6	0.0775	1.5860
1970.6	0.0779	1.5365
2060.6	0.0783	1.4909
2150.6	0.0788	1.4491
2240.6	0.0793	1.4109
2330.6	0.0799	1.3762

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Temperature (°F)	Specific heat (BTU/lbm · °F)	Thermal conductivity (BTU/hr · ft · °F)
2420.6	0.0805	1.3449
2510.6	0.0813	1.3172
2600.6	0.0821	1.2928
2690.6	0.0830	1.2718
2780.6	0.0840	1.2542
2870.6	0.0851	1.2399
2960.6	0.0864	1.2290
3050.6	0.0879	1.2213
3140.6	0.0895	1.2170
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

Continued on next page…

Temperature (°F)	Specific heat (BTU/lbm · °F)	Thermal conductivity (BTU/hr · ft · °F)
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	1.9307
5480.6	0.2059	1.9792
5570.6	0.2128	2.0282
5660.6	0.2199	2.0777
5750.6	0.2270	2.1276
5840.6	0.2343	2.1777

A.3.2 Transient Analysis

For transient analysis, 325 rods are modeled: 289 rods in the hot assembly and 36 lumped rods. Therefore, the input for card `RODS.1` is different than that from the steady-state scoping analysis. Fuel rod type and channel connection information for transient analyses are listed in Tables A.10, A.11, and A.12. The number of fuel assemblies model by lumped channels and rods for transient analyses are taken from Figure 5.3 and listed in Table A.9. Tables A.10, A.11, A.12, and the relative rod power factors for transient analysis in Table A.22 are input into card `RODS.9` for the transient analysis. The data in these tables is used in the same manner for the transient analysis input deck formulation for card `RODS.9` as in the steady-state scoping analysis. This table has been left out due to length restrictions.

CARD	*RECORD*	*VALUE*	*BASIS*
RODS.1	INFLAG	rods	group identification flag
	NAXP	1	1 specified axial power profile, defined on *CARDS* RODS.3 and RODS.5
	NROD	325	325 rods modeled in steady-state scoping analysis
	NC	1	1 activates the rod internal conduction model
	NFUELT	2	2 types of rod geometries: fuel rods and control rods/ instrument tubes with outer diameters from Table 5.1
	NMAT	1	1 rod materials for which properties will be input on *CARDS* RODS.70 and RODS.71; rod materials are burnup-dependent thermal-physical properties for UO_2

Continued on next page...

CARD	*RECORD*	*VALUE*	*BASIS*
	IGPFF	0	default value; no temporal gap conductance forcing functions are used
	NFPFF	0	default value; 0 if *RECORD* IGPFF is 0
	NOPT	0	default value; specifies normal rod layout input
	IPOWV	0	default value; specifies constant axial power profiles with time
	ICPR	0	default value; no critical power ratio calculations are required
	IRFF	0	default value; constant radial power factors with time
	NMATB	0	default value; no built-in burnup-dependent fuel properties

Table A.22: Rod relative power factors for transient analysis from neutronic calculations (fresh fuel)

Rod	Relative power factor	Rod	Relative power factor	Rod	Relative power factor
1	0.9232	23	0.9200	45	1.4122
2	1.0250	24	0.9200	46	1.4444
3	0.8600	25	1.3986	47	1.4962
4	0.8000	26	1.3836	48	1.4508
5	0.7900	27	1.3810	49	1.4496
6	1.0800	28	1.3930	50	1.4940
7	1.0200	29	1.4103	51	1.4496
8	1.0700	30	1.4257	52	1.4508
9	1.1500	31	1.4205	53	1.4962
10	0.8200	32	1.4208	54	1.4444
11	0.8800	33	1.4283	55	1.4122
12	0.8600	34	1.4208	56	1.3832
13	1.0700	35	1.4205	57	1.3739
14	1.0700	36	1.4257	58	1.3836
15	1.0700	37	1.4103	59	1.3810
16	1.0700	38	1.3930	60	1.3832
17	0.9500	39	1.3810	61	1.4227
18	1.2500	40	1.3836	62	1.5047
19	0.9300	41	1.3986	63	1.5369
20	1.3600	42	1.3836	64	0.0000
21	0.9200	43	1.3739	65	1.5180
22	0.9200	44	1.3832	66	1.5135

Continued on next page...

Rod	Relative power factor	Rod	Relative power factor	Rod	Relative power factor
67	0.0000	92	1.3930	117	1.5239
68	1.5135	93	1.4103	118	0.0000
69	1.5180	94	1.4444	119	1.5239
70	0.0000	95	1.5369	120	1.5280
71	1.5369	96	1.5612	121	0.0000
72	1.5047	97	1.5226	122	1.5449
73	1.4227	98	1.5449	123	1.5486
74	1.3832	99	1.4781	124	0.0000
75	1.3810	100	1.4719	125	1.4962
76	1.3930	101	1.5222	126	1.4257
77	1.4122	102	1.4719	127	1.4205
78	1.5047	103	1.4781	128	1.4508
79	0.0000	104	1.5449	129	1.5180
80	1.5612	105	1.5226	130	1.4764
81	1.5486	106	1.5612	131	1.4781
82	1.4764	107	1.5369	132	1.5280
83	1.4691	108	1.4444	133	1.4729
84	1.5189	109	1.4103	134	1.4710
85	1.4691	110	1.4257	135	1.5224
86	1.4764	111	1.4962	136	1.4710
87	1.5486	112	0.0000	137	1.4729
88	1.5612	113	1.5486	138	1.5280
89	0.0000	114	1.5449	139	1.4781
90	1.5047	115	0.0000	140	1.4764
91	1.4122	116	1.5280	141	1.5180

Continued on next page. . .

Rod	Relative power factor	Rod	Relative power factor	Rod	Relative power factor
142	1.4508	167	1.5224	192	1.5135
143	1.4205	168	1.5219	193	1.4496
144	1.4208	169	0.0000	194	1.4208
145	1.4496	170	1.5219	195	1.4205
146	1.5135	171	1.5224	196	1.4508
147	1.4691	172	0.0000	197	1.5180
148	1.4719	173	1.5222	198	1.4764
149	1.5239	174	1.5189	199	1.4781
150	1.4710	175	0.0000	200	1.5280
151	1.4702	176	1.4940	201	1.4729
152	1.5219	177	1.4283	202	1.4710
153	1.4702	178	1.4208	203	1.5224
154	1.4710	179	1.4496	204	1.4710
155	1.5239	180	1.5135	205	1.4729
156	1.4719	181	1.4691	206	1.5280
157	1.4691	182	1.4719	207	1.4781
158	1.5135	183	1.5239	208	1.4764
159	1.4496	184	1.4710	209	1.5180
160	1.4208	185	1.4702	210	1.4508
161	1.4283	186	1.5219	211	1.4205
162	1.4940	187	1.4702	212	1.4257
163	0.0000	188	1.4710	213	1.4962
164	1.5189	189	1.5239	214	0.0000
165	1.5222	190	1.4719	215	1.5486
166	0.0000	191	1.4691	216	1.5449

Continued on next page…

Rod	Relative power factor	Rod	Relative power factor	Rod	Relative power factor
217	0.0000	242	1.5612	267	1.5369
218	1.5280	243	1.5369	268	0.0000
219	1.5239	244	1.4444	269	1.5180
220	0.0000	245	1.4103	270	1.5135
221	1.5239	246	1.3930	271	0.0000
222	1.5280	247	1.4122	272	1.5135
223	0.0000	248	1.5047	273	1.5180
224	1.5449	249	0.0000	274	0.0000
225	1.5486	250	1.5612	275	1.5369
226	0.0000	251	1.5486	276	1.5047
227	1.4962	252	1.4764	277	1.4227
228	1.4257	253	1.4691	278	1.3832
229	1.4103	254	1.5189	279	1.3810
230	1.4444	255	1.4691	280	1.3836
231	1.5369	256	1.4764	281	1.3739
232	1.5612	257	1.5486	282	1.3832
233	1.5226	258	1.5612	283	1.4122
234	1.5449	259	0.0000	284	1.4444
235	1.4781	260	1.5047	285	1.4962
236	1.4719	261	1.4122	286	1.4508
237	1.5222	262	1.3930	287	1.4496
238	1.4719	263	1.3810	288	1.4940
239	1.4781	264	1.3832	289	1.4496
240	1.5449	265	1.4227	290	1.4508
241	1.5226	266	1.5047	291	1.4962

Continued on next page...

Rod	Relative power factor	Rod	Relative power factor	Rod	Relative power factor
292	1.4444	317	1.1000	—	—
293	1.4122	318	0.8200	—	—
294	1.3832	319	1.1200	—	—
295	1.3739	320	1.1600	—	—
296	1.3836	321	1.0300	—	—
297	1.3986	322	0.8300	—	—
298	1.3836	323	0.8300	—	—
299	1.3810	324	0.8300	—	—
300	1.3930	325	0.8300	—	—
301	1.4103	—	—	—	—
302	1.4257	—	—	—	—
303	1.4205	—	—	—	—
304	1.4208	—	—	—	—
305	1.4283	—	—	—	—
306	1.4208	—	—	—	—
307	1.4205	—	—	—	—
308	1.4257	—	—	—	—
309	1.4103	—	—	—	—
310	1.3930	—	—	—	—
311	1.3810	—	—	—	—
312	1.3836	—	—	—	—
313	1.3986	—	—	—	—
314	1.1000	—	—	—	—
315	1.1000	—	—	—	—
316	1.1000	—	—	—	—

A.4 PROP

CARD	*RECORD*	*VALUE*	*BASIS*
PROP.1	INFLAG	prop	group identification flag
	NPROP	0	0 specifies direct calculation of water properties from built in EPRI functions
	ISTEAM	0	no superheated steam property tables required
	NFPROP	2	EPRI water property functions are used to directly calculate all fluid properties
	IPVAR	1	fluid properties are evaluated at the local axial level pressure

A.5 DRAG

CARD	*RECORD*	*VALUE*	*BASIS*
DRAG.1	INFLAG	drag	group identification flag
	NCHTP	0	default axial friction correlation is applied to all channels
	NGPTP	1	1 lateral drag loss correlation is specified on *RECORD* DRAG.8 using Equation 3.4
	KIJOPT	4	the lateral loss coefficient is computed with user-specified correlation on *CARD* DRAG.8 and multiplied by LENGTH/PPITCH for each gap
DRAG.7	DDOK	0.374	nominal rod diameter, from Table 5.1
	PPITCH	0.496	nominal rod-to-rod pitch, from Table 5.1
DRAG.8	ATG	3.1515804	coefficients for the lateral drag loss correlation are calculated using Equation 3.4 for the rod diameter and rod-to-rod pitch in Table 5.1
	BTG	-0.2	B coefficient from Equation 3.4
	CTG	0	there is no C coefficient in Equation 3.4
	ALG	3.1515804	the same coefficients are used for laminar flow as for turbulent flow above
	BLG	-0.2	“ ”
	CLG	0	“ ”

A.6 GRID

As stated in Section 5, fuel assemblies employ 8 grid-spacers over the length of the assembly. Grid-spacers are assumed to be located every 20 inches starting 2 inches above the beginning of the heated length. Table A.24 lists the location of each grid-spacer modeled in VIPRE. The form loss coefficient for the grid-spacers has been adjusted to 0.61 to induce the same pressure drop across the core as for the reference core in Table 3.1.

CARD	*RECORD*	*VALUE*	*BASIS*
GRID.1	INFLAG	grid	group identification flag
	KOPT	0	a constant local loss coefficient is used in VIPRE calculations for all grid-spacers
	NKCOR	1	1 constant loss coefficient is applied to all grid-spacers
GRID.2	CDK	0.61	constant loss coefficient which results in the same core pressure drop as for the reference core in Table 3.1
GRID.4	NCI	-1	all channels are subjected to the same grid-spacer design
	NLEV	8	8 axial locations are input to model 8 grid-spacers
GRID.6	AXJ	6	axial level at which the local loss occurs
	KOR	1	index number of the local loss coefficient, *RECORD* NKCOR
	AXJ	26	“ ”
	KOR	1	“ ”
	AXJ	46	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	KOR	1	“ ”
	AXJ	66	“ ”
	KOR	1	“ ”
	AXJ	86	“ ”
	KOR	1	“ ”
	AXJ	106	“ ”
	KOR	1	“ ”
	AXJ	126	“ ”
	KOR	1	“ ”
	AXJ	146	“ ”
	KOR	1	“ ”

Table A.24: Grid-spacer locations

Gridspacer number	Height (in.)
1	6
2	26
3	46
4	66
5	86
6	106
7	126
8	146

A.7 CORR

CARD	*RECORD*	*VALUE*	*BASIS*
CORR.1	INFLAG	corr	group identification flag
	NCOR	1	number of CHF correlations to use for DNBR calculations
	NHTC	1	default correlations are selected for single-phase convection and nucleate boiling flow regimes
	IXCHF	0	default value; heat transfer regime is switched to post-CHF when the DNBR is equal to 1.0
CORR.2	NSCVD	epri	default subcooled void correlation
	NBLVD	epri	default bulk void/quality correlation
	NFRML	epri	default two-phase friction multiplier correlation
	NHTWL	none	default value; no hot wall friction correlation
CORR.3	CHN	0.2	default value for subcooled void correlation
CORR.6	NFCON	epri	default single-phase forced convection heat transfer correlation
	NSUBC	thsp	default subcooled nucleate boiling heat transfer correlation
	NSATB	thsp	default saturated nucleate boiling heat transfer correlation
	NCHFC	w-3l	W-3L CHF correlation is used to define the peak of the boiling curve

Continued on next page...

CARD	*RECORD*	*VALUE*	*BASIS*
	NTRNB	cond	default transition boiling heat transfer correlation
	NFLMB	g5.7	default film boiling heat transfer correlation
	IWALLT	0	default value for NFLMB
CORR.7	CDB	0	default value for NFCON
CORR.9	NCHF	w-3l	DNB analyses are performed using the W-3L CHF correlation
CORR.11	TDCL	0.042	default value for L-grid mixing factor to support W-3L correlation
	SPK	0.066	grid spacing factor to support W-3L correlation, from [35]
	FLGRD	0.986	default value for L-grid factor leading coefficient to support W-3L correlation

A.8 OPER

A.8.1 Steady-State Scoping Analysis

CARD	*RECORD*	*VALUE*	*BASIS*
OPER.1	INFLAG	oper	group identification flag
	IH	1	coolant inlet condition is specified as uniform inlet temperature for *RECORD* HIN on *CARD* OPER.5
	IG	1	inlet flow is specified in lbm/sec in *RECORD* GIN on *CARD* OPER.5
	ISP	0	inlet flow split is set for equal mass flux per channel
	NPOWER	0	core power is specified as power per rod in kW/ft in *RECORD* PWRINP on *CARD* OPER.5
	NDNB	0	no iteration to reach MDNBR limit
	IRUN	1	run 1 case with current boundary conditions
	IFVCR	0	default value; no heat generation in coolant
	LUF	0	read temporal forcing functions (if any) directly from input file
	IHBAL	0	default value
	IKEN	0	default value
OPER.2	DPS	0	use inlet flow boundary conditions specified in *RECORD* IG on *CARD* OPER.1
	DNBRL	0	input is ignored

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	FCOOL	0	default value; no heat generation in coolant
	DNBRC	0.005	default convergence criteria for CHF calculations
	IHROD	0	input is ignored
OPER.5	PREF	2235.03	system operating pressure, from Table 3.1
	HIN	563.18	coolant inlet temperature, from Table 3.1
	GIN	4941.11	total flow for 1/8th core, from Table 3.1
	PWRINP	6.273	average core power in kW/ft, calculated by dividing core power by total number of fuel rods and then the core active height
	HOUT	640.5	core coolant exit enthalpy, calculated for the coolant at system pressure at average exit temperature; input is irrelevant for PWR systems where flow does not reverse
OPER.12	NP	0	no temporal forcing functions for steady-state calculations

A.8.2 Transient Analysis

For transient analyses, the card `OPER.12` is modified so that VIPRE references tables of time-dependent forcing functions for core pressure, coolant inlet temperature, coolant inlet mass flow rate, and core power in cards `OPER.13`, `OPER.14`, `OPER.17`, and `OPER.20`. For complete LOFA transient analysis, Tables A.28, A.29, A.30, and A.31 are used to fill cards `OPER.13`, `OPER.14`, `OPER.17`, and `OPER.20`. Tables A.32, A.33, A.34, and A.35 are used for partial LOFA transient analysis.

CARD	*RECORD*	*VALUE*	*BASIS*
OPER.12	NP	28	number of time-versus-multiplier entries for system pressure on *CARD* OPER.13
	NH	28	number of time-versus-multiplier entries for coolant inlet temperature on *CARD* OPER.14
	NG	28	number of time-versus-multiplier entries for coolant inlet mass flow rate on *CARD* OPER.17
	NQ	28	number of time-versus-multiplier entries for core power on *CARD* OPER.20
OPER.13	YP	0.0000	time in seconds, from Table A.28
	FP	1.0000	pressure multiplier, from Table A.28
	YP	0.0446	time in seconds, from Table A.28
	FP	1.0000	pressure multiplier, from Table A.28
	YP	1.0446	“ ”
	FP	1.0000	“ ”
	YP	2.0446	“ ”
	FP	1.0000	“ ”

Continued on next page…

CARD	*RECORD*	*VALUE*	*BASIS*
	YP	3.0446	“ ”
	FP	1.0000	“ ”
	YP	4.0446	“ ”
	FP	1.0000	“ ”
	YP	5.0446	“ ”
	FP	1.0000	“ ”
	YP	5.5620	“ ”
	FP	1.0008	“ ”
	YP	6.0837	“ ”
	FP	0.9998	“ ”
	YP	6.6146	“ ”
	FP	1.0008	“ ”
	YP	7.0200	“ ”
	FP	1.0016	“ ”
	YP	7.5715	“ ”
	FP	1.0029	“ ”
	YP	8.1374	“ ”
	FP	1.0053	“ ”
	YP	8.5724	“ ”
	FP	1.0078	“ ”
	YP	9.0175	“ ”
	FP	1.0108	“ ”
	YP	9.6285	“ ”
	FP	1.0158	“ ”
	YP	10.1017	“ ”
	FP	1.0205	“ ”
	YP	10.5893	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	FP	1.0250	“ ”
	YP	11.0951	“ ”
	FP	1.0211	“ ”
	YP	11.6264	“ ”
	FP	1.0133	“ ”
	YP	12.1885	“ ”
	FP	1.0001	“ ”
	YP	12.5823	“ ”
	FP	0.9840	“ ”
	YP	13.1823	“ ”
	FP	0.9716	“ ”
	YP	13.5823	“ ”
	FP	0.9692	“ ”
	YP	14.1823	“ ”
	FP	0.9631	“ ”
	YP	14.5823	“ ”
	FP	0.9570	“ ”
	YP	15.1823	“ ”
	FP	0.9493	“ ”
	YP	15.5823	“ ”
	FP	0.9451	“ ”
OPER.14	YH	0.0000	time in seconds, from Table A.29
	FH	1.0000	temperature multiplier, from Table A.29
	YH	0.0446	time in seconds, from Table A.29
	FH	1.0000	temperature multiplier, from Table A.29

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	YH	1.0446	“ ”
	FH	1.0000	“ ”
	YH	2.0446	“ ”
	FH	1.0000	“ ”
	YH	3.0446	“ ”
	FH	1.0000	“ ”
	YH	4.0446	“ ”
	FH	1.0000	“ ”
	YH	5.0446	“ ”
	FH	1.0000	“ ”
	YH	5.5620	“ ”
	FH	1.0000	“ ”
	YH	6.0837	“ ”
	FH	1.0000	“ ”
	YH	6.6146	“ ”
	FH	1.0000	“ ”
	YH	7.0200	“ ”
	FH	1.0000	“ ”
	YH	7.5715	“ ”
	FH	1.0000	“ ”
	YH	8.1374	“ ”
	FH	1.0000	“ ”
	YH	8.5724	“ ”
	FH	1.0000	“ ”
	YH	9.0175	“ ”
	FH	0.9999	“ ”
	YH	9.6285	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	FH	0.9999	“ ”
	YH	10.1017	“ ”
	FH	0.9999	“ ”
	YH	10.5893	“ ”
	FH	0.9998	“ ”
	YH	11.0951	“ ”
	FH	0.9996	“ ”
	YH	11.6264	“ ”
	FH	0.9994	“ ”
	YH	12.1885	“ ”
	FH	0.9991	“ ”
	YH	12.5823	“ ”
	FH	0.9988	“ ”
	YH	13.1823	“ ”
	FH	0.9985	“ ”
	YH	13.5823	“ ”
	FH	0.9983	“ ”
	YH	14.1823	“ ”
	FH	0.9980	“ ”
	YH	14.5823	“ ”
	FH	0.9978	“ ”
	YH	15.1823	“ ”
	FH	0.9974	“ ”
	YH	15.5823	“ ”
	FH	0.9972	“ ”
OPER.17	YG	0.0000	time in seconds, from Table A.30

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CARD	*RECORD*	*VALUE*	*BASIS*
	FG	1.0000	mass flow rate multiplier, from Table A.30
	YG	0.0446	time in seconds, from Table A.30
	FG	1.0000	mass flow rate multiplier, from Table A.30
	YG	1.0446	“ ”
	FG	1.0000	“ ”
	YG	2.0446	“ ”
	FG	1.0000	“ ”
	YG	3.0446	“ ”
	FG	1.0000	“ ”
	YG	4.0446	“ ”
	FG	1.0000	“ ”
	YG	5.0446	“ ”
	FG	1.0000	“ ”
	YG	5.5620	“ ”
	FG	0.9955	“ ”
	YG	6.0837	“ ”
	FG	0.9802	“ ”
	YG	6.6146	“ ”
	FG	0.9602	“ ”
	YG	7.0200	“ ”
	FG	0.9443	“ ”
	YG	7.5715	“ ”
	FG	0.9217	“ ”
	YG	8.1374	“ ”
	FG	0.8980	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	YG	8.5724	“ ”
	FG	0.8794	“ ”
	YG	9.0175	“ ”
	FG	0.8601	“ ”
	YG	9.6285	“ ”
	FG	0.8330	“ ”
	YG	10.1017	“ ”
	FG	0.8115	“ ”
	YG	10.5893	“ ”
	FG	0.7894	“ ”
	YG	11.0951	“ ”
	FG	0.7678	“ ”
	YG	11.6264	“ ”
	FG	0.7440	“ ”
	YG	12.1885	“ ”
	FG	0.7176	“ ”
	YG	12.5823	“ ”
	FG	0.7010	“ ”
	YG	13.1823	“ ”
	FG	0.6644	“ ”
	YG	13.5823	“ ”
	FG	0.6415	“ ”
	YG	14.1823	“ ”
	FG	0.6063	“ ”
	YG	14.5823	“ ”
	FG	0.5819	“ ”
	YG	15.1823	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	FG	0.5429	“ ”
	YG	15.5823	“ ”
	FG	0.5192	“ ”
OPER.20	YQ	0.0000	time in seconds, from Table A.31
	FQ	1.0000	core power multiplier, from Table A.31
	YQ	0.0446	“ ”
	FQ	1.0000	“ ”
	YQ	1.0446	“ ”
	FQ	1.0000	“ ”
	YQ	2.0446	“ ”
	FQ	1.0000	“ ”
	YQ	3.0446	“ ”
	FQ	1.0000	“ ”
	YQ	4.0446	“ ”
	FQ	1.0000	“ ”
	YQ	5.0446	“ ”
	FQ	1.0000	“ ”
	YQ	5.5620	“ ”
	FQ	1.0000	“ ”
	YQ	6.0837	“ ”
	FQ	1.0000	“ ”
	YQ	6.6146	“ ”
	FQ	1.0000	“ ”
	YQ	7.0200	“ ”
	FQ	1.0000	“ ”
	YQ	7.5715	“ ”

Continued on next page. . .

CARD	*RECORD*	*VALUE*	*BASIS*
	FQ	1.0000	“ ”
	YQ	8.1374	“ ”
	FQ	1.0000	“ ”
	YQ	8.5724	“ ”
	FQ	0.9977	“ ”
	YQ	9.0175	“ ”
	FQ	0.9958	“ ”
	YQ	9.6285	“ ”
	FQ	0.6664	“ ”
	YQ	10.1017	“ ”
	FQ	0.1731	“ ”
	YQ	10.5893	“ ”
	FQ	0.1180	“ ”
	YQ	11.0951	“ ”
	FQ	0.1028	“ ”
	YQ	11.6264	“ ”
	FQ	0.0948	“ ”
	YQ	12.1885	“ ”
	FQ	0.0915	“ ”
	YQ	12.5823	“ ”
	FQ	0.0896	“ ”
	YQ	13.1823	“ ”
	FQ	0.0867	“ ”
	YQ	13.5823	“ ”
	FQ	0.0847	“ ”
	YQ	14.1823	“ ”
	FQ	0.0818	“ ”

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CARD	*RECORD*	*VALUE*	*BASIS*
	YQ	14.5823	“ ”
	FQ	0.0802	“ ”
	YQ	15.1823	“ ”
	FQ	0.0785	“ ”
	YQ	15.5823	“ ”
	FQ	0.0773	“ ”

A.9 CONT

A.9.1 Steady-State Scoping Analysis

CARD	*RECORD*	*VALUE*	*BASIS*
CONT.1	INFLAG	cont	group identification flag
CONT.2	TTDUM	0.0	transient time, 0 for steady-state calculations
	NDTDUM	0	input is ignored
	NTRYDM	40	input is ignored for direct solution method
	ITRY	60	input is ignored for direct solution method
	ITRYM	2	default value; minimum number of external iterations
	IDRECT	1	default option; direct solution method
	ITSTEP	0	input ignored for steady-state calculations
	ITMOD	0	input ignored for steady-state calculations
CONT.3	WERRX	0.1	default cross-flow convergence criteria
	WERRY	0.0001	input is ignored for direct solution method
	FERROR	0.0015	default axial flow convergence criteria
	TERROR	0.05	default rod temperature convergence criteria
	HTCERR	0.01	default heat transfer convergence criteria
	DAMPNG	0.8	default cross-flow damping factor

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CARD	*RECORD*	*VALUE*	*BASIS*
	ACCELY	1.5	input is ignored for direct solution method
	ACCELF	1	default axial flow damping factor
CONT.6	NOUT	6	results are only printed for steady-state exit summary and bundle average results
	NPCHAN	0	input is ignored for NOUT=6
	NPGAP	0	input is ignored for NOUT=6
	NPROD	0	input is ignored for NOUT=6
	NPCHF	0	input is ignored for NOUT=6
	NPWL	0	input is ignored for NOUT=6
	NSKIPT	0	input is ignored for steady-state analysis
	NSKIPX	1	default value; number of axial levels to skip when printing results
	LPOPT	0	default value; no line printer plots
	ICOPT	0	default value; no ASP file
	MFOPT	0	default value; no fiche file
	NODUMP	1	default value; no restart file
	IDTAIL	0	input is ignored for NOUT=6
	IDTL1	0	input is ignored for NOUT=6
	IDTL2	0	input is ignored for NOUT=6
CONT.7	TMAX	1000	maximum amount of CPU time allowed for calculations
	TPRINT	0	default value
	DUMPT	0	default value
	TLPLOT	0	default value

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CARD	*RECORD*	*VALUE*	*BASIS*
	TFICHE	0	default value
	TPDUMP	0	default value

Table A.28
Core pressure CLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5620	1.0008
6.0837	0.9998	6.6146	1.0008	7.0200	1.0016	7.5715	1.0029
8.1374	1.0053	8.5724	1.0078	9.0175	1.0108	9.6285	1.0158
10.1017	1.0205	10.5893	1.0250	11.0951	1.0211	11.6264	1.0133
12.1885	1.0001	12.5823	0.9840	13.1823	0.9716	13.5823	0.9692
14.1823	0.9631	14.5823	0.9570	15.1823	0.9493	15.5823	0.9451

Table A.29
Coolant inlet temperature CLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5620	1.0000
6.0837	1.0000	6.6146	1.0000	7.0200	1.0000	7.5715	1.0000
8.1374	1.0000	8.5724	1.0000	9.0175	0.9999	9.6285	0.9999
10.1017	0.9999	10.5893	0.9998	11.0951	0.9996	11.6264	0.9994
12.1885	0.9991	12.5823	0.9988	13.1823	0.9985	13.5823	0.9983
14.1823	0.9980	14.5823	0.9978	15.1823	0.9974	15.5823	0.9972

Table A.30
Coolant inlet mass flow rate CLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5620	0.9955
6.0837	0.9802	6.6146	0.9602	7.0200	0.9443	7.5715	0.9217
8.1374	0.8980	8.5724	0.8794	9.0175	0.8601	9.6285	0.8330
10.1017	0.8115	10.5893	0.7894	11.0951	0.7678	11.6264	0.7440
12.1885	0.7176	12.5823	0.7010	13.1823	0.6644	13.5823	0.6415
14.1823	0.6063	14.5823	0.5819	15.1823	0.5429	15.5823	0.5192

Table A.31

Core power CLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5620	1.0000
6.0837	1.0000	6.6146	1.0000	7.0200	1.0000	7.5715	1.0000
8.1374	1.0000	8.5724	0.9977	9.0175	0.9958	9.6285	0.6664
10.1017	0.1731	10.5893	0.1180	11.0951	0.1028	11.6264	0.0948
12.1885	0.0915	12.5823	0.0896	13.1823	0.0867	13.5823	0.0847
14.1823	0.0818	14.5823	0.0802	15.1823	0.0785	15.5823	0.0773

Table A.32
Core pressure PLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5618	1.0008
6.0798	0.9996	6.6002	1.0001	7.1231	1.0005	7.5168	1.0002
8.0441	1.0001	8.5742	1.0005	9.1073	1.0010	9.5090	1.0014
10.0477	1.0001	10.5926	0.9893	11.0081	0.9828	11.5728	0.9772
12.0037	0.9716	12.5875	0.9622	13.0324	0.9551	13.6347	0.9463
14.0932	0.9401	14.5577	0.9358	15.0284	0.9308	15.5048	0.9252

Table A.33
Coolant inlet temperature PLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5618	1.0000
6.0798	1.0000	6.6002	1.0000	7.1231	1.0000	7.5168	1.0000
8.0441	0.9999	8.5742	0.9999	9.1073	0.9998	9.5090	0.9998
10.0477	0.9997	10.5926	0.9996	11.0081	0.9995	11.5728	0.9994
12.0037	0.9993	12.5875	0.9992	13.0324	0.9991	13.6347	0.9991
14.0932	0.9990	14.5577	0.9990	15.0284	0.9989	15.5048	0.9989

Table A.34
Coolant inlet mass flow rate PLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5618	0.9991
6.0798	0.9953	6.6002	0.9902	7.1231	0.9850	7.5168	0.9810
8.0441	0.9753	8.5742	0.9694	9.1073	0.9634	9.5090	0.9588
10.0477	0.9535	10.5926	0.9492	11.0081	0.9440	11.5728	0.9372
12.0037	0.9320	12.5875	0.9239	13.0324	0.9169	13.6347	0.9071
14.0932	0.8992	14.5577	0.8901	15.0284	0.8820	15.5048	0.8728

Table A.35

Core power PLOFA transient forcing functions

Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier	Time (s)	Multiplier
0.0000	1.0000	0.0446	1.0000	1.0446	1.0000	2.0446	1.0000
3.0446	1.0000	4.0446	1.0000	5.0446	1.0000	5.5618	1.0000
6.0798	1.0000	6.6002	1.0000	7.1231	1.0000	7.5168	1.0000
8.0441	1.0000	8.5742	0.9997	9.1073	0.9974	9.5090	0.9958
10.0477	0.4653	10.5926	0.1444	11.0081	0.1170	11.5728	0.1015
12.0037	0.0944	12.5875	0.0913	13.0324	0.0891	13.6347	0.0862
14.0932	0.0840	14.5577	0.0817	15.0284	0.0800	15.5048	0.0786

A.9.2 Transient Analysis

CARD	*RECORD*	*VALUE*	*BASIS*
CONT.1	INFLAG	cont	group identification flag
CONT.2	TTDUM	15.0	transient time
	NDTDUM	1500	number of time-steps
	NTRYDM	40	maximum number of external iterations, increased from 20 to 40 due to size of problem (325 rods, 292 channels, 31 axial nodes)
	ITRY	60	maximum number of internal iterations, increased from 50 to 60 due to size of problem
	ITRYM	2	default value; minimum number of external iterations
	IDRECT	0	iterative solution method due to size of problem
	ITSTEP	0	constant time step sizes are used
	ITMOD	0	user-specified time step (15 seconds / 1500 time steps = 0.01 s)
CONT.3	WERRX	0.1	default cross-flow convergence criteria
	WERRY	0.0001	default pressure/energy convergence criteria for iterative solution
	FERROR	0.0015	axial flow convergence criteria increased from 0.001 to 0.0015 due to problem size
	TERROR	0.05	default rod temperature convergence criteria

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CARD	*RECORD*	*VALUE*	*BASIS*
	HTCERR	0.01	default heat transfer convergence criteria
	DAMPNG	0.8	default cross-flow damping factor
	ACCELY	1.5	input is ignored for direct solution method
	ACCELF	1	default axial flow damping factor
CONT.6	NOUT	6	results are only printed for steady-state exit summary and bundle average results
	NPCHAN	0	input is ignored for NOUT=6
	NPGAP	0	input is ignored for NOUT=6
	NPROD	0	input is ignored for NOUT=6
	NPCHF	0	input is ignored for NOUT=6
	NPWL	0	input is ignored for NOUT=6
	NSKIPT	1	default value; number of time steps to skip between printed results
	NSKIPX	1	default value; number of axial levels to skip when printing results
	LPOPT	0	default value; no line printer plots
	ICOPT	0	default value; no ASP file
	MFOPT	0	default value; no fiche file
	NODUMP	0	restart file created for transient analysis
	IDTAIL	0	input is ignored for NOUT=6
	IDTL1	0	input is ignored for NOUT=6
	IDTL2	0	input is ignored for NOUT=6

Continued on next page...

CARD	*RECORD*	*VALUE*	*BASIS*
CONT.7	TMAX	10000	maximum amount of CPU time allowed for calculations, maximum time increased due to size of transient problem
	TPRINT	0	default value
	DUMPT	5	information written to restart file every 5 simulation seconds
	TLPLOT	0	default value
	TFICHE	0	default value
	TPDUMP	0	default value

APPENDIX B
VIPRE INPUT DECKS

The following are the input decks for VIPRE-01 MOD2.3 described in Section 5. There are three representative input decks for for the reference UO_2 design: a steady-state scoping analysis deck, a partial LOFA analysis deck, and a complete LOFA analysis deck.

B.1 Steady-state Scoping Analysis

```
*
* UOX 4.9% U235 17x17 Assembly Westinghouse 4-Loop PWR (Comanche Peak)
* 118%Power, T=+2C,-5%Flow, APP=CC1.55,MPEAK=2.42
1,0,0,-1,0    *vipre.1
1/8 PWR Core Hot Bundle Analysis  (uox1 - 02/14/09)  *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
1,0.0590,0.6299,0.4406,1,2,0.122,0    *geom.4
2,0.1362,1.1750,1.1750,2,3,0.122,0,4,0.122,0    *geom.4
3,0.0681,0.5875,0.5875,1,5,0.122,0    *geom.4
4,0.1180,1.2598,0.8812,2,5,0.122,0,7,0.068,0    *geom.4
5,0.1362,1.1750,1.1750,2,6,0.122,0,8,0.122,0    *geom.4
6,0.0590,0.6299,0.4406,1,9,0.068,0    *geom.4
7,0.1180,1.2598,0.8812,2,8,0.122,0,11,0.122,0    *geom.4
8,0.1362,1.1750,1.1750,2,9,0.122,0,12,0.122,0    *geom.4
9,0.1180,1.2598,0.8812,2,10,0.068,0,13,0.122,0    *geom.4
```

```
10,0.0590,0.6299,0.4406,1,14,0.122,0    *geom.4
11,0.1362,1.1750,1.1750,2,12,0.122,0,16,0.122,0    *geom.4
12,0.1362,1.1750,1.1750,2,13,0.122,0,17,0.122,0    *geom.4
13,0.1362,1.1750,1.1750,2,14,0.122,0,18,0.122,0    *geom.4
14,0.1362,1.1750,1.1750,2,15,0.122,0,19,0.122,0    *geom.4
15,0.0590,0.6299,0.4406,1,20,0.068,0    *geom.4
16,0.1180,1.2598,0.8812,2,17,0.122,0,22,0.068,0    *geom.4
17,0.1362,1.1750,1.1750,2,18,0.122,0,23,0.122,0    *geom.4
18,0.1180,1.2598,0.8812,2,19,0.068,0,24,0.068,0    *geom.4
19,0.1180,1.2598,0.8812,2,20,0.122,0,25,0.068,0    *geom.4
20,0.1180,1.2598,0.8812,2,21,0.068,0,26,0.122,0    *geom.4
21,0.0590,0.6299,0.4406,1,27,0.122,0    *geom.4
22,0.1180,1.2598,0.8812,2,23,0.122,0,29,0.122,0    *geom.4
23,0.1362,1.1750,1.1750,2,24,0.122,0,30,0.122,0    *geom.4
24,0.1180,1.2598,0.8812,2,25,0.068,0,31,0.122,0    *geom.4
25,0.1180,1.2598,0.8812,2,26,0.122,0,32,0.122,0    *geom.4
26,0.1362,1.1750,1.1750,2,27,0.122,0,33,0.122,0    *geom.4
27,0.1362,1.1750,1.1750,2,28,0.122,0,34,0.122,0    *geom.4
28,0.0681,0.5875,0.5875,1,35,0.122,0    *geom.4
29,0.1362,1.1750,1.1750,2,30,0.122,0,37,0.122,0    *geom.4
30,0.1362,1.1750,1.1750,2,31,0.122,0,37,0.122,0    *geom.4
31,0.1362,1.1750,1.1750,2,32,0.122,0,37,0.122,0    *geom.4
32,0.1362,1.1750,1.1750,2,33,0.122,0,37,0.122,0    *geom.4
33,0.1362,1.1750,1.1750,2,34,0.122,0,38,0.122,0    *geom.4
34,0.1362,1.1750,1.1750,2,35,0.122,0,38,0.122,0    *geom.4
35,0.1362,1.1750,1.1750,2,36,0.122,0,38,0.122,0    *geom.4
36,0.0681,0.5875,0.5875,1,38,0.122,0    *geom.4
37,5.3584,48.492,43.473,2,38,1.054,0,39,0.488,0    *geom.4
38,5.3764,48.657,43.620,2,39,0.566,0,40,1.054,0    *geom.4
```

```
39,9.8333,87.011,77.547,2,40,1.054,0,41,1.054,0    *geom.4
40,19.360,174.02,155.09,1,42,2.108,0    *geom.4
41,19.360,174.02,155.09,2,42,2.108,0,44,1.054,0    *geom.4
42,38.415,348.04,310.19,2,43,2.108,0,44,2.108,0    *geom.4
43,19.360,174.02,155.09,1,44,2.108,0    *geom.4
44,267.07,2436.3,2171.3,1,45,9.486,0    *geom.4
45,533.52,4872.6,4342.6    *geom.4
*
* fluid properties are generated from EPRI functions
prop,0,0,2,1    *prop.1
*
* lateral flow resistance is determined by Blasius-type relation
* from Idel'chik
drag,0,1,4    *drag.1
0.374,0.496    *drag.7
3.15,-0.2,0,3.15,-0.2,0    *drag.8
*
* 8 grid spacers, located every 20 in.
* form loss coefficient is 0.61
grid,0,1    *grid.1
0.61    *grid.2
-1,8    *grid.4
6,1,26,1,46,1,66,1,86,1,106,1,126,1,146,1    *grid.6
0    *grid.4
*
* Correlations
*
corr,1,1,0    *corr.1
epri,epri,epri,none    *corr.2
```

```
0.2    *corr.3
epri,thsp,thsp,w-3l,cond,g5.7,0    *corr.6
0    *corr.7
w-3l    *corr.9
0.042,0.066,0.986    *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
2235.03,563.18,4941.11,6.273,640.5    *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
6,0,0,0,0,0,1,1,0,0,0,1,0,0,0    *cont.6
1000,0,0,0,0,0    *cont.7
*
summ,2    *summ.1
6,1,1    *summ.2
8,1,1    *summ.2
*
* Rod Layout - mixed nuclear and control rods
*
* 54 rods with 2 geometry types (nuclear & dummy)
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
```

```
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5254,1,1,0.25,2,0.25    *rods.9
3,1,1.4778,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5259,1,2,0.25,4,0.25    *rods.9
5,1,1.4786,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4804,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5274,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5311,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5259,1,7,0.25,11,0.25    *rods.9
12,1,1.4795,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4852,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5466,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5256,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5229,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4769,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4836,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5499,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5611,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
```

```
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5179,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5219,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5389,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5095,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4343,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.5000,1,22,0.25,29,0.25    *rods.9
30,1,1.4592,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4602,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5019,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4543,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4249,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3984,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3899,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4403,1,29,0.25,37,0.25    *rods.9
38,1,1.4334,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4331,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4378,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4237,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4078,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3968,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3991,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4131,1,36,0.125,38,0.375    *rods.9
46,1,1.47641,1,37,35    *rods.9
47,1,1.47641,1,38,35.125    *rods.9
48,1,1.47641,1,39,66    *rods.9
49,1,1.47641,1,40,132    *rods.9
```

```
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.4351,530.6,0.0687,3.2010,
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,
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,
5840.6,0.2343,2.1777,
endd
*
*
2,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 6.453999E+00
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
```

```
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5254,1,1,0.25,2,0.25    *rods.9
3,1,1.4776,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5259,1,2,0.25,4,0.25    *rods.9
5,1,1.4784,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4802,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5274,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5311,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5258,1,7,0.25,11,0.25    *rods.9
12,1,1.4793,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4850,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5466,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5255,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5228,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4768,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4834,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5499,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
```

```
23,1,1.5178,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5219,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5389,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5096,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4341,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.5000,1,22,0.25,29,0.25    *rods.9
30,1,1.4590,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4601,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5019,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4541,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4247,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3982,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3898,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4401,1,29,0.25,37,0.25    *rods.9
38,1,1.4332,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4329,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4377,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4235,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4077,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3966,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3990,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4131,1,36,0.125,38,0.375    *rods.9
46,1,1.47631,1,37,35    *rods.9
47,1,1.47631,1,38,35.125    *rods.9
48,1,1.47631,1,39,66    *rods.9
49,1,1.47631,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
```

```
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.4160,530.6,0.0687,3.1845,
620.6,0.0698,2.9824,710.6,0.0707,2.8045,
800.6,0.0715,2.6467,890.6,0.0722,2.5059,
980.6,0.0729,2.3794,1070.6,0.0735,2.2651,
1160.6,0.0740,2.1615,1250.6,0.0745,2.0670,
1340.6,0.0750,1.9804,1430.6,0.0754,1.9009,
1520.6,0.0758,1.8276,1610.6,0.0762,1.7600,
1700.6,0.0767,1.6974,1790.6,0.0771,1.6395,
1880.6,0.0775,1.5860,1970.6,0.0779,1.5365,
2060.6,0.0783,1.4909,2150.6,0.0788,1.4491,
2240.6,0.0793,1.4109,2330.6,0.0799,1.3762,
2420.6,0.0805,1.3449,2510.6,0.0813,1.3172,
2600.6,0.0821,1.2928,2690.6,0.0830,1.2718,
2780.6,0.0840,1.2542,2870.6,0.0851,1.2399,
```

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2960.6,0.0864,1.2290,3050.6,0.0879,1.2213,
3140.6,0.0895,1.2170,3230.6,0.0914,1.2158,
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,
5300.6,0.1924,1.8827,5390.6,0.1990,1.9307,
5480.6,0.2059,1.9792,5570.6,0.2128,2.0282,
5660.6,0.2199,2.0777,5750.6,0.2270,2.1276,
5840.6,0.2343,2.1777,
endd
*
*
3,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.290800E+01
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
```

```
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5251,1,1,0.25,2,0.25    *rods.9
3,1,1.4771,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5257,1,2,0.25,4,0.25    *rods.9
5,1,1.4779,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4797,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5272,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5309,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5256,1,7,0.25,11,0.25    *rods.9
12,1,1.4789,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4846,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5464,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5253,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5227,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4764,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4830,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5499,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5177,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5218,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
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25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5390,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5096,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4340,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.5000,1,22,0.25,29,0.25    *rods.9
30,1,1.4587,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4598,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5019,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4540,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4245,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3980,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3896,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4398,1,29,0.25,37,0.25    *rods.9
38,1,1.4329,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4326,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4374,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4233,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4075,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3965,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3990,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4131,1,36,0.125,38,0.375    *rods.9
46,1,1.47611,1,37,35    *rods.9
47,1,1.47611,1,38,35.125    *rods.9
48,1,1.47611,1,39,66    *rods.9
49,1,1.47611,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
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54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.4117,530.6,0.0687,3.1807,
620.6,0.0698,2.9791,710.6,0.0707,2.8016,
800.6,0.0715,2.6442,890.6,0.0722,2.5037,
980.6,0.0729,2.3775,1070.6,0.0735,2.2636,
1160.6,0.0740,2.1602,1250.6,0.0745,2.0659,
1340.6,0.0750,1.9795,1430.6,0.0754,1.9002,
1520.6,0.0758,1.8270,1610.6,0.0762,1.7595,
1700.6,0.0767,1.6970,1790.6,0.0771,1.6392,
1880.6,0.0775,1.5857,1970.6,0.0779,1.5363,
2060.6,0.0783,1.4907,2150.6,0.0788,1.4489,
2240.6,0.0793,1.4107,2330.6,0.0799,1.3760,
2420.6,0.0805,1.3448,2510.6,0.0813,1.3171,
2600.6,0.0821,1.2927,2690.6,0.0830,1.2717,
2780.6,0.0840,1.2541,2870.6,0.0851,1.2398,
2960.6,0.0864,1.2289,3050.6,0.0879,1.2213,
3140.6,0.0895,1.2169,3230.6,0.0914,1.2158,
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3320.6,0.0934,1.2179,3410.6,0.0956,1.2231,
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,
4220.6,0.1254,1.3970,4310.6,0.1299,1.4286,
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,
5840.6,0.2343,2.1777,
endd
*
*
4,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.936200E+01
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
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1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5250,1,1,0.25,2,0.25    *rods.9
3,1,1.4768,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5255,1,2,0.25,4,0.25    *rods.9
5,1,1.4776,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4794,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5270,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5307,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5255,1,7,0.25,11,0.25    *rods.9
12,1,1.4786,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4843,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5463,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5251,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5226,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4761,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4827,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5498,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5176,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5217,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5390,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
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27,1,1.5096,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4337,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4999,1,22,0.25,29,0.25    *rods.9
30,1,1.4585,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4596,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5019,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4537,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4243,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3977,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3894,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4395,1,29,0.25,37,0.25    *rods.9
38,1,1.4326,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4323,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4372,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4230,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4072,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3962,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3988,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4130,1,36,0.125,38,0.375    *rods.9
46,1,1.47591,1,37,35    *rods.9
47,1,1.47591,1,38,35.125    *rods.9
48,1,1.47591,1,39,66    *rods.9
49,1,1.47591,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
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*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.4087,530.6,0.0687,3.1781,
620.6,0.0698,2.9768,710.6,0.0707,2.7996,
800.6,0.0715,2.6425,890.6,0.0722,2.5022,
980.6,0.0729,2.3762,1070.6,0.0735,2.2625,
1160.6,0.0740,2.1592,1250.6,0.0745,2.0651,
1340.6,0.0750,1.9789,1430.6,0.0754,1.8996,
1520.6,0.0758,1.8266,1610.6,0.0762,1.7591,
1700.6,0.0767,1.6967,1790.6,0.0771,1.6389,
1880.6,0.0775,1.5855,1970.6,0.0779,1.5361,
2060.6,0.0783,1.4906,2150.6,0.0788,1.4488,
2240.6,0.0793,1.4106,2330.6,0.0799,1.3759,
2420.6,0.0805,1.3448,2510.6,0.0813,1.3170,
2600.6,0.0821,1.2926,2690.6,0.0830,1.2717,
2780.6,0.0840,1.2540,2870.6,0.0851,1.2398,
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,
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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,
4940.6,0.1671,1.6994,5030.6,0.1732,1.7438,
5120.6,0.1794,1.7892,5210.6,0.1858,1.8355,
5300.6,0.1924,1.8827,5390.6,0.1990,1.9306,
5480.6,0.2059,1.9792,5570.6,0.2128,2.0282,
5660.6,0.2199,2.0777,5750.6,0.2270,2.1276,
5840.6,0.2343,2.1776,
endd
*
*
5,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.581599E+01
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
```

```
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5248,1,1,0.25,2,0.25    *rods.9
3,1,1.4765,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5254,1,2,0.25,4,0.25    *rods.9
5,1,1.4773,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4791,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5269,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5306,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5253,1,7,0.25,11,0.25    *rods.9
12,1,1.4783,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4840,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5462,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5249,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5224,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4758,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4825,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5497,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5175,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5216,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5390,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5095,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4335,1,21,0.125,27,0.25,28,0.125    *rods.9
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29,1,1.4997,1,22,0.25,29,0.25    *rods.9
30,1,1.4582,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4594,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5018,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4535,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4240,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3975,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3892,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4393,1,29,0.25,37,0.25    *rods.9
38,1,1.4323,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4320,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4369,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4227,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4070,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3960,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3986,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4129,1,36,0.125,38,0.375    *rods.9
46,1,1.47571,1,37,35    *rods.9
47,1,1.47571,1,38,35.125    *rods.9
48,1,1.47571,1,39,66    *rods.9
49,1,1.47571,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
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* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.4062,530.6,0.0687,3.1760,
620.6,0.0698,2.9750,710.6,0.0707,2.7980,
800.6,0.0715,2.6410,890.6,0.0722,2.5009,
980.6,0.0729,2.3751,1070.6,0.0735,2.2615,
1160.6,0.0740,2.1585,1250.6,0.0745,2.0644,
1340.6,0.0750,1.9783,1430.6,0.0754,1.8992,
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,
2060.6,0.0783,1.4905,2150.6,0.0788,1.4487,
2240.6,0.0793,1.4105,2330.6,0.0799,1.3759,
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,
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4040.6,0.1172,1.3403,4130.6,0.1212,1.3675,
4220.6,0.1254,1.3969,4310.6,0.1299,1.4285,
4400.6,0.1346,1.4621,4490.6,0.1395,1.4977,
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,
5480.6,0.2059,1.9792,5570.6,0.2128,2.0282,
5660.6,0.2199,2.0777,5750.6,0.2270,2.1275,
5840.6,0.2343,2.1776,
endd
*
*
6,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.226999E+01
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
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2,1,1.5247,1,1,0.25,2,0.25    *rods.9

3,1,1.4763,1,1,0.125,2,0.25,3,0.125    *rods.9

4,1,1.5252,1,2,0.25,4,0.25    *rods.9

5,1,1.4771,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9

6,1,1.4789,1,3,0.125,5,0.25,6,0.125    *rods.9

7,2,0,1,4,0.25,7,0.25,0,0    *rods.9

8,1,1.5268,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9

9,1,1.5305,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9

10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9

11,1,1.5252,1,7,0.25,11,0.25    *rods.9

12,1,1.4781,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9

13,1,1.4838,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9

14,1,1.5461,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9

15,1,1.5248,1,10,0.125,14,0.25,15,0.125    *rods.9

16,1,1.5223,1,11,0.25,16,0.25,0,0    *rods.9

17,1,1.4756,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9

18,1,1.4823,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.5496,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.5175,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.5216,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.5390,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.5095,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.4334,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.4997,1,22,0.25,29,0.25    *rods.9

30,1,1.4581,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
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31,1,1.4592,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5017,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4534,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4239,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3974,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3891,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4392,1,29,0.25,37,0.25    *rods.9
38,1,1.4322,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4319,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4368,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4226,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4069,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3959,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3986,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4129,1,36,0.125,38,0.375    *rods.9
46,1,1.47561,1,37,35    *rods.9
47,1,1.47561,1,38,35.125    *rods.9
48,1,1.47561,1,39,66    *rods.9
49,1,1.47561,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
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0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.4041,530.6,0.0687,3.1742,
620.6,0.0698,2.9734,710.6,0.0707,2.7966,
800.6,0.0715,2.6398,890.6,0.0722,2.4999,
980.6,0.0729,2.3742,1070.6,0.0735,2.2608,
1160.6,0.0740,2.1578,1250.6,0.0745,2.0639,
1340.6,0.0750,1.9779,1430.6,0.0754,1.8988,
1520.6,0.0758,1.8259,1610.6,0.0762,1.7586,
1700.6,0.0767,1.6962,1790.6,0.0771,1.6385,
1880.6,0.0775,1.5851,1970.6,0.0779,1.5358,
2060.6,0.0783,1.4903,2150.6,0.0788,1.4486,
2240.6,0.0793,1.4104,2330.6,0.0799,1.3758,
2420.6,0.0805,1.3446,2510.6,0.0813,1.3169,
2600.6,0.0821,1.2925,2690.6,0.0830,1.2715,
2780.6,0.0840,1.2539,2870.6,0.0851,1.2397,
2960.6,0.0864,1.2288,3050.6,0.0879,1.2212,
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,
3860.6,0.1099,1.2932,3950.6,0.1134,1.3155,
4040.6,0.1172,1.3403,4130.6,0.1212,1.3675,
4220.6,0.1254,1.3969,4310.6,0.1299,1.4285,
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4400.6,0.1346,1.4621,4490.6,0.1395,1.4976,
4580.6,0.1446,1.5349,4670.6,0.1499,1.5739,
4760.6,0.1555,1.6144,4850.6,0.1612,1.6562,
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,
5840.6,0.2343,2.1776,
endd
*
*
7,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.613499E+02
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5245,1,1,0.25,2,0.25    *rods.9
3,1,1.4759,1,1,0.125,2,0.25,3,0.125    *rods.9
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4,1,1.5250,1,2,0.25,4,0.25    *rods.9
5,1,1.4767,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4785,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5266,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5303,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5251,1,7,0.25,11,0.25    *rods.9
12,1,1.4777,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4835,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5460,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5246,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5222,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4753,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4820,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5496,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5173,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5215,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5390,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5095,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4332,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4996,1,22,0.25,29,0.25    *rods.9
30,1,1.4579,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4590,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5017,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
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33,1,1.4532,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.4237,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,1.3971,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,1.3889,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.4389,1,29,0.25,37,0.25    *rods.9

38,1,1.4319,1,29,0.25,30,0.25,37,0.5    *rods.9

39,1,1.4316,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,1.4365,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,1.4224,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9

42,1,1.4066,1,33,0.25,34,0.25,38,0.5    *rods.9

43,1,1.3957,1,34,0.25,35,0.25,38,0.5    *rods.9

44,1,1.3984,1,35,0.25,36,0.25,38,0.5    *rods.9

45,1,1.4128,1,36,0.125,38,0.375    *rods.9

46,1,1.47541,1,37,35    *rods.9

47,1,1.47541,1,38,35.125    *rods.9

48,1,1.47541,1,39,66    *rods.9

49,1,1.47541,1,40,132    *rods.9

50,1,1.382,1,41,132    *rods.9

51,1,1.261,1,42,264    *rods.9

52,1,1.226,1,43,132    *rods.9

53,1,0.941,1,44,1848    *rods.9

54,1,0.942,1,45,3696    *rods.9

0    *rods.9

*              Fuel Geometry Types

*

* nuclear type geometry - used for nuclear rods

1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62

0,1,0,0,0,2000,0.95,0    *rods.63

*
```

```
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.3806,530.6,0.0687,3.1537,
620.6,0.0698,2.9555,710.6,0.0707,2.7810,
800.6,0.0715,2.6261,890.6,0.0722,2.4879,
980.6,0.0729,2.3638,1070.6,0.0735,2.2518,
1160.6,0.0740,2.1502,1250.6,0.0745,2.0574,
1340.6,0.0750,1.9725,1430.6,0.0754,1.8943,
1520.6,0.0758,1.8221,1610.6,0.0762,1.7553,
1700.6,0.0767,1.6934,1790.6,0.0771,1.6361,
1880.6,0.0775,1.5831,1970.6,0.0779,1.5340,
2060.6,0.0783,1.4887,2150.6,0.0788,1.4471,
2240.6,0.0793,1.4091,2330.6,0.0799,1.3746,
2420.6,0.0805,1.3435,2510.6,0.0813,1.3159,
2600.6,0.0821,1.2916,2690.6,0.0830,1.2707,
2780.6,0.0840,1.2532,2870.6,0.0851,1.2390,
2960.6,0.0864,1.2281,3050.6,0.0879,1.2205,
3140.6,0.0895,1.2162,3230.6,0.0914,1.2151,
3320.6,0.0934,1.2172,3410.6,0.0956,1.2225,
3500.6,0.0980,1.2307,3590.6,0.1006,1.2420,
3680.6,0.1035,1.2562,3770.6,0.1066,1.2732,
3860.6,0.1099,1.2929,3950.6,0.1134,1.3152,
4040.6,0.1172,1.3400,4130.6,0.1212,1.3671,
4220.6,0.1254,1.3966,4310.6,0.1299,1.4282,
4400.6,0.1346,1.4618,4490.6,0.1395,1.4973,
4580.6,0.1446,1.5346,4670.6,0.1499,1.5736,
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4760.6,0.1555,1.6141,4850.6,0.1612,1.6560,
4940.6,0.1671,1.6992,5030.6,0.1732,1.7435,
5120.6,0.1794,1.7889,5210.6,0.1858,1.8353,
5300.6,0.1924,1.8825,5390.6,0.1990,1.9304,
5480.6,0.2059,1.9789,5570.6,0.2128,2.0280,
5660.6,0.2199,2.0775,5750.6,0.2270,2.1273,
5840.6,0.2343,2.1774,
endd
*
*
8,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.226999E+02
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5244,1,1,0.25,2,0.25    *rods.9
3,1,1.4757,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5250,1,2,0.25,4,0.25    *rods.9
5,1,1.4766,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
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6,1,1.4783,1,3,0.125,5,0.25,6,0.125    *rods.9

7,2,0,1,4,0.25,7,0.25,0,0    *rods.9

8,1,1.5265,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9

9,1,1.5302,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9

10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9

11,1,1.5250,1,7,0.25,11,0.25    *rods.9

12,1,1.4776,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9

13,1,1.4833,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9

14,1,1.5459,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9

15,1,1.5245,1,10,0.125,14,0.25,15,0.125    *rods.9

16,1,1.5221,1,11,0.25,16,0.25,0,0    *rods.9

17,1,1.4751,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9

18,1,1.4818,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.5495,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.5172,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.5214,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.5389,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.5093,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.4329,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.4994,1,22,0.25,29,0.25    *rods.9

30,1,1.4576,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.4588,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.5015,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.4530,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.4234,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
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35,1,1.3968,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3885,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4386,1,29,0.25,37,0.25    *rods.9
38,1,1.4316,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4313,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4363,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4221,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4063,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3954,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3981,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4125,1,36,0.125,38,0.375    *rods.9
46,1,1.47521,1,37,35    *rods.9
47,1,1.47521,1,38,35.125    *rods.9
48,1,1.47521,1,39,66    *rods.9
49,1,1.47521,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
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*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.3614,530.6,0.0687,3.1370,
620.6,0.0698,2.9409,710.6,0.0707,2.7681,
800.6,0.0715,2.6148,890.6,0.0722,2.4780,
980.6,0.0729,2.3552,1070.6,0.0735,2.2443,
1160.6,0.0740,2.1437,1250.6,0.0745,2.0519,
1340.6,0.0750,1.9677,1430.6,0.0754,1.8902,
1520.6,0.0758,1.8186,1610.6,0.0762,1.7523,
1700.6,0.0767,1.6908,1790.6,0.0771,1.6338,
1880.6,0.0775,1.5810,1970.6,0.0779,1.5322,
2060.6,0.0783,1.4871,2150.6,0.0788,1.4457,
2240.6,0.0793,1.4078,2330.6,0.0799,1.3734,
2420.6,0.0805,1.3424,2510.6,0.0813,1.3148,
2600.6,0.0821,1.2906,2690.6,0.0830,1.2698,
2780.6,0.0840,1.2523,2870.6,0.0851,1.2382,
2960.6,0.0864,1.2273,3050.6,0.0879,1.2198,
3140.6,0.0895,1.2155,3230.6,0.0914,1.2145,
3320.6,0.0934,1.2166,3410.6,0.0956,1.2219,
3500.6,0.0980,1.2302,3590.6,0.1006,1.2415,
3680.6,0.1035,1.2557,3770.6,0.1066,1.2727,
3860.6,0.1099,1.2924,3950.6,0.1134,1.3147,
4040.6,0.1172,1.3395,4130.6,0.1212,1.3667,
4220.6,0.1254,1.3962,4310.6,0.1299,1.4278,
4400.6,0.1346,1.4614,4490.6,0.1395,1.4970,
4580.6,0.1446,1.5343,4670.6,0.1499,1.5733,
4760.6,0.1555,1.6138,4850.6,0.1612,1.6557,
4940.6,0.1671,1.6989,5030.6,0.1732,1.7432,
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5120.6,0.1794,1.7887,5210.6,0.1858,1.8350,
5300.6,0.1924,1.8822,5390.6,0.1990,1.9301,
5480.6,0.2059,1.9787,5570.6,0.2128,2.0278,
5660.6,0.2199,2.0773,5750.6,0.2270,2.1271,
5840.6,0.2343,2.1772,
endd
*
*
9,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 6.453998E+02
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5243,1,1,0.25,2,0.25    *rods.9
3,1,1.4755,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5248,1,2,0.25,4,0.25    *rods.9
5,1,1.4763,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4781,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
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8,1,1.5264,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5301,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5248,1,7,0.25,11,0.25    *rods.9
12,1,1.4773,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4831,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5459,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5244,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5220,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4749,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4816,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5495,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5171,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5213,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5389,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5093,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4327,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4993,1,22,0.25,29,0.25    *rods.9
30,1,1.4574,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4585,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5014,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4528,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4231,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3964,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3882,1,28,0.125,35,0.25,36,0.125    *rods.9
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37,1,1.4383,1,29,0.25,37,0.25    *rods.9
38,1,1.4313,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4310,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4360,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4218,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4059,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3950,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3978,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4122,1,36,0.125,38,0.375    *rods.9
46,1,1.47501,1,37,35    *rods.9
47,1,1.47501,1,38,35.125    *rods.9
48,1,1.47501,1,39,66    *rods.9
49,1,1.47501,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
```

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1,61,651.186,UOX    *rods.70
440.6,0.0673,3.3295,530.6,0.0687,3.1093,
620.6,0.0698,2.9166,710.6,0.0707,2.7467,
800.6,0.0715,2.5960,890.6,0.0722,2.4614,
980.6,0.0729,2.3407,1070.6,0.0735,2.2317,
1160.6,0.0740,2.1327,1250.6,0.0745,2.0424,
1340.6,0.0750,1.9595,1430.6,0.0754,1.8831,
1520.6,0.0758,1.8124,1610.6,0.0762,1.7469,
1700.6,0.0767,1.6861,1790.6,0.0771,1.6296,
1880.6,0.0775,1.5773,1970.6,0.0779,1.5288,
2060.6,0.0783,1.4840,2150.6,0.0788,1.4429,
2240.6,0.0793,1.4052,2330.6,0.0799,1.3710,
2420.6,0.0805,1.3402,2510.6,0.0813,1.3128,
2600.6,0.0821,1.2887,2690.6,0.0830,1.2680,
2780.6,0.0840,1.2507,2870.6,0.0851,1.2366,
2960.6,0.0864,1.2259,3050.6,0.0879,1.2184,
3140.6,0.0895,1.2142,3230.6,0.0914,1.2132,
3320.6,0.0934,1.2154,3410.6,0.0956,1.2207,
3500.6,0.0980,1.2291,3590.6,0.1006,1.2404,
3680.6,0.1035,1.2547,3770.6,0.1066,1.2717,
3860.6,0.1099,1.2915,3950.6,0.1134,1.3138,
4040.6,0.1172,1.3387,4130.6,0.1212,1.3659,
4220.6,0.1254,1.3954,4310.6,0.1299,1.4271,
4400.6,0.1346,1.4607,4490.6,0.1395,1.4963,
4580.6,0.1446,1.5336,4670.6,0.1499,1.5726,
4760.6,0.1555,1.6131,4850.6,0.1612,1.6551,
4940.6,0.1671,1.6983,5030.6,0.1732,1.7427,
5120.6,0.1794,1.7881,5210.6,0.1858,1.8345,
5300.6,0.1924,1.8817,5390.6,0.1990,1.9296,
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5480.6,0.2059,1.9782,5570.6,0.2128,2.0273,
5660.6,0.2199,2.0768,5750.6,0.2270,2.1267,
5840.6,0.2343,2.1768,
endd
*
*
10,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 9.680997E+02
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*            Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5241,1,1,0.25,2,0.25    *rods.9
3,1,1.4752,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5246,1,2,0.25,4,0.25    *rods.9
5,1,1.4760,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4778,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5262,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5299,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
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10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9

11,1,1.5247,1,7,0.25,11,0.25    *rods.9

12,1,1.4770,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9

13,1,1.4828,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9

14,1,1.5457,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9

15,1,1.5242,1,10,0.125,14,0.25,15,0.125    *rods.9

16,1,1.5218,1,11,0.25,16,0.25,0,0    *rods.9

17,1,1.4745,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9

18,1,1.4813,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.5494,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.5611,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.5169,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.5211,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.5388,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.5091,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.4323,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.4991,1,22,0.25,29,0.25    *rods.9

30,1,1.4570,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.4582,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.5012,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.4524,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.4227,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,1.3959,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,1.3877,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.4379,1,29,0.25,37,0.25    *rods.9

38,1,1.4308,1,29,0.25,30,0.25,37,0.5    *rods.9
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39,1,1.4306,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,1.4356,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,1.4213,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9

42,1,1.4055,1,33,0.25,34,0.25,38,0.5    *rods.9

43,1,1.3945,1,34,0.25,35,0.25,38,0.5    *rods.9

44,1,1.3973,1,35,0.25,36,0.25,38,0.5    *rods.9

45,1,1.4118,1,36,0.125,38,0.375    *rods.9

46,1,1.47471,1,37,35    *rods.9

47,1,1.47471,1,38,35.125    *rods.9

48,1,1.47471,1,39,66    *rods.9

49,1,1.47471,1,40,132    *rods.9

50,1,1.382,1,41,132    *rods.9

51,1,1.261,1,42,264    *rods.9

52,1,1.226,1,43,132    *rods.9

53,1,0.941,1,44,1848    *rods.9

54,1,0.942,1,45,3696    *rods.9

0    *rods.9

*             Fuel Geometry Types

*

* nuclear type geometry - used for nuclear rods

1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62

0,1,0,0,0,2000,0.95,0    *rods.63

*

* dummy type geometry - used for control rods

2,dumy,0.482,0,0    *rods.68

*

* Fuel thermal-physical property table

1,61,651.186,UOX    *rods.70

440.6,0.0673,3.3005,530.6,0.0687,3.0840,
```

```
620.6,0.0698,2.8945,710.6,0.0707,2.7272,
800.6,0.0715,2.5788,890.6,0.0722,2.4463,
980.6,0.0729,2.3273,1070.6,0.0735,2.2200,
1160.6,0.0740,2.1226,1250.6,0.0745,2.0336,
1340.6,0.0750,1.9519,1430.6,0.0754,1.8765,
1520.6,0.0758,1.8066,1610.6,0.0762,1.7418,
1700.6,0.0767,1.6816,1790.6,0.0771,1.6257,
1880.6,0.0775,1.5737,1970.6,0.0779,1.5256,
2060.6,0.0783,1.4811,2150.6,0.0788,1.4402,
2240.6,0.0793,1.4028,2330.6,0.0799,1.3687,
2420.6,0.0805,1.3381,2510.6,0.0813,1.3108,
2600.6,0.0821,1.2869,2690.6,0.0830,1.2663,
2780.6,0.0840,1.2490,2870.6,0.0851,1.2351,
2960.6,0.0864,1.2244,3050.6,0.0879,1.2170,
3140.6,0.0895,1.2129,3230.6,0.0914,1.2120,
3320.6,0.0934,1.2142,3410.6,0.0956,1.2196,
3500.6,0.0980,1.2280,3590.6,0.1006,1.2394,
3680.6,0.1035,1.2537,3770.6,0.1066,1.2708,
3860.6,0.1099,1.2906,3950.6,0.1134,1.3130,
4040.6,0.1172,1.3378,4130.6,0.1212,1.3651,
4220.6,0.1254,1.3946,4310.6,0.1299,1.4263,
4400.6,0.1346,1.4600,4490.6,0.1395,1.4956,
4580.6,0.1446,1.5330,4670.6,0.1499,1.5720,
4760.6,0.1555,1.6125,4850.6,0.1612,1.6545,
4940.6,0.1671,1.6977,5030.6,0.1732,1.7421,
5120.6,0.1794,1.7876,5210.6,0.1858,1.8340,
5300.6,0.1924,1.8812,5390.6,0.1990,1.9291,
5480.6,0.2059,1.9777,5570.6,0.2128,2.0268,
5660.6,0.2199,2.0764,5750.6,0.2270,2.1262,
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5840.6,0.2343,2.1764,
endd
*
*
11,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.290799E+03
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*              Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5240,1,1,0.25,2,0.25    *rods.9
3,1,1.4749,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5245,1,2,0.25,4,0.25    *rods.9
5,1,1.4758,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4776,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5261,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5298,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5245,1,7,0.25,11,0.25    *rods.9
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12,1,1.4768,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4826,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5457,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5242,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5217,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4743,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4811,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5493,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5611,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5168,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5210,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5388,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5090,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4320,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4989,1,22,0.25,29,0.25    *rods.9
30,1,1.4568,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4579,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5011,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4522,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4224,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3956,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3873,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4376,1,29,0.25,37,0.25    *rods.9
38,1,1.4305,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4303,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4353,1,31,0.25,32,0.25,37,0.5    *rods.9
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41,1,1.4210,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4051,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3942,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3970,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4115,1,36,0.125,38,0.375    *rods.9
46,1,1.47451,1,37,35    *rods.9
47,1,1.47451,1,38,35.125    *rods.9
48,1,1.47451,1,39,66    *rods.9
49,1,1.47451,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.2729,530.6,0.0687,3.0599,
620.6,0.0698,2.8733,710.6,0.0707,2.7085,
800.6,0.0715,2.5623,890.6,0.0722,2.4317,
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980.6,0.0729,2.3145,1070.6,0.0735,2.2088,
1160.6,0.0740,2.1128,1250.6,0.0745,2.0251,
1340.6,0.0750,1.9445,1430.6,0.0754,1.8700,
1520.6,0.0758,1.8010,1610.6,0.0762,1.7369,
1700.6,0.0767,1.6772,1790.6,0.0771,1.6217,
1880.6,0.0775,1.5702,1970.6,0.0779,1.5224,
2060.6,0.0783,1.4782,2150.6,0.0788,1.4375,
2240.6,0.0793,1.4003,2330.6,0.0799,1.3665,
2420.6,0.0805,1.3360,2510.6,0.0813,1.3089,
2600.6,0.0821,1.2851,2690.6,0.0830,1.2646,
2780.6,0.0840,1.2474,2870.6,0.0851,1.2335,
2960.6,0.0864,1.2230,3050.6,0.0879,1.2157,
3140.6,0.0895,1.2116,3230.6,0.0914,1.2108,
3320.6,0.0934,1.2131,3410.6,0.0956,1.2185,
3500.6,0.0980,1.2270,3590.6,0.1006,1.2384,
3680.6,0.1035,1.2527,3770.6,0.1066,1.2698,
3860.6,0.1099,1.2897,3950.6,0.1134,1.3121,
4040.6,0.1172,1.3370,4130.6,0.1212,1.3643,
4220.6,0.1254,1.3939,4310.6,0.1299,1.4256,
4400.6,0.1346,1.4593,4490.6,0.1395,1.4949,
4580.6,0.1446,1.5323,4670.6,0.1499,1.5713,
4760.6,0.1555,1.6119,4850.6,0.1612,1.6539,
4940.6,0.1671,1.6971,5030.6,0.1732,1.7415,
5120.6,0.1794,1.7870,5210.6,0.1858,1.8334,
5300.6,0.1924,1.8807,5390.6,0.1990,1.9286,
5480.6,0.2059,1.9772,5570.6,0.2128,2.0264,
5660.6,0.2199,2.0759,5750.6,0.2270,2.1258,
5840.6,0.2343,2.1759,
endd
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*
*
12,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.613499E+03
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5240,1,1,0.25,2,0.25    *rods.9
3,1,1.4749,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5245,1,2,0.25,4,0.25    *rods.9
5,1,1.4757,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4775,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5261,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5298,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5245,1,7,0.25,11,0.25    *rods.9
12,1,1.4767,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4825,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
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14,1,1.5457,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5242,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5217,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4743,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4810,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5494,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5168,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5210,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5388,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5090,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4319,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4989,1,22,0.25,29,0.25    *rods.9
30,1,1.4567,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4578,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5010,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4520,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4222,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3953,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3870,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4374,1,29,0.25,37,0.25    *rods.9
38,1,1.4303,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4301,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4351,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4208,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4049,1,33,0.25,34,0.25,38,0.5    *rods.9
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43,1,1.3939,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3967,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4112,1,36,0.125,38,0.375    *rods.9
46,1,1.47441,1,37,35    *rods.9
47,1,1.47441,1,38,35.125    *rods.9
48,1,1.47441,1,39,66    *rods.9
49,1,1.47441,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.2460,530.6,0.0687,3.0364,
620.6,0.0698,2.8526,710.6,0.0707,2.6903,
800.6,0.0715,2.5461,890.6,0.0722,2.4175,
980.6,0.0729,2.3020,1070.6,0.0735,2.1978,
1160.6,0.0740,2.1032,1250.6,0.0745,2.0167,
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1340.6,0.0750,1.9372,1430.6,0.0754,1.8637,
1520.6,0.0758,1.7954,1610.6,0.0762,1.7320,
1700.6,0.0767,1.6729,1790.6,0.0771,1.6179,
1880.6,0.0775,1.5667,1970.6,0.0779,1.5192,
2060.6,0.0783,1.4753,2150.6,0.0788,1.4349,
2240.6,0.0793,1.3979,2330.6,0.0799,1.3642,
2420.6,0.0805,1.3339,2510.6,0.0813,1.3069,
2600.6,0.0821,1.2832,2690.6,0.0830,1.2629,
2780.6,0.0840,1.2458,2870.6,0.0851,1.2320,
2960.6,0.0864,1.2215,3050.6,0.0879,1.2143,
3140.6,0.0895,1.2103,3230.6,0.0914,1.2095,
3320.6,0.0934,1.2119,3410.6,0.0956,1.2174,
3500.6,0.0980,1.2259,3590.6,0.1006,1.2374,
3680.6,0.1035,1.2517,3770.6,0.1066,1.2689,
3860.6,0.1099,1.2888,3950.6,0.1134,1.3112,
4040.6,0.1172,1.3362,4130.6,0.1212,1.3635,
4220.6,0.1254,1.3931,4310.6,0.1299,1.4248,
4400.6,0.1346,1.4586,4490.6,0.1395,1.4942,
4580.6,0.1446,1.5316,4670.6,0.1499,1.5707,
4760.6,0.1555,1.6113,4850.6,0.1612,1.6533,
4940.6,0.1671,1.6965,5030.6,0.1732,1.7410,
5120.6,0.1794,1.7865,5210.6,0.1858,1.8329,
5300.6,0.1924,1.8802,5390.6,0.1990,1.9281,
5480.6,0.2059,1.9768,5570.6,0.2128,2.0259,
5660.6,0.2199,2.0754,5750.6,0.2270,2.1253,
5840.6,0.2343,2.1755,
endd
*
*
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13,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.258899E+03
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5238,1,1,0.25,2,0.25    *rods.9
3,1,1.4745,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5243,1,2,0.25,4,0.25    *rods.9
5,1,1.4753,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4771,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5259,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5297,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5243,1,7,0.25,11,0.25    *rods.9
12,1,1.4763,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4822,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5456,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5240,1,10,0.125,14,0.25,15,0.125    *rods.9
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16,1,1.5215,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4739,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4807,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5493,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5166,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5208,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5387,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5087,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4313,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4986,1,22,0.25,29,0.25    *rods.9
30,1,1.4562,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4574,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5007,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4516,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4216,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3946,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3863,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4368,1,29,0.25,37,0.25    *rods.9
38,1,1.4297,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4295,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4345,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4201,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4041,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3931,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3959,1,35,0.25,36,0.25,38,0.5    *rods.9
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45,1,1.4105,1,36,0.125,38,0.375    *rods.9
46,1,1.47401,1,37,35    *rods.9
47,1,1.47401,1,38,35.125    *rods.9
48,1,1.47401,1,39,66    *rods.9
49,1,1.47401,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.1939,530.6,0.0687,2.9909,
620.6,0.0698,2.8125,710.6,0.0707,2.6549,
800.6,0.0715,2.5147,890.6,0.0722,2.3897,
980.6,0.0729,2.2775,1070.6,0.0735,2.1763,
1160.6,0.0740,2.0843,1250.6,0.0745,2.0003,
1340.6,0.0750,1.9229,1430.6,0.0754,1.8512,
1520.6,0.0758,1.7845,1610.6,0.0762,1.7223,
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1700.6,0.0767,1.6643,1790.6,0.0771,1.6102,
1880.6,0.0775,1.5598,1970.6,0.0779,1.5130,
2060.6,0.0783,1.4696,2150.6,0.0788,1.4297,
2240.6,0.0793,1.3931,2330.6,0.0799,1.3598,
2420.6,0.0805,1.3298,2510.6,0.0813,1.3031,
2600.6,0.0821,1.2796,2690.6,0.0830,1.2595,
2780.6,0.0840,1.2426,2870.6,0.0851,1.2290,
2960.6,0.0864,1.2187,3050.6,0.0879,1.2116,
3140.6,0.0895,1.2077,3230.6,0.0914,1.2071,
3320.6,0.0934,1.2096,3410.6,0.0956,1.2151,
3500.6,0.0980,1.2238,3590.6,0.1006,1.2353,
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,
4220.6,0.1254,1.3916,4310.6,0.1299,1.4234,
4400.6,0.1346,1.4572,4490.6,0.1395,1.4929,
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,
5300.6,0.1924,1.8791,5390.6,0.1990,1.9272,
5480.6,0.2059,1.9758,5570.6,0.2128,2.0249,
5660.6,0.2199,2.0745,5750.6,0.2270,2.1245,
5840.6,0.2343,2.1746,
endd
*
*
14,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.904299E+03
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rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*              Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5236,1,1,0.25,2,0.25    *rods.9
3,1,1.4741,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5241,1,2,0.25,4,0.25    *rods.9
5,1,1.4749,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4768,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5257,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5295,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5241,1,7,0.25,11,0.25    *rods.9
12,1,1.4760,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4818,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5455,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5239,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5212,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4735,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
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18,1,1.4803,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.5492,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.5163,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.5206,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.5385,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.5084,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.4307,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.4982,1,22,0.25,29,0.25    *rods.9

30,1,1.4558,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.4569,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.5004,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.4511,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.4210,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,1.3939,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,1.3855,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.4362,1,29,0.25,37,0.25    *rods.9

38,1,1.4291,1,29,0.25,30,0.25,37,0.5    *rods.9

39,1,1.4289,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,1.4339,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,1.4195,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9

42,1,1.4035,1,33,0.25,34,0.25,38,0.5    *rods.9

43,1,1.3924,1,34,0.25,35,0.25,38,0.5    *rods.9

44,1,1.3952,1,35,0.25,36,0.25,38,0.5    *rods.9

45,1,1.4098,1,36,0.125,38,0.375    *rods.9

46,1,1.47361,1,37,35    *rods.9
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47,1,1.47361,1,38,35.125    *rods.9
48,1,1.47361,1,39,66    *rods.9
49,1,1.47361,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.1436,530.6,0.0687,2.9468,
620.6,0.0698,2.7736,710.6,0.0707,2.6204,
800.6,0.0715,2.4842,890.6,0.0722,2.3626,
980.6,0.0729,2.2535,1070.6,0.0735,2.1552,
1160.6,0.0740,2.0659,1250.6,0.0745,1.9841,
1340.6,0.0750,1.9088,1430.6,0.0754,1.8388,
1520.6,0.0758,1.7737,1610.6,0.0762,1.7128,
1700.6,0.0767,1.6558,1790.6,0.0771,1.6026,
1880.6,0.0775,1.5530,1970.6,0.0779,1.5068,
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2060.6,0.0783,1.4640,2150.6,0.0788,1.4245,
2240.6,0.0793,1.3883,2330.6,0.0799,1.3554,
2420.6,0.0805,1.3257,2510.6,0.0813,1.2992,
2600.6,0.0821,1.2760,2690.6,0.0830,1.2561,
2780.6,0.0840,1.2394,2870.6,0.0851,1.2260,
2960.6,0.0864,1.2158,3050.6,0.0879,1.2089,
3140.6,0.0895,1.2052,3230.6,0.0914,1.2046,
3320.6,0.0934,1.2072,3410.6,0.0956,1.2129,
3500.6,0.0980,1.2217,3590.6,0.1006,1.2333,
3680.6,0.1035,1.2479,3770.6,0.1066,1.2652,
3860.6,0.1099,1.2852,3950.6,0.1134,1.3078,
4040.6,0.1172,1.3329,4130.6,0.1212,1.3603,
4220.6,0.1254,1.3901,4310.6,0.1299,1.4219,
4400.6,0.1346,1.4557,4490.6,0.1395,1.4915,
4580.6,0.1446,1.5290,4670.6,0.1499,1.5681,
4760.6,0.1555,1.6088,4850.6,0.1612,1.6509,
4940.6,0.1671,1.6942,5030.6,0.1732,1.7387,
5120.6,0.1794,1.7843,5210.6,0.1858,1.8308,
5300.6,0.1924,1.8781,5390.6,0.1990,1.9262,
5480.6,0.2059,1.9748,5570.6,0.2128,2.0240,
5660.6,0.2199,2.0736,5750.6,0.2270,2.1236,
5840.6,0.2343,2.1738,
endd
*
*
15,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.549699E+03
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
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* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5235,1,1,0.25,2,0.25    *rods.9
3,1,1.4739,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5240,1,2,0.25,4,0.25    *rods.9
5,1,1.4747,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4765,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5256,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5294,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5240,1,7,0.25,11,0.25    *rods.9
12,1,1.4757,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4816,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5455,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5238,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5211,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4732,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4801,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5492,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
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20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5162,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5204,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5385,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5083,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4303,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4980,1,22,0.25,29,0.25    *rods.9
30,1,1.4554,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4566,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.5002,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4507,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4205,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3933,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3849,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4358,1,29,0.25,37,0.25    *rods.9
38,1,1.4286,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4284,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4334,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4190,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4029,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3918,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3946,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4092,1,36,0.125,38,0.375    *rods.9
46,1,1.47331,1,37,35    *rods.9
47,1,1.47331,1,38,35.125    *rods.9
48,1,1.47331,1,39,66    *rods.9
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49,1,1.47331,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.0947,530.6,0.0687,2.9039,
620.6,0.0698,2.7357,710.6,0.0707,2.5868,
800.6,0.0715,2.4543,890.6,0.0722,2.3361,
980.6,0.0729,2.2300,1070.6,0.0735,2.1345,
1160.6,0.0740,2.0477,1250.6,0.0745,1.9682,
1340.6,0.0750,1.8949,1430.6,0.0754,1.8267,
1520.6,0.0758,1.7630,1610.6,0.0762,1.7033,
1700.6,0.0767,1.6474,1790.6,0.0771,1.5951,
1880.6,0.0775,1.5462,1970.6,0.0779,1.5007,
2060.6,0.0783,1.4584,2150.6,0.0788,1.4194,
2240.6,0.0793,1.3836,2330.6,0.0799,1.3510,
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2420.6,0.0805,1.3216,2510.6,0.0813,1.2954,
2600.6,0.0821,1.2724,2690.6,0.0830,1.2527,
2780.6,0.0840,1.2362,2870.6,0.0851,1.2230,
2960.6,0.0864,1.2130,3050.6,0.0879,1.2062,
3140.6,0.0895,1.2026,3230.6,0.0914,1.2022,
3320.6,0.0934,1.2049,3410.6,0.0956,1.2107,
3500.6,0.0980,1.2195,3590.6,0.1006,1.2313,
3680.6,0.1035,1.2459,3770.6,0.1066,1.2633,
3860.6,0.1099,1.2834,3950.6,0.1134,1.3061,
4040.6,0.1172,1.3313,4130.6,0.1212,1.3588,
4220.6,0.1254,1.3885,4310.6,0.1299,1.4204,
4400.6,0.1346,1.4543,4490.6,0.1395,1.4901,
4580.6,0.1446,1.5277,4670.6,0.1499,1.5669,
4760.6,0.1555,1.6076,4850.6,0.1612,1.6497,
4940.6,0.1671,1.6931,5030.6,0.1732,1.7376,
5120.6,0.1794,1.7832,5210.6,0.1858,1.8297,
5300.6,0.1924,1.8771,5390.6,0.1990,1.9252,
5480.6,0.2059,1.9739,5570.6,0.2128,2.0231,
5660.6,0.2199,2.0727,5750.6,0.2270,2.1227,
5840.6,0.2343,2.1729,
endd
*
*
16,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.195099E+03
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
```

```
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5233,1,1,0.25,2,0.25    *rods.9
3,1,1.4735,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5238,1,2,0.25,4,0.25    *rods.9
5,1,1.4743,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4761,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5254,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5292,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5238,1,7,0.25,11,0.25    *rods.9
12,1,1.4753,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4812,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5454,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5236,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5209,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4729,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4797,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5491,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5611,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
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22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5160,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5202,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5383,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5080,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4297,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4977,1,22,0.25,29,0.25    *rods.9
30,1,1.4549,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4561,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.4999,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4502,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4199,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3926,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3841,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4352,1,29,0.25,37,0.25    *rods.9
38,1,1.4281,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4278,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4329,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4183,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4022,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3910,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3938,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4085,1,36,0.125,38,0.375    *rods.9
46,1,1.47291,1,37,35    *rods.9
47,1,1.47291,1,38,35.125    *rods.9
48,1,1.47291,1,39,66    *rods.9
49,1,1.47291,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
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51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.0474,530.6,0.0687,2.8622,
620.6,0.0698,2.6988,710.6,0.0707,2.5540,
800.6,0.0715,2.4251,890.6,0.0722,2.3101,
980.6,0.0729,2.2070,1070.6,0.0735,2.1142,
1160.6,0.0740,2.0298,1250.6,0.0745,1.9526,
1340.6,0.0750,1.8811,1430.6,0.0754,1.8146,
1520.6,0.0758,1.7524,1610.6,0.0762,1.6940,
1700.6,0.0767,1.6391,1790.6,0.0771,1.5876,
1880.6,0.0775,1.5395,1970.6,0.0779,1.4946,
2060.6,0.0783,1.4528,2150.6,0.0788,1.4142,
2240.6,0.0793,1.3788,2330.6,0.0799,1.3466,
2420.6,0.0805,1.3175,2510.6,0.0813,1.2916,
2600.6,0.0821,1.2689,2690.6,0.0830,1.2494,
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2780.6,0.0840,1.2331,2870.6,0.0851,1.2200,
2960.6,0.0864,1.2102,3050.6,0.0879,1.2035,
3140.6,0.0895,1.2001,3230.6,0.0914,1.1998,
3320.6,0.0934,1.2026,3410.6,0.0956,1.2085,
3500.6,0.0980,1.2174,3590.6,0.1006,1.2293,
3680.6,0.1035,1.2440,3770.6,0.1066,1.2615,
3860.6,0.1099,1.2817,3950.6,0.1134,1.3044,
4040.6,0.1172,1.3296,4130.6,0.1212,1.3572,
4220.6,0.1254,1.3870,4310.6,0.1299,1.4190,
4400.6,0.1346,1.4529,4490.6,0.1395,1.4888,
4580.6,0.1446,1.5264,4670.6,0.1499,1.5656,
4760.6,0.1555,1.6064,4850.6,0.1612,1.6485,
4940.6,0.1671,1.6919,5030.6,0.1732,1.7365,
5120.6,0.1794,1.7821,5210.6,0.1858,1.8287,
5300.6,0.1924,1.8761,5390.6,0.1990,1.9242,
5480.6,0.2059,1.9729,5570.6,0.2128,2.0222,
5660.6,0.2199,2.0718,5750.6,0.2270,2.1218,
5840.6,0.2343,2.1721,
endd
*
*
17,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.840499E+03
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
```

```
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5232,1,1,0.25,2,0.25    *rods.9
3,1,1.4732,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5237,1,2,0.25,4,0.25    *rods.9
5,1,1.4741,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4759,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5252,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5291,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5237,1,7,0.25,11,0.25    *rods.9
12,1,1.4751,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4810,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5453,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5236,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5208,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4726,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4795,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5491,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5158,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
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24,1,1.5201,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5383,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5078,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4293,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4975,1,22,0.25,29,0.25    *rods.9
30,1,1.4546,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4558,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.4996,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4499,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4194,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3920,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3835,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4348,1,29,0.25,37,0.25    *rods.9
38,1,1.4276,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4273,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4324,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4178,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.4016,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3904,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3932,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4079,1,36,0.125,38,0.375    *rods.9
46,1,1.47261,1,37,35    *rods.9
47,1,1.47261,1,38,35.125    *rods.9
48,1,1.47261,1,39,66    *rods.9
49,1,1.47261,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
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53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,3.0014,530.6,0.0687,2.8216,
620.6,0.0698,2.6628,710.6,0.0707,2.5219,
800.6,0.0715,2.3966,890.6,0.0722,2.2847,
980.6,0.0729,2.1845,1070.6,0.0735,2.0942,
1160.6,0.0740,2.0123,1250.6,0.0745,1.9371,
1340.6,0.0750,1.8676,1430.6,0.0754,1.8028,
1520.6,0.0758,1.7419,1610.6,0.0762,1.6847,
1700.6,0.0767,1.6309,1790.6,0.0771,1.5803,
1880.6,0.0775,1.5328,1970.6,0.0779,1.4885,
2060.6,0.0783,1.4473,2150.6,0.0788,1.4092,
2240.6,0.0793,1.3741,2330.6,0.0799,1.3422,
2420.6,0.0805,1.3135,2510.6,0.0813,1.2878,
2600.6,0.0821,1.2653,2690.6,0.0830,1.2460,
2780.6,0.0840,1.2300,2870.6,0.0851,1.2171,
2960.6,0.0864,1.2074,3050.6,0.0879,1.2009,
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3140.6,0.0895,1.1976,3230.6,0.0914,1.1974,
3320.6,0.0934,1.2003,3410.6,0.0956,1.2064,
3500.6,0.0980,1.2154,3590.6,0.1006,1.2273,
3680.6,0.1035,1.2421,3770.6,0.1066,1.2597,
3860.6,0.1099,1.2799,3950.6,0.1134,1.3027,
4040.6,0.1172,1.3280,4130.6,0.1212,1.3556,
4220.6,0.1254,1.3855,4310.6,0.1299,1.4175,
4400.6,0.1346,1.4515,4490.6,0.1395,1.4874,
4580.6,0.1446,1.5251,4670.6,0.1499,1.5643,
4760.6,0.1555,1.6051,4850.6,0.1612,1.6473,
4940.6,0.1671,1.6908,5030.6,0.1732,1.7354,
5120.6,0.1794,1.7811,5210.6,0.1858,1.8277,
5300.6,0.1924,1.8751,5390.6,0.1990,1.9232,
5480.6,0.2059,1.9720,5570.6,0.2128,2.0212,
5660.6,0.2199,2.0709,5750.6,0.2270,2.1209,
5840.6,0.2343,2.1712,
endd
*
*
18,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 7.744797E+03
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
```

```
*
1.55    *rods.5
*
*              Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5225,1,1,0.25,2,0.25    *rods.9
3,1,1.4720,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5231,1,2,0.25,4,0.25    *rods.9
5,1,1.4728,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4747,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5246,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5285,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5230,1,7,0.25,11,0.25    *rods.9
12,1,1.4739,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4799,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5450,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5231,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5201,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4713,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4783,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5488,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5611,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5150,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5194,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
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26,1,1.5378,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.5069,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.4273,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.4963,1,22,0.25,29,0.25    *rods.9

30,1,1.4530,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.4542,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.4986,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.4482,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.4172,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,1.3894,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,1.3807,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.4327,1,29,0.25,37,0.25    *rods.9

38,1,1.4254,1,29,0.25,30,0.25,37,0.5    *rods.9

39,1,1.4252,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,1.4303,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,1.4155,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9

42,1,1.3990,1,33,0.25,34,0.25,38,0.5    *rods.9

43,1,1.3876,1,34,0.25,35,0.25,38,0.5    *rods.9

44,1,1.3904,1,35,0.25,36,0.25,38,0.5    *rods.9

45,1,1.4053,1,36,0.125,38,0.375    *rods.9

46,1,1.47121,1,37,35    *rods.9

47,1,1.47121,1,38,35.125    *rods.9

48,1,1.47121,1,39,66    *rods.9

49,1,1.47121,1,40,132    *rods.9

50,1,1.382,1,41,132    *rods.9

51,1,1.261,1,42,264    *rods.9

52,1,1.226,1,43,132    *rods.9

53,1,0.941,1,44,1848    *rods.9

54,1,0.942,1,45,3696    *rods.9
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```
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,2.8108,530.6,0.0687,2.6528,
620.6,0.0698,2.5124,710.6,0.0707,2.3875,
800.6,0.0715,2.2762,890.6,0.0722,2.1771,
980.6,0.0729,2.0886,1070.6,0.0735,2.0090,
1160.6,0.0740,1.9369,1250.6,0.0745,1.8707,
1340.6,0.0750,1.8092,1430.6,0.0754,1.7513,
1520.6,0.0758,1.6964,1610.6,0.0762,1.6443,
1700.6,0.0767,1.5948,1790.6,0.0771,1.5479,
1880.6,0.0775,1.5036,1970.6,0.0779,1.4619,
2060.6,0.0783,1.4230,2150.6,0.0788,1.3868,
2240.6,0.0793,1.3535,2330.6,0.0799,1.3230,
2420.6,0.0805,1.2956,2510.6,0.0813,1.2711,
2600.6,0.0821,1.2497,2690.6,0.0830,1.2313,
2780.6,0.0840,1.2161,2870.6,0.0851,1.2039,
2960.6,0.0864,1.1949,3050.6,0.0879,1.1891,
3140.6,0.0895,1.1864,3230.6,0.0914,1.1867,
3320.6,0.0934,1.1902,3410.6,0.0956,1.1966,
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3500.6,0.0980,1.2061,3590.6,0.1006,1.2184,
3680.6,0.1035,1.2336,3770.6,0.1066,1.2515,
3860.6,0.1099,1.2721,3950.6,0.1134,1.2952,
4040.6,0.1172,1.3208,4130.6,0.1212,1.3487,
4220.6,0.1254,1.3788,4310.6,0.1299,1.4110,
4400.6,0.1346,1.4453,4490.6,0.1395,1.4814,
4580.6,0.1446,1.5192,4670.6,0.1499,1.5587,
4760.6,0.1555,1.5997,4850.6,0.1612,1.6421,
4940.6,0.1671,1.6857,5030.6,0.1732,1.7305,
5120.6,0.1794,1.7763,5210.6,0.1858,1.8230,
5300.6,0.1924,1.8706,5390.6,0.1990,1.9188,
5480.6,0.2059,1.9677,5570.6,0.2128,2.0171,
5660.6,0.2199,2.0669,5750.6,0.2270,2.1170,
5840.6,0.2343,2.1674,
endd
*
*
19,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.064909E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
```

```
*
*            Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5223,1,1,0.25,2,0.25    *rods.9
3,1,1.4713,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5228,1,2,0.25,4,0.25    *rods.9
5,1,1.4721,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4740,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5244,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5283,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5227,1,7,0.25,11,0.25    *rods.9
12,1,1.4731,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4792,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5450,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5229,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5197,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4705,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4776,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5488,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5145,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5189,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5376,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5063,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
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28,1,1.4257,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4956,1,22,0.25,29,0.25    *rods.9
30,1,1.4518,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4530,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.4978,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4469,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4155,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3873,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3784,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4312,1,29,0.25,37,0.25    *rods.9
38,1,1.4238,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4235,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4287,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4137,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.3970,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3854,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3882,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.4032,1,36,0.125,38,0.375    *rods.9
46,1,1.47021,1,37,35    *rods.9
47,1,1.47021,1,38,35.125    *rods.9
48,1,1.47021,1,39,66    *rods.9
49,1,1.47021,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
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*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,2.6449,530.6,0.0687,2.5047,
620.6,0.0698,2.3796,710.6,0.0707,2.2681,
800.6,0.0715,2.1687,890.6,0.0722,2.0803,
980.6,0.0729,2.0017,1070.6,0.0735,1.9314,
1160.6,0.0740,1.8678,1250.6,0.0745,1.8093,
1340.6,0.0750,1.7548,1430.6,0.0754,1.7030,
1520.6,0.0758,1.6536,1610.6,0.0762,1.6061,
1700.6,0.0767,1.5606,1790.6,0.0771,1.5170,
1880.6,0.0775,1.4756,1970.6,0.0779,1.4364,
2060.6,0.0783,1.3995,2150.6,0.0788,1.3652,
2240.6,0.0793,1.3335,2330.6,0.0799,1.3045,
2420.6,0.0805,1.2782,2510.6,0.0813,1.2549,
2600.6,0.0821,1.2344,2690.6,0.0830,1.2170,
2780.6,0.0840,1.2025,2870.6,0.0851,1.1911,
2960.6,0.0864,1.1828,3050.6,0.0879,1.1776,
3140.6,0.0895,1.1754,3230.6,0.0914,1.1763,
3320.6,0.0934,1.1802,3410.6,0.0956,1.1871,
3500.6,0.0980,1.1970,3590.6,0.1006,1.2097,
3680.6,0.1035,1.2252,3770.6,0.1066,1.2435,
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3860.6,0.1099,1.2644,3950.6,0.1134,1.2878,
4040.6,0.1172,1.3136,4130.6,0.1212,1.3418,
4220.6,0.1254,1.3722,4310.6,0.1299,1.4047,
4400.6,0.1346,1.4391,4490.6,0.1395,1.4754,
4580.6,0.1446,1.5135,4670.6,0.1499,1.5532,
4760.6,0.1555,1.5943,4850.6,0.1612,1.6369,
4940.6,0.1671,1.6807,5030.6,0.1732,1.7256,
5120.6,0.1794,1.7715,5210.6,0.1858,1.8184,
5300.6,0.1924,1.8661,5390.6,0.1990,1.9145,
5480.6,0.2059,1.9635,5570.6,0.2128,2.0130,
5660.6,0.2199,2.0629,5750.6,0.2270,2.1132,
5840.6,0.2343,2.1637,
endd
*
*
20,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.355339E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*              Normal Rod input
```

```
1,2,0,1,1,0.125    *rods.9

2,1,1.5220,1,1,0.25,2,0.25    *rods.9

3,1,1.4706,1,1,0.125,2,0.25,3,0.125    *rods.9

4,1,1.5225,1,2,0.25,4,0.25    *rods.9

5,1,1.4715,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9

6,1,1.4733,1,3,0.125,5,0.25,6,0.125    *rods.9

7,2,0,1,4,0.25,7,0.25,0,0    *rods.9

8,1,1.5241,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9

9,1,1.5280,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9

10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9

11,1,1.5224,1,7,0.25,11,0.25    *rods.9

12,1,1.4724,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9

13,1,1.4786,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9

14,1,1.5448,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9

15,1,1.5226,1,10,0.125,14,0.25,15,0.125    *rods.9

16,1,1.5193,1,11,0.25,16,0.25,0,0    *rods.9

17,1,1.4698,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9

18,1,1.4769,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.5486,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.5140,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.5185,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.5372,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.5056,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.4244,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.4948,1,22,0.25,29,0.25    *rods.9
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30,1,1.4508,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.4520,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.4971,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.4458,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.4140,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,1.3855,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,1.3765,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.4299,1,29,0.25,37,0.25    *rods.9

38,1,1.4225,1,29,0.25,30,0.25,37,0.5    *rods.9

39,1,1.4222,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,1.4274,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,1.4122,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9

42,1,1.3952,1,33,0.25,34,0.25,38,0.5    *rods.9

43,1,1.3835,1,34,0.25,35,0.25,38,0.5    *rods.9

44,1,1.3863,1,35,0.25,36,0.25,38,0.5    *rods.9

45,1,1.4013,1,36,0.125,38,0.375    *rods.9

46,1,1.46931,1,37,35    *rods.9

47,1,1.46931,1,38,35.125    *rods.9

48,1,1.46931,1,39,66    *rods.9

49,1,1.46931,1,40,132    *rods.9

50,1,1.382,1,41,132    *rods.9

51,1,1.261,1,42,264    *rods.9

52,1,1.226,1,43,132    *rods.9

53,1,0.941,1,44,1848    *rods.9

54,1,0.942,1,45,3696    *rods.9

0    *rods.9

*              Fuel Geometry Types

*

* nuclear type geometry - used for nuclear rods
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1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,2.5003,530.6,0.0687,2.3749,
620.6,0.0698,2.2625,710.6,0.0707,2.1621,
800.6,0.0715,2.0727,890.6,0.0722,1.9934,
980.6,0.0729,1.9232,1070.6,0.0735,1.8608,
1160.6,0.0740,1.8045,1250.6,0.0745,1.7528,
1340.6,0.0750,1.7043,1430.6,0.0754,1.6581,
1520.6,0.0758,1.6134,1610.6,0.0762,1.5701,
1700.6,0.0767,1.5281,1790.6,0.0771,1.4876,
1880.6,0.0775,1.4488,1970.6,0.0779,1.4119,
2060.6,0.0783,1.3770,2150.6,0.0788,1.3444,
2240.6,0.0793,1.3142,2330.6,0.0799,1.2865,
2420.6,0.0805,1.2615,2510.6,0.0813,1.2391,
2600.6,0.0821,1.2196,2690.6,0.0830,1.2030,
2780.6,0.0840,1.1893,2870.6,0.0851,1.1786,
2960.6,0.0864,1.1710,3050.6,0.0879,1.1663,
3140.6,0.0895,1.1647,3230.6,0.0914,1.1661,
3320.6,0.0934,1.1705,3410.6,0.0956,1.1778,
3500.6,0.0980,1.1881,3590.6,0.1006,1.2012,
3680.6,0.1035,1.2170,3770.6,0.1066,1.2356,
3860.6,0.1099,1.2568,3950.6,0.1134,1.2805,
4040.6,0.1172,1.3066,4130.6,0.1212,1.3351,
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4220.6,0.1254,1.3657,4310.6,0.1299,1.3984,
4400.6,0.1346,1.4331,4490.6,0.1395,1.4696,
4580.6,0.1446,1.5079,4670.6,0.1499,1.5477,
4760.6,0.1555,1.5890,4850.6,0.1612,1.6317,
4940.6,0.1671,1.6757,5030.6,0.1732,1.7208,
5120.6,0.1794,1.7669,5210.6,0.1858,1.8139,
5300.6,0.1924,1.8617,5390.6,0.1990,1.9102,
5480.6,0.2059,1.9594,5570.6,0.2128,2.0090,
5660.6,0.2199,2.0590,5750.6,0.2270,2.1094,
5840.6,0.2343,2.1600,
endd
*
*
21,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.645769E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5219,1,1,0.25,2,0.25    *rods.9
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3,1,1.4703,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5224,1,2,0.25,4,0.25    *rods.9
5,1,1.4711,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4730,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5240,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5280,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5222,1,7,0.25,11,0.25    *rods.9
12,1,1.4721,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4783,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5448,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5225,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5191,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4693,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4765,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5486,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5612,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5137,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5182,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5370,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5051,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4234,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4943,1,22,0.25,29,0.25    *rods.9
30,1,1.4501,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4513,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
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32,1,1.4966,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4450,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4130,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3842,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3751,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4290,1,29,0.25,37,0.25    *rods.9
38,1,1.4215,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4212,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4264,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4111,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.3939,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3821,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3848,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.3998,1,36,0.125,38,0.375    *rods.9
46,1,1.46871,1,37,35    *rods.9
47,1,1.46871,1,38,35.125    *rods.9
48,1,1.46871,1,39,66    *rods.9
49,1,1.46871,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
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*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,2.3739,530.6,0.0687,2.2607,
620.6,0.0698,2.1590,710.6,0.0707,2.0680,
800.6,0.0715,1.9870,890.6,0.0722,1.9155,
980.6,0.0729,1.8524,1070.6,0.0735,1.7967,
1160.6,0.0740,1.7467,1250.6,0.0745,1.7008,
1340.6,0.0750,1.6577,1430.6,0.0754,1.6162,
1520.6,0.0758,1.5758,1610.6,0.0762,1.5362,
1700.6,0.0767,1.4974,1790.6,0.0771,1.4597,
1880.6,0.0775,1.4233,1970.6,0.0779,1.3885,
2060.6,0.0783,1.3555,2150.6,0.0788,1.3244,
2240.6,0.0793,1.2956,2330.6,0.0799,1.2692,
2420.6,0.0805,1.2452,2510.6,0.0813,1.2239,
2600.6,0.0821,1.2053,2690.6,0.0830,1.1895,
2780.6,0.0840,1.1765,2870.6,0.0851,1.1665,
2960.6,0.0864,1.1594,3050.6,0.0879,1.1553,
3140.6,0.0895,1.1542,3230.6,0.0914,1.1561,
3320.6,0.0934,1.1609,3410.6,0.0956,1.1687,
3500.6,0.0980,1.1793,3590.6,0.1006,1.1928,
3680.6,0.1035,1.2090,3770.6,0.1066,1.2279,
3860.6,0.1099,1.2494,3950.6,0.1134,1.2734,
4040.6,0.1172,1.2998,4130.6,0.1212,1.3285,
4220.6,0.1254,1.3593,4310.6,0.1299,1.3923,
4400.6,0.1346,1.4271,4490.6,0.1395,1.4639,
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4580.6,0.1446,1.5023,4670.6,0.1499,1.5423,
4760.6,0.1555,1.5838,4850.6,0.1612,1.6267,
4940.6,0.1671,1.6708,5030.6,0.1732,1.7160,
5120.6,0.1794,1.7623,5210.6,0.1858,1.8094,
5300.6,0.1924,1.8574,5390.6,0.1990,1.9060,
5480.6,0.2059,1.9553,5570.6,0.2128,2.0050,
5660.6,0.2199,2.0552,5750.6,0.2270,2.1056,
5840.6,0.2343,2.1563,
endd
*
*
22,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 1.936199E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.5218,1,1,0.25,2,0.25    *rods.9
3,1,1.4701,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.5223,1,2,0.25,4,0.25    *rods.9
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5,1,1.4709,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.4728,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.5238,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.5279,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.5221,1,7,0.25,11,0.25    *rods.9
12,1,1.4718,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.4780,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.5448,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.5225,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.5189,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.4690,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.4763,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.5485,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.5611,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.5134,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.5179,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.5368,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.5046,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.4226,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.4939,1,22,0.25,29,0.25    *rods.9
30,1,1.4495,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.4507,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.4961,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.4443,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
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34,1,1.4121,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.3832,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.3739,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.4282,1,29,0.25,37,0.25    *rods.9
38,1,1.4207,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.4204,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.4256,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.4102,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.3929,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.3809,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.3835,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.3986,1,36,0.125,38,0.375    *rods.9
46,1,1.46821,1,37,35    *rods.9
47,1,1.46821,1,38,35.125    *rods.9
48,1,1.46821,1,39,66    *rods.9
49,1,1.46821,1,40,132    *rods.9
50,1,1.382,1,41,132    *rods.9
51,1,1.261,1,42,264    *rods.9
52,1,1.226,1,43,132    *rods.9
53,1,0.941,1,44,1848    *rods.9
54,1,0.942,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
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2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,2.2629,530.6,0.0687,2.1599,
620.6,0.0698,2.0671,710.6,0.0707,1.9841,
800.6,0.0715,1.9103,890.6,0.0722,1.8453,
980.6,0.0729,1.7884,1070.6,0.0735,1.7383,
1160.6,0.0740,1.6938,1250.6,0.0745,1.6529,
1340.6,0.0750,1.6144,1430.6,0.0754,1.5772,
1520.6,0.0758,1.5405,1610.6,0.0762,1.5042,
1700.6,0.0767,1.4684,1790.6,0.0771,1.4332,
1880.6,0.0775,1.3990,1970.6,0.0779,1.3661,
2060.6,0.0783,1.3348,2150.6,0.0788,1.3052,
2240.6,0.0793,1.2777,2330.6,0.0799,1.2524,
2420.6,0.0805,1.2295,2510.6,0.0813,1.2091,
2600.6,0.0821,1.1913,2690.6,0.0830,1.1763,
2780.6,0.0840,1.1641,2870.6,0.0851,1.1547,
2960.6,0.0864,1.1482,3050.6,0.0879,1.1446,
3140.6,0.0895,1.1440,3230.6,0.0914,1.1464,
3320.6,0.0934,1.1516,3410.6,0.0956,1.1598,
3500.6,0.0980,1.1708,3590.6,0.1006,1.1846,
3680.6,0.1035,1.2012,3770.6,0.1066,1.2204,
3860.6,0.1099,1.2421,3950.6,0.1134,1.2664,
4040.6,0.1172,1.2930,4130.6,0.1212,1.3220,
4220.6,0.1254,1.3531,4310.6,0.1299,1.3862,
4400.6,0.1346,1.4213,4490.6,0.1395,1.4582,
4580.6,0.1446,1.4968,4670.6,0.1499,1.5370,
4760.6,0.1555,1.5787,4850.6,0.1612,1.6217,
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4940.6,0.1671,1.6660,5030.6,0.1732,1.7114,
5120.6,0.1794,1.7578,5210.6,0.1858,1.8051,
5300.6,0.1924,1.8531,5390.6,0.1990,1.9019,
5480.6,0.2059,1.9512,5570.6,0.2128,2.0011,
5660.6,0.2199,2.0513,5750.6,0.2270,2.1019,
5840.6,0.2343,2.1527,
endd
*
*
23,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.226629E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.2766,1,1,0.25,2,0.25    *rods.9
3,1,1.2332,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2771,1,2,0.25,4,0.25    *rods.9
5,1,1.2339,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.2355,1,3,0.125,5,0.25,6,0.125    *rods.9
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7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.2783,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.2817,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.2768,1,7,0.25,11,0.25    *rods.9
12,1,1.2346,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.2399,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.2959,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.2772,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.2741,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.2323,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.2384,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.2990,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3096,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.2695,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2732,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.2890,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.2619,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.1929,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.2529,1,22,0.25,29,0.25    *rods.9
30,1,1.2157,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.2167,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.2548,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.2113,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.1841,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.1597,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
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36,1,1.1518,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.1977,1,29,0.25,37,0.25    *rods.9

38,1,1.1914,1,29,0.25,30,0.25,37,0.5    *rods.9

39,1,1.1911,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,1.1954,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,1.1825,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9

42,1,1.1679,1,33,0.25,34,0.25,38,0.5    *rods.9

43,1,1.1577,1,34,0.25,35,0.25,38,0.5    *rods.9

44,1,1.1599,1,35,0.25,36,0.25,38,0.5    *rods.9

45,1,1.1724,1,36,0.125,38,0.375    *rods.9

46,1,1.23141,1,37,35    *rods.9

47,1,1.23141,1,38,35.125    *rods.9

48,1,1.23141,1,39,66    *rods.9

49,1,1.23141,1,40,132    *rods.9

50,1,1.230,1,41,132    *rods.9

51,1,1.120,1,42,264    *rods.9

52,1,1.080,1,43,132    *rods.9

53,1,0.990,1,44,1848    *rods.9

54,1,0.960,1,45,3696    *rods.9

0    *rods.9

*              Fuel Geometry Types

*

* nuclear type geometry - used for nuclear rods

1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62

0,1,0,0,0,2000,0.95,0    *rods.63

*

* dummy type geometry - used for control rods

2,dumy,0.482,0,0    *rods.68

*
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* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,2.1647,530.6,0.0687,2.0704,
620.6,0.0698,1.9852,710.6,0.0707,1.9090,
800.6,0.0715,1.8413,890.6,0.0722,1.7819,
980.6,0.0729,1.7302,1070.6,0.0735,1.6852,
1160.6,0.0740,1.6452,1250.6,0.0745,1.6088,
1340.6,0.0750,1.5744,1430.6,0.0754,1.5408,
1520.6,0.0758,1.5075,1610.6,0.0762,1.4741,
1700.6,0.0767,1.4409,1790.6,0.0771,1.4080,
1880.6,0.0775,1.3758,1970.6,0.0779,1.3447,
2060.6,0.0783,1.3149,2150.6,0.0788,1.2867,
2240.6,0.0793,1.2604,2330.6,0.0799,1.2362,
2420.6,0.0805,1.2143,2510.6,0.0813,1.1948,
2600.6,0.0821,1.1778,2690.6,0.0830,1.1635,
2780.6,0.0840,1.1519,2870.6,0.0851,1.1431,
2960.6,0.0864,1.1372,3050.6,0.0879,1.1342,
3140.6,0.0895,1.1341,3230.6,0.0914,1.1368,
3320.6,0.0934,1.1425,3410.6,0.0956,1.1511,
3500.6,0.0980,1.1624,3590.6,0.1006,1.1766,
3680.6,0.1035,1.1935,3770.6,0.1066,1.2130,
3860.6,0.1099,1.2350,3950.6,0.1134,1.2595,
4040.6,0.1172,1.2864,4130.6,0.1212,1.3156,
4220.6,0.1254,1.3469,4310.6,0.1299,1.3803,
4400.6,0.1346,1.4156,4490.6,0.1395,1.4527,
4580.6,0.1446,1.4915,4670.6,0.1499,1.5318,
4760.6,0.1555,1.5737,4850.6,0.1612,1.6169,
4940.6,0.1671,1.6613,5030.6,0.1732,1.7068,
5120.6,0.1794,1.7533,5210.6,0.1858,1.8007,
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5300.6,0.1924,1.8489,5390.6,0.1990,1.8978,
5480.6,0.2059,1.9473,5570.6,0.2128,1.9972,
5660.6,0.2199,2.0476,5750.6,0.2270,2.0982,
5840.6,0.2343,2.1491,
endd
*
*
24,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.517059E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.2766,1,1,0.25,2,0.25    *rods.9
3,1,1.2333,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2771,1,2,0.25,4,0.25    *rods.9
5,1,1.2340,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.2356,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.2783,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
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9,1,1.2817,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9

10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9

11,1,1.2768,1,7,0.25,11,0.25    *rods.9

12,1,1.2347,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9

13,1,1.2399,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9

14,1,1.2960,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9

15,1,1.2773,1,10,0.125,14,0.25,15,0.125    *rods.9

16,1,1.2740,1,11,0.25,16,0.25,0,0    *rods.9

17,1,1.2322,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9

18,1,1.2383,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.2989,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.3096,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.2693,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.2731,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.2889,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.2617,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.1926,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.2527,1,22,0.25,29,0.25    *rods.9

30,1,1.2155,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.2165,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.2545,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.2110,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.1837,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,1.1592,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,1.1512,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.1974,1,29,0.25,37,0.25    *rods.9
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38,1,1.1911,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.1908,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.1951,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.1821,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.1674,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.1571,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.1592,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.1717,1,36,0.125,38,0.375    *rods.9
46,1,1.23121,1,37,35    *rods.9
47,1,1.23121,1,38,35.125    *rods.9
48,1,1.23121,1,39,66    *rods.9
49,1,1.23121,1,40,132    *rods.9
50,1,1.230,1,41,132    *rods.9
51,1,1.120,1,42,264    *rods.9
52,1,1.080,1,43,132    *rods.9
53,1,0.990,1,44,1848    *rods.9
54,1,0.960,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
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440.6,0.0673,2.0774,530.6,0.0687,1.9905,
620.6,0.0698,1.9119,710.6,0.0707,1.8414,
800.6,0.0715,1.7790,890.6,0.0722,1.7245,
980.6,0.0729,1.6774,1070.6,0.0735,1.6365,
1160.6,0.0740,1.6006,1250.6,0.0745,1.5680,
1340.6,0.0750,1.5371,1430.6,0.0754,1.5068,
1520.6,0.0758,1.4764,1610.6,0.0762,1.4457,
1700.6,0.0767,1.4149,1790.6,0.0771,1.3841,
1880.6,0.0775,1.3537,1970.6,0.0779,1.3242,
2060.6,0.0783,1.2958,2150.6,0.0788,1.2689,
2240.6,0.0793,1.2438,2330.6,0.0799,1.2206,
2420.6,0.0805,1.1996,2510.6,0.0813,1.1809,
2600.6,0.0821,1.1647,2690.6,0.0830,1.1511,
2780.6,0.0840,1.1401,2870.6,0.0851,1.1319,
2960.6,0.0864,1.1265,3050.6,0.0879,1.1240,
3140.6,0.0895,1.1243,3230.6,0.0914,1.1275,
3320.6,0.0934,1.1336,3410.6,0.0956,1.1425,
3500.6,0.0980,1.1543,3590.6,0.1006,1.1687,
3680.6,0.1035,1.1859,3770.6,0.1066,1.2057,
3860.6,0.1099,1.2280,3950.6,0.1134,1.2528,
4040.6,0.1172,1.2799,4130.6,0.1212,1.3093,
4220.6,0.1254,1.3408,4310.6,0.1299,1.3744,
4400.6,0.1346,1.4099,4490.6,0.1395,1.4472,
4580.6,0.1446,1.4862,4670.6,0.1499,1.5267,
4760.6,0.1555,1.5687,4850.6,0.1612,1.6120,
4940.6,0.1671,1.6566,5030.6,0.1732,1.7023,
5120.6,0.1794,1.7489,5210.6,0.1858,1.7964,
5300.6,0.1924,1.8448,5390.6,0.1990,1.8938,
5480.6,0.2059,1.9433,5570.6,0.2128,1.9934,
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5660.6,0.2199,2.0439,5750.6,0.2270,2.0946,
5840.6,0.2343,2.1456,
endd
*
*
25,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 2.807489E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.2768,1,1,0.25,2,0.25    *rods.9
3,1,1.2335,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2772,1,2,0.25,4,0.25    *rods.9
5,1,1.2342,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.2358,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.2785,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.2819,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
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11,1,1.2769,1,7,0.25,11,0.25    *rods.9
12,1,1.2349,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.2402,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.2961,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.2775,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.2741,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.2324,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.2385,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.2990,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3096,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.2693,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2731,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.2888,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.2615,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.1925,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.2526,1,22,0.25,29,0.25    *rods.9
30,1,1.2156,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.2165,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.2544,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.2109,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.1836,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.1590,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.1509,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.1974,1,29,0.25,37,0.25    *rods.9
38,1,1.1911,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.1908,1,30,0.25,31,0.25,37,0.5    *rods.9
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40,1,1.1950,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.1819,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.1671,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.1568,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.1588,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.1712,1,36,0.125,38,0.375    *rods.9
46,1,1.23121,1,37,35    *rods.9
47,1,1.23121,1,38,35.125    *rods.9
48,1,1.23121,1,39,66    *rods.9
49,1,1.23121,1,40,132    *rods.9
50,1,1.230,1,41,132    *rods.9
51,1,1.120,1,42,264    *rods.9
52,1,1.080,1,43,132    *rods.9
53,1,0.990,1,44,1848    *rods.9
54,1,0.960,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.9993,530.6,0.0687,1.9187,
620.6,0.0698,1.8458,710.6,0.0707,1.7804,
```

```
800.6,0.0715,1.7226,890.6,0.0722,1.6723,
980.6,0.0729,1.6290,1070.6,0.0735,1.5919,
1160.6,0.0740,1.5595,1250.6,0.0745,1.5302,
1340.6,0.0750,1.5024,1430.6,0.0754,1.4750,
1520.6,0.0758,1.4472,1610.6,0.0762,1.4189,
1700.6,0.0767,1.3901,1790.6,0.0771,1.3612,
1880.6,0.0775,1.3326,1970.6,0.0779,1.3045,
2060.6,0.0783,1.2775,2150.6,0.0788,1.2518,
2240.6,0.0793,1.2277,2330.6,0.0799,1.2055,
2420.6,0.0805,1.1853,2510.6,0.0813,1.1674,
2600.6,0.0821,1.1519,2690.6,0.0830,1.1390,
2780.6,0.0840,1.1286,2870.6,0.0851,1.1210,
2960.6,0.0864,1.1161,3050.6,0.0879,1.1140,
3140.6,0.0895,1.1148,3230.6,0.0914,1.1184,
3320.6,0.0934,1.1249,3410.6,0.0956,1.1342,
3500.6,0.0980,1.1462,3590.6,0.1006,1.1610,
3680.6,0.1035,1.1785,3770.6,0.1066,1.1986,
3860.6,0.1099,1.2212,3950.6,0.1134,1.2462,
4040.6,0.1172,1.2735,4130.6,0.1212,1.3032,
4220.6,0.1254,1.3349,4310.6,0.1299,1.3687,
4400.6,0.1346,1.4043,4490.6,0.1395,1.4418,
4580.6,0.1446,1.4810,4670.6,0.1499,1.5217,
4760.6,0.1555,1.5638,4850.6,0.1612,1.6073,
4940.6,0.1671,1.6520,5030.6,0.1732,1.6978,
5120.6,0.1794,1.7446,5210.6,0.1858,1.7922,
5300.6,0.1924,1.8407,5390.6,0.1990,1.8898,
5480.6,0.2059,1.9395,5570.6,0.2128,1.9896,
5660.6,0.2199,2.0402,5750.6,0.2270,2.0910,
5840.6,0.2343,2.1421,
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endd
*
*
26,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.097919E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.2769,1,1,0.25,2,0.25    *rods.9
3,1,1.2338,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2773,1,2,0.25,4,0.25    *rods.9
5,1,1.2345,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.2361,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.2786,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.2820,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.2770,1,7,0.25,11,0.25    *rods.9
12,1,1.2351,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
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13,1,1.2404,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9

14,1,1.2962,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9

15,1,1.2777,1,10,0.125,14,0.25,15,0.125    *rods.9

16,1,1.2741,1,11,0.25,16,0.25,0,0    *rods.9

17,1,1.2326,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9

18,1,1.2387,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.2991,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.3096,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.2693,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.2731,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.2887,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.2614,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,1.1924,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.2526,1,22,0.25,29,0.25    *rods.9

30,1,1.2156,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.2166,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.2543,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.2109,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,1.1835,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,1.1588,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,1.1507,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,1.1973,1,29,0.25,37,0.25    *rods.9

38,1,1.1911,1,29,0.25,30,0.25,37,0.5    *rods.9

39,1,1.1907,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,1.1949,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,1.1818,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
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42,1,1.1670,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.1566,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.1585,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.1708,1,36,0.125,38,0.375    *rods.9
46,1,1.23121,1,37,35    *rods.9
47,1,1.23121,1,38,35.125    *rods.9
48,1,1.23121,1,39,66    *rods.9
49,1,1.23121,1,40,132    *rods.9
50,1,1.230,1,41,132    *rods.9
51,1,1.120,1,42,264    *rods.9
52,1,1.080,1,43,132    *rods.9
53,1,0.990,1,44,1848    *rods.9
54,1,0.960,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.9290,530.6,0.0687,1.8540,
620.6,0.0698,1.7860,710.6,0.0707,1.7250,
800.6,0.0715,1.6711,890.6,0.0722,1.6245,
980.6,0.0729,1.5847,1070.6,0.0735,1.5508,
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1160.6,0.0740,1.5215,1250.6,0.0745,1.4950,
1340.6,0.0750,1.4700,1430.6,0.0754,1.4451,
1520.6,0.0758,1.4197,1610.6,0.0762,1.3935,
1700.6,0.0767,1.3666,1790.6,0.0771,1.3394,
1880.6,0.0775,1.3123,1970.6,0.0779,1.2856,
2060.6,0.0783,1.2598,2150.6,0.0788,1.2352,
2240.6,0.0793,1.2121,2330.6,0.0799,1.1908,
2420.6,0.0805,1.1715,2510.6,0.0813,1.1543,
2600.6,0.0821,1.1395,2690.6,0.0830,1.1272,
2780.6,0.0840,1.1174,2870.6,0.0851,1.1103,
2960.6,0.0864,1.1059,3050.6,0.0879,1.1043,
3140.6,0.0895,1.1055,3230.6,0.0914,1.1095,
3320.6,0.0934,1.1164,3410.6,0.0956,1.1260,
3500.6,0.0980,1.1384,3590.6,0.1006,1.1535,
3680.6,0.1035,1.1712,3770.6,0.1066,1.1916,
3860.6,0.1099,1.2144,3950.6,0.1134,1.2397,
4040.6,0.1172,1.2673,4130.6,0.1212,1.2971,
4220.6,0.1254,1.3290,4310.6,0.1299,1.3630,
4400.6,0.1346,1.3989,4490.6,0.1395,1.4365,
4580.6,0.1446,1.4758,4670.6,0.1499,1.5167,
4760.6,0.1555,1.5590,4850.6,0.1612,1.6026,
4940.6,0.1671,1.6475,5030.6,0.1732,1.6934,
5120.6,0.1794,1.7403,5210.6,0.1858,1.7881,
5300.6,0.1924,1.8366,5390.6,0.1990,1.8859,
5480.6,0.2059,1.9357,5570.6,0.2128,1.9859,
5660.6,0.2199,2.0366,5750.6,0.2270,2.0875,
5840.6,0.2343,2.1387,
endd
*
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```
*
27,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 3.388348E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.2771,1,1,0.25,2,0.25    *rods.9
3,1,1.2342,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2775,1,2,0.25,4,0.25    *rods.9
5,1,1.2349,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.2365,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.2788,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.2822,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.2772,1,7,0.25,11,0.25    *rods.9
12,1,1.2355,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.2408,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.2963,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
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15,1,1.2779,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.2742,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.2329,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.2390,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.2991,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3096,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.2694,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2731,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.2886,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.2613,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.1924,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.2525,1,22,0.25,29,0.25    *rods.9
30,1,1.2158,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.2167,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.2542,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.2110,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.1836,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.1588,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.1506,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.1975,1,29,0.25,37,0.25    *rods.9
38,1,1.1912,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.1909,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.1950,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.1819,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.1670,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.1565,1,34,0.25,35,0.25,38,0.5    *rods.9
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44,1,1.1583,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.1706,1,36,0.125,38,0.375    *rods.9
46,1,1.23131,1,37,35    *rods.9
47,1,1.23131,1,38,35.125    *rods.9
48,1,1.23131,1,39,66    *rods.9
49,1,1.23131,1,40,132    *rods.9
50,1,1.230,1,41,132    *rods.9
51,1,1.120,1,42,264    *rods.9
52,1,1.080,1,43,132    *rods.9
53,1,0.990,1,44,1848    *rods.9
54,1,0.960,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.8654,530.6,0.0687,1.7953,
620.6,0.0698,1.7315,710.6,0.0707,1.6744,
800.6,0.0715,1.6241,890.6,0.0722,1.5807,
980.6,0.0729,1.5439,1070.6,0.0735,1.5128,
1160.6,0.0740,1.4861,1250.6,0.0745,1.4623,
1340.6,0.0750,1.4396,1430.6,0.0754,1.4170,
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1520.6,0.0758,1.3936,1610.6,0.0762,1.3694,
1700.6,0.0767,1.3443,1790.6,0.0771,1.3186,
1880.6,0.0775,1.2929,1970.6,0.0779,1.2675,
2060.6,0.0783,1.2428,2150.6,0.0788,1.2193,
2240.6,0.0793,1.1971,2330.6,0.0799,1.1766,
2420.6,0.0805,1.1581,2510.6,0.0813,1.1416,
2600.6,0.0821,1.1275,2690.6,0.0830,1.1157,
2780.6,0.0840,1.1065,2870.6,0.0851,1.0999,
2960.6,0.0864,1.0960,3050.6,0.0879,1.0948,
3140.6,0.0895,1.0964,3230.6,0.0914,1.1008,
3320.6,0.0934,1.1080,3410.6,0.0956,1.1180,
3500.6,0.0980,1.1307,3590.6,0.1006,1.1461,
3680.6,0.1035,1.1641,3770.6,0.1066,1.1847,
3860.6,0.1099,1.2078,3950.6,0.1134,1.2333,
4040.6,0.1172,1.2611,4130.6,0.1212,1.2911,
4220.6,0.1254,1.3233,4310.6,0.1299,1.3574,
4400.6,0.1346,1.3935,4490.6,0.1395,1.4313,
4580.6,0.1446,1.4708,4670.6,0.1499,1.5118,
4760.6,0.1555,1.5542,4850.6,0.1612,1.5980,
4940.6,0.1671,1.6430,5030.6,0.1732,1.6890,
5120.6,0.1794,1.7361,5210.6,0.1858,1.7840,
5300.6,0.1924,1.8326,5390.6,0.1990,1.8820,
5480.6,0.2059,1.9319,5570.6,0.2128,1.9822,
5660.6,0.2199,2.0330,5750.6,0.2270,2.0840,
5840.6,0.2343,2.1353,
endd
*
*
28,0,0,-1,0    *vipre.1
```

```
Burnup [MWd/t] at 3.678779E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.2773,1,1,0.25,2,0.25    *rods.9
3,1,1.2347,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2777,1,2,0.25,4,0.25    *rods.9
5,1,1.2353,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.2369,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.2790,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.2824,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.2774,1,7,0.25,11,0.25    *rods.9
12,1,1.2359,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.2412,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.2965,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.2782,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.2744,1,11,0.25,16,0.25,0,0    *rods.9
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17,1,1.2333,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.2395,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.2993,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3096,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.2695,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2732,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.2886,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.2613,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.1926,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.2526,1,22,0.25,29,0.25    *rods.9
30,1,1.2160,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.2170,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.2542,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.2112,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.1838,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.1590,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.1507,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.1977,1,29,0.25,37,0.25    *rods.9
38,1,1.1915,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.1911,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.1952,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.1820,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.1671,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.1565,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.1583,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.1704,1,36,0.125,38,0.375    *rods.9
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46,1,1.23151,1,37,35    *rods.9
47,1,1.23151,1,38,35.125    *rods.9
48,1,1.23151,1,39,66    *rods.9
49,1,1.23151,1,40,132    *rods.9
50,1,1.230,1,41,132    *rods.9
51,1,1.120,1,42,264    *rods.9
52,1,1.080,1,43,132    *rods.9
53,1,0.990,1,44,1848    *rods.9
54,1,0.960,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.8076,530.6,0.0687,1.7417,
620.6,0.0698,1.6818,710.6,0.0707,1.6281,
800.6,0.0715,1.5809,890.6,0.0722,1.5403,
980.6,0.0729,1.5062,1070.6,0.0735,1.4776,
1160.6,0.0740,1.4533,1250.6,0.0745,1.4316,
1340.6,0.0750,1.4111,1430.6,0.0754,1.3905,
1520.6,0.0758,1.3690,1610.6,0.0762,1.3464,
1700.6,0.0767,1.3229,1790.6,0.0771,1.2987,
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1880.6,0.0775,1.2743,1970.6,0.0779,1.2501,

2060.6,0.0783,1.2265,2150.6,0.0788,1.2038,

2240.6,0.0793,1.1826,2330.6,0.0799,1.1629,

2420.6,0.0805,1.1451,2510.6,0.0813,1.1293,

2600.6,0.0821,1.1157,2690.6,0.0830,1.1045,

2780.6,0.0840,1.0958,2870.6,0.0851,1.0897,

2960.6,0.0864,1.0863,3050.6,0.0879,1.0855,

3140.6,0.0895,1.0875,3230.6,0.0914,1.0923,

3320.6,0.0934,1.0998,3410.6,0.0956,1.1101,

3500.6,0.0980,1.1231,3590.6,0.1006,1.1388,

3680.6,0.1035,1.1571,3770.6,0.1066,1.1779,

3860.6,0.1099,1.2013,3950.6,0.1134,1.2270,

4040.6,0.1172,1.2551,4130.6,0.1212,1.2853,

4220.6,0.1254,1.3176,4310.6,0.1299,1.3520,

4400.6,0.1346,1.3882,4490.6,0.1395,1.4262,

4580.6,0.1446,1.4658,4670.6,0.1499,1.5070,

4760.6,0.1555,1.5496,4850.6,0.1612,1.5935,

4940.6,0.1671,1.6386,5030.6,0.1732,1.6848,

5120.6,0.1794,1.7319,5210.6,0.1858,1.7799,

5300.6,0.1924,1.8287,5390.6,0.1990,1.8782,

5480.6,0.2059,1.9282,5570.6,0.2128,1.9786,

5660.6,0.2199,2.0295,5750.6,0.2270,2.0806,

5840.6,0.2343,2.1319,

endd

*

*

29,0,0,-1,0    *vipre.1

Burnup [MWd/t] at 3.969209E+04

rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
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*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*              Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.2775,1,1,0.25,2,0.25    *rods.9
3,1,1.2351,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.2779,1,2,0.25,4,0.25    *rods.9
5,1,1.2357,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.2373,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.2791,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.2825,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.2775,1,7,0.25,11,0.25    *rods.9
12,1,1.2363,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.2416,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.2966,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.2784,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.2745,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.2337,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.2398,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
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19,1,1.2992,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.3095,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.2695,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.2732,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.2884,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.2611,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,1.1927,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.2525,1,22,0.25,29,0.25    *rods.9
30,1,1.2162,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.2171,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.2541,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.2113,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,1.1839,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,1.1591,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,1.1506,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,1.1979,1,29,0.25,37,0.25    *rods.9
38,1,1.1916,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,1.1913,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,1.1953,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,1.1821,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,1.1671,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,1.1565,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,1.1581,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,1.1702,1,36,0.125,38,0.375    *rods.9
46,1,1.23161,1,37,35    *rods.9
47,1,1.23161,1,38,35.125    *rods.9
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48,1,1.23161,1,39,66    *rods.9
49,1,1.23161,1,40,132    *rods.9
50,1,1.230,1,41,132    *rods.9
51,1,1.120,1,42,264    *rods.9
52,1,1.080,1,43,132    *rods.9
53,1,0.990,1,44,1848    *rods.9
54,1,0.960,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.7548,530.6,0.0687,1.6927,
620.6,0.0698,1.6362,710.6,0.0707,1.5855,
800.6,0.0715,1.5411,890.6,0.0722,1.5030,
980.6,0.0729,1.4712,1070.6,0.0735,1.4448,
1160.6,0.0740,1.4225,1250.6,0.0745,1.4029,
1340.6,0.0750,1.3843,1430.6,0.0754,1.3654,
1520.6,0.0758,1.3456,1610.6,0.0762,1.3246,
1700.6,0.0767,1.3025,1790.6,0.0771,1.2796,
1880.6,0.0775,1.2564,1970.6,0.0779,1.2333,
2060.6,0.0783,1.2106,2150.6,0.0788,1.1889,
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2240.6,0.0793,1.1685,2330.6,0.0799,1.1495,
2420.6,0.0805,1.1324,2510.6,0.0813,1.1173,
2600.6,0.0821,1.1043,2690.6,0.0830,1.0936,
2780.6,0.0840,1.0855,2870.6,0.0851,1.0798,
2960.6,0.0864,1.0768,3050.6,0.0879,1.0764,
3140.6,0.0895,1.0788,3230.6,0.0914,1.0839,
3320.6,0.0934,1.0918,3410.6,0.0956,1.1024,
3500.6,0.0980,1.1157,3590.6,0.1006,1.1317,
3680.6,0.1035,1.1502,3770.6,0.1066,1.1713,
3860.6,0.1099,1.1949,3950.6,0.1134,1.2208,
4040.6,0.1172,1.2491,4130.6,0.1212,1.2795,
4220.6,0.1254,1.3121,4310.6,0.1299,1.3466,
4400.6,0.1346,1.3830,4490.6,0.1395,1.4211,
4580.6,0.1446,1.4609,4670.6,0.1499,1.5022,
4760.6,0.1555,1.5450,4850.6,0.1612,1.5890,
4940.6,0.1671,1.6342,5030.6,0.1732,1.6805,
5120.6,0.1794,1.7278,5210.6,0.1858,1.7759,
5300.6,0.1924,1.8248,5390.6,0.1990,1.8744,
5480.6,0.2059,1.9245,5570.6,0.2128,1.9750,
5660.6,0.2199,2.0260,5750.6,0.2270,2.0772,
5840.6,0.2343,2.1286,
endd
*
*
30,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.259638E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
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144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.0574,1,1,0.25,2,0.25    *rods.9
3,1,1.0226,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.0578,1,2,0.25,4,0.25    *rods.9
5,1,1.0231,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.0245,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.0588,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.0616,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.0574,1,7,0.25,11,0.25    *rods.9
12,1,1.0236,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0280,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.0732,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0583,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0549,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0214,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0264,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0753,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0838,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
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21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.0507,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0538,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.0663,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0437,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.9873,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0367,1,22,0.25,29,0.25    *rods.9
30,1,1.0068,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.0076,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.0379,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.0027,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,0.9800,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,0.9595,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,0.9525,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,0.9916,1,29,0.25,37,0.25    *rods.9
38,1,0.9865,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,0.9862,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,0.9895,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,0.9786,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,0.9662,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,0.9573,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,0.9586,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,0.9684,1,36,0.125,38,0.375    *rods.9
46,1,1.01951,1,37,35    *rods.9
47,1,1.01951,1,38,35.125    *rods.9
48,1,1.01951,1,39,66    *rods.9
49,1,1.01951,1,40,132    *rods.9
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50,1,1.070,1,41,132    *rods.9
51,1,1.030,1,42,264    *rods.9
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.7063,530.6,0.0687,1.6476,
620.6,0.0698,1.5941,710.6,0.0707,1.5462,
800.6,0.0715,1.5042,890.6,0.0722,1.4684,
980.6,0.0729,1.4386,1070.6,0.0735,1.4142,
1160.6,0.0740,1.3938,1250.6,0.0745,1.3759,
1340.6,0.0750,1.3589,1430.6,0.0754,1.3417,
1520.6,0.0758,1.3234,1610.6,0.0762,1.3038,
1700.6,0.0767,1.2830,1790.6,0.0771,1.2613,
1880.6,0.0775,1.2392,1970.6,0.0779,1.2170,
2060.6,0.0783,1.1953,2150.6,0.0788,1.1745,
2240.6,0.0793,1.1548,2330.6,0.0799,1.1366,
2420.6,0.0805,1.1201,2510.6,0.0813,1.1056,
```

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2600.6,0.0821,1.0931,2690.6,0.0830,1.0830,
2780.6,0.0840,1.0753,2870.6,0.0851,1.0701,
2960.6,0.0864,1.0675,3050.6,0.0879,1.0676,
3140.6,0.0895,1.0703,3230.6,0.0914,1.0758,
3320.6,0.0934,1.0840,3410.6,0.0956,1.0949,
3500.6,0.0980,1.1084,3590.6,0.1006,1.1247,
3680.6,0.1035,1.1435,3770.6,0.1066,1.1648,
3860.6,0.1099,1.1886,3950.6,0.1134,1.2148,
4040.6,0.1172,1.2432,4130.6,0.1212,1.2739,
4220.6,0.1254,1.3066,4310.6,0.1299,1.3413,
4400.6,0.1346,1.3778,4490.6,0.1395,1.4161,
4580.6,0.1446,1.4561,4670.6,0.1499,1.4975,
4760.6,0.1555,1.5404,4850.6,0.1612,1.5846,
4940.6,0.1671,1.6299,5030.6,0.1732,1.6764,
5120.6,0.1794,1.7238,5210.6,0.1858,1.7720,
5300.6,0.1924,1.8210,5390.6,0.1990,1.8706,
5480.6,0.2059,1.9208,5570.6,0.2128,1.9715,
5660.6,0.2199,2.0225,5750.6,0.2270,2.0738,
5840.6,0.2343,2.1253,
endd
*
*
31,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.550068E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
```

```
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.0577,1,1,0.25,2,0.25    *rods.9
3,1,1.0231,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.0581,1,2,0.25,4,0.25    *rods.9
5,1,1.0237,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.0250,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.0591,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.0619,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.0577,1,7,0.25,11,0.25    *rods.9
12,1,1.0241,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0284,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.0734,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0586,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0551,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0219,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0269,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0755,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0838,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
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23,1,1.0509,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.0540,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.0663,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.0438,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,0.9876,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.0368,1,22,0.25,29,0.25    *rods.9

30,1,1.0072,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.0080,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.0381,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.0030,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,0.9804,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9

35,1,0.9599,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9

36,1,0.9528,1,28,0.125,35,0.25,36,0.125    *rods.9

37,1,0.9920,1,29,0.25,37,0.25    *rods.9

38,1,0.9869,1,29,0.25,30,0.25,37,0.5    *rods.9

39,1,0.9866,1,30,0.25,31,0.25,37,0.5    *rods.9

40,1,0.9899,1,31,0.25,32,0.25,37,0.5    *rods.9

41,1,0.9789,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9

42,1,0.9665,1,33,0.25,34,0.25,38,0.5    *rods.9

43,1,0.9576,1,34,0.25,35,0.25,38,0.5    *rods.9

44,1,0.9588,1,35,0.25,36,0.25,38,0.5    *rods.9

45,1,0.9685,1,36,0.125,38,0.375    *rods.9

46,1,1.01981,1,37,35    *rods.9

47,1,1.01981,1,38,35.125    *rods.9

48,1,1.01981,1,39,66    *rods.9

49,1,1.01981,1,40,132    *rods.9

50,1,1.070,1,41,132    *rods.9

51,1,1.030,1,42,264    *rods.9
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```
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.6616,530.6,0.0687,1.6059,
620.6,0.0698,1.5551,710.6,0.0707,1.5097,
800.6,0.0715,1.4699,890.6,0.0722,1.4361,
980.6,0.0729,1.4082,1070.6,0.0735,1.3855,
1160.6,0.0740,1.3667,1250.6,0.0745,1.3504,
1340.6,0.0750,1.3350,1430.6,0.0754,1.3191,
1520.6,0.0758,1.3022,1610.6,0.0762,1.2839,
1700.6,0.0767,1.2643,1790.6,0.0771,1.2437,
1880.6,0.0775,1.2226,1970.6,0.0779,1.2014,
2060.6,0.0783,1.1806,2150.6,0.0788,1.1605,
2240.6,0.0793,1.1415,2330.6,0.0799,1.1240,
2420.6,0.0805,1.1081,2510.6,0.0813,1.0942,
2600.6,0.0821,1.0823,2690.6,0.0830,1.0726,
2780.6,0.0840,1.0654,2870.6,0.0851,1.0606,
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2960.6,0.0864,1.0584,3050.6,0.0879,1.0589,
3140.6,0.0895,1.0620,3230.6,0.0914,1.0677,
3320.6,0.0934,1.0762,3410.6,0.0956,1.0874,
3500.6,0.0980,1.1013,3590.6,0.1006,1.1178,
3680.6,0.1035,1.1368,3770.6,0.1066,1.1584,
3860.6,0.1099,1.1824,3950.6,0.1134,1.2088,
4040.6,0.1172,1.2375,4130.6,0.1212,1.2683,
4220.6,0.1254,1.3012,4310.6,0.1299,1.3360,
4400.6,0.1346,1.3728,4490.6,0.1395,1.4112,
4580.6,0.1446,1.4513,4670.6,0.1499,1.4929,
4760.6,0.1555,1.5359,4850.6,0.1612,1.5802,
4940.6,0.1671,1.6257,5030.6,0.1732,1.6723,
5120.6,0.1794,1.7198,5210.6,0.1858,1.7681,
5300.6,0.1924,1.8172,5390.6,0.1990,1.8670,
5480.6,0.2059,1.9173,5570.6,0.2128,1.9680,
5660.6,0.2199,2.0191,5750.6,0.2270,2.0705,
5840.6,0.2343,2.1221,
endd
*
*
32,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 4.840498E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
```

```
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.0580,1,1,0.25,2,0.25    *rods.9
3,1,1.0236,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.0583,1,2,0.25,4,0.25    *rods.9
5,1,1.0242,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.0255,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.0593,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.0621,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.0579,1,7,0.25,11,0.25    *rods.9
12,1,1.0246,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0289,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.0736,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0589,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0553,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0223,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0273,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0756,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0838,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.0510,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0541,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
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25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.0663,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0438,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.9879,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0370,1,22,0.25,29,0.25    *rods.9
30,1,1.0076,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.0083,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.0382,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.0033,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,0.9808,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,0.9603,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,0.9531,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,0.9924,1,29,0.25,37,0.25    *rods.9
38,1,0.9874,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,0.9870,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,0.9902,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,0.9793,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,0.9669,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,0.9579,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,0.9590,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,0.9686,1,36,0.125,38,0.375    *rods.9
46,1,1.02011,1,37,35    *rods.9
47,1,1.02011,1,38,35.125    *rods.9
48,1,1.02011,1,39,66    *rods.9
49,1,1.02011,1,40,132    *rods.9
50,1,1.070,1,41,132    *rods.9
51,1,1.030,1,42,264    *rods.9
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
```

```
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.6203,530.6,0.0687,1.5673,
620.6,0.0698,1.5189,710.6,0.0707,1.4757,
800.6,0.0715,1.4379,890.6,0.0722,1.4060,
980.6,0.0729,1.3797,1070.6,0.0735,1.3586,
1160.6,0.0740,1.3413,1250.6,0.0745,1.3263,
1340.6,0.0750,1.3122,1430.6,0.0754,1.2977,
1520.6,0.0758,1.2820,1610.6,0.0762,1.2649,
1700.6,0.0767,1.2463,1790.6,0.0771,1.2268,
1880.6,0.0775,1.2066,1970.6,0.0779,1.1863,
2060.6,0.0783,1.1662,2150.6,0.0788,1.1469,
2240.6,0.0793,1.1286,2330.6,0.0799,1.1117,
2420.6,0.0805,1.0965,2510.6,0.0813,1.0830,
2600.6,0.0821,1.0717,2690.6,0.0830,1.0625,
2780.6,0.0840,1.0557,2870.6,0.0851,1.0514,
2960.6,0.0864,1.0495,3050.6,0.0879,1.0503,
3140.6,0.0895,1.0538,3230.6,0.0914,1.0599,
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3320.6,0.0934,1.0687,3410.6,0.0956,1.0802,
3500.6,0.0980,1.0943,3590.6,0.1006,1.1110,
3680.6,0.1035,1.1303,3770.6,0.1066,1.1521,
3860.6,0.1099,1.1764,3950.6,0.1134,1.2029,
4040.6,0.1172,1.2318,4130.6,0.1212,1.2628,
4220.6,0.1254,1.2959,4310.6,0.1299,1.3309,
4400.6,0.1346,1.3678,4490.6,0.1395,1.4064,
4580.6,0.1446,1.4466,4670.6,0.1499,1.4884,
4760.6,0.1555,1.5315,4850.6,0.1612,1.5759,
4940.6,0.1671,1.6215,5030.6,0.1732,1.6682,
5120.6,0.1794,1.7158,5210.6,0.1858,1.7643,
5300.6,0.1924,1.8135,5390.6,0.1990,1.8633,
5480.6,0.2059,1.9137,5570.6,0.2128,1.9646,
5660.6,0.2199,2.0158,5750.6,0.2270,2.0672,
5840.6,0.2343,2.1189,
endd
*
*
33,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 5.130927E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
```

```
1.55    *rods.5
*
*              Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.0582,1,1,0.25,2,0.25    *rods.9
3,1,1.0241,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.0585,1,2,0.25,4,0.25    *rods.9
5,1,1.0247,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.0260,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.0595,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.0623,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.0581,1,7,0.25,11,0.25    *rods.9
12,1,1.0251,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0294,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.0738,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0592,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0555,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0228,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0278,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0757,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0838,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.0512,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0542,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.0663,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
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27,1,1.0439,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.9883,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0371,1,22,0.25,29,0.25    *rods.9
30,1,1.0080,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.0087,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.0383,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.0036,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,0.9812,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,0.9607,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,0.9535,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,0.9928,1,29,0.25,37,0.25    *rods.9
38,1,0.9878,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,0.9875,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,0.9906,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,0.9797,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,0.9672,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,0.9583,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,0.9593,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,0.9688,1,36,0.125,38,0.375    *rods.9
46,1,1.02041,1,37,35    *rods.9
47,1,1.02041,1,38,35.125    *rods.9
48,1,1.02041,1,39,66    *rods.9
49,1,1.02041,1,40,132    *rods.9
50,1,1.070,1,41,132    *rods.9
51,1,1.030,1,42,264    *rods.9
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
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*             Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.5818,530.6,0.0687,1.5313,
620.6,0.0698,1.4852,710.6,0.0707,1.4439,
800.6,0.0715,1.4080,890.6,0.0722,1.3777,
980.6,0.0729,1.3530,1070.6,0.0735,1.3332,
1160.6,0.0740,1.3172,1250.6,0.0745,1.3035,
1340.6,0.0750,1.2906,1430.6,0.0754,1.2773,
1520.6,0.0758,1.2627,1610.6,0.0762,1.2466,
1700.6,0.0767,1.2291,1790.6,0.0771,1.2104,
1880.6,0.0775,1.1911,1970.6,0.0779,1.1716,
2060.6,0.0783,1.1523,2150.6,0.0788,1.1337,
2240.6,0.0793,1.1161,2330.6,0.0799,1.0998,
2420.6,0.0805,1.0851,2510.6,0.0813,1.0722,
2600.6,0.0821,1.0613,2690.6,0.0830,1.0526,
2780.6,0.0840,1.0462,2870.6,0.0851,1.0423,
2960.6,0.0864,1.0408,3050.6,0.0879,1.0420,
3140.6,0.0895,1.0458,3230.6,0.0914,1.0522,
3320.6,0.0934,1.0613,3410.6,0.0956,1.0730,
3500.6,0.0980,1.0874,3590.6,0.1006,1.1044,
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3680.6,0.1035,1.1239,3770.6,0.1066,1.1459,
3860.6,0.1099,1.1704,3950.6,0.1134,1.1972,
4040.6,0.1172,1.2262,4130.6,0.1212,1.2574,
4220.6,0.1254,1.2906,4310.6,0.1299,1.3258,
4400.6,0.1346,1.3628,4490.6,0.1395,1.4016,
4580.6,0.1446,1.4420,4670.6,0.1499,1.4839,
4760.6,0.1555,1.5272,4850.6,0.1612,1.5717,
4940.6,0.1671,1.6174,5030.6,0.1732,1.6642,
5120.6,0.1794,1.7119,5210.6,0.1858,1.7605,
5300.6,0.1924,1.8098,5390.6,0.1990,1.8597,
5480.6,0.2059,1.9102,5570.6,0.2128,1.9612,
5660.6,0.2199,2.0124,5750.6,0.2270,2.0640,
5840.6,0.2343,2.1157,
endd
*
*
34,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 5.421357E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
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*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.0584,1,1,0.25,2,0.25    *rods.9
3,1,1.0247,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.0588,1,2,0.25,4,0.25    *rods.9
5,1,1.0252,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.0265,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.0598,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.0626,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.0583,1,7,0.25,11,0.25    *rods.9
12,1,1.0256,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0299,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.0739,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0595,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0557,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0233,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0282,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0758,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0838,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.0513,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0544,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.0663,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0439,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.9887,1,21,0.125,27,0.25,28,0.125    *rods.9
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29,1,1.0373,1,22,0.25,29,0.25    *rods.9
30,1,1.0084,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.0091,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.0384,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.0040,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,0.9816,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,0.9612,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,0.9539,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,0.9933,1,29,0.25,37,0.25    *rods.9
38,1,0.9883,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,0.9879,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,0.9910,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,0.9801,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,0.9676,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,0.9586,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,0.9596,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,0.9690,1,36,0.125,38,0.375    *rods.9
46,1,1.02071,1,37,35    *rods.9
47,1,1.02071,1,38,35.125    *rods.9
48,1,1.02071,1,39,66    *rods.9
49,1,1.02071,1,40,132    *rods.9
50,1,1.070,1,41,132    *rods.9
51,1,1.030,1,42,264    *rods.9
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
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* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.5459,530.6,0.0687,1.4977,
620.6,0.0698,1.4536,710.6,0.0707,1.4142,
800.6,0.0715,1.3799,890.6,0.0722,1.3511,
980.6,0.0729,1.3277,1070.6,0.0735,1.3092,
1160.6,0.0740,1.2944,1250.6,0.0745,1.2819,
1340.6,0.0750,1.2701,1430.6,0.0754,1.2577,
1520.6,0.0758,1.2442,1610.6,0.0762,1.2290,
1700.6,0.0767,1.2124,1790.6,0.0771,1.1947,
1880.6,0.0775,1.1762,1970.6,0.0779,1.1574,
2060.6,0.0783,1.1389,2150.6,0.0788,1.1209,
2240.6,0.0793,1.1039,2330.6,0.0799,1.0882,
2420.6,0.0805,1.0740,2510.6,0.0813,1.0616,
2600.6,0.0821,1.0512,2690.6,0.0830,1.0429,
2780.6,0.0840,1.0370,2870.6,0.0851,1.0334,
2960.6,0.0864,1.0323,3050.6,0.0879,1.0338,
3140.6,0.0895,1.0379,3230.6,0.0914,1.0446,
3320.6,0.0934,1.0540,3410.6,0.0956,1.0660,
3500.6,0.0980,1.0806,3590.6,0.1006,1.0979,
3680.6,0.1035,1.1176,3770.6,0.1066,1.1399,
3860.6,0.1099,1.1645,3950.6,0.1134,1.1915,
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4040.6,0.1172,1.2207,4130.6,0.1212,1.2521,
4220.6,0.1254,1.2855,4310.6,0.1299,1.3208,
4400.6,0.1346,1.3580,4490.6,0.1395,1.3969,
4580.6,0.1446,1.4374,4670.6,0.1499,1.4794,
4760.6,0.1555,1.5229,4850.6,0.1612,1.5675,
4940.6,0.1671,1.6134,5030.6,0.1732,1.6603,
5120.6,0.1794,1.7081,5210.6,0.1858,1.7568,
5300.6,0.1924,1.8062,5390.6,0.1990,1.8562,
5480.6,0.2059,1.9068,5570.6,0.2128,1.9578,
5660.6,0.2199,2.0092,5750.6,0.2270,2.0608,
5840.6,0.2343,2.1126,
endd
*
*
35,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 5.711787E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
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2,1,1.0586,1,1,0.25,2,0.25    *rods.9
3,1,1.0252,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.0590,1,2,0.25,4,0.25    *rods.9
5,1,1.0257,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.0270,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.0600,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.0627,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.0585,1,7,0.25,11,0.25    *rods.9
12,1,1.0261,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0304,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.0740,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0597,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0559,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0237,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0287,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0758,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0838,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.0515,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0545,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.0663,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0440,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.9890,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0374,1,22,0.25,29,0.25    *rods.9
30,1,1.0087,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
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31,1,1.0095,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.0385,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
33,1,1.0043,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,0.9820,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,0.9616,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,0.9543,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,0.9937,1,29,0.25,37,0.25    *rods.9
38,1,0.9887,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,0.9884,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,0.9914,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,0.9805,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,0.9681,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,0.9590,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,0.9599,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,0.9691,1,36,0.125,38,0.375    *rods.9
46,1,1.02101,1,37,35    *rods.9
47,1,1.02101,1,38,35.125    *rods.9
48,1,1.02101,1,39,66    *rods.9
49,1,1.02101,1,40,132    *rods.9
50,1,1.070,1,41,132    *rods.9
51,1,1.030,1,42,264    *rods.9
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
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0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.5124,530.6,0.0687,1.4662,
620.6,0.0698,1.4240,710.6,0.0707,1.3863,
800.6,0.0715,1.3535,890.6,0.0722,1.3260,
980.6,0.0729,1.3039,1070.6,0.0735,1.2865,
1160.6,0.0740,1.2728,1250.6,0.0745,1.2613,
1340.6,0.0750,1.2504,1430.6,0.0754,1.2390,
1520.6,0.0758,1.2264,1610.6,0.0762,1.2121,
1700.6,0.0767,1.1964,1790.6,0.0771,1.1794,
1880.6,0.0775,1.1617,1970.6,0.0779,1.1437,
2060.6,0.0783,1.1258,2150.6,0.0788,1.1084,
2240.6,0.0793,1.0920,2330.6,0.0799,1.0769,
2420.6,0.0805,1.0632,2510.6,0.0813,1.0513,
2600.6,0.0821,1.0413,2690.6,0.0830,1.0335,
2780.6,0.0840,1.0279,2870.6,0.0851,1.0247,
2960.6,0.0864,1.0240,3050.6,0.0879,1.0258,
3140.6,0.0895,1.0302,3230.6,0.0914,1.0372,
3320.6,0.0934,1.0468,3410.6,0.0956,1.0591,
3500.6,0.0980,1.0740,3590.6,0.1006,1.0915,
3680.6,0.1035,1.1114,3770.6,0.1066,1.1339,
3860.6,0.1099,1.1587,3950.6,0.1134,1.1859,
4040.6,0.1172,1.2153,4130.6,0.1212,1.2468,
4220.6,0.1254,1.2804,4310.6,0.1299,1.3159,
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4400.6,0.1346,1.3532,4490.6,0.1395,1.3923,
4580.6,0.1446,1.4329,4670.6,0.1499,1.4751,
4760.6,0.1555,1.5186,4850.6,0.1612,1.5634,
4940.6,0.1671,1.6094,5030.6,0.1732,1.6564,
5120.6,0.1794,1.7043,5210.6,0.1858,1.7531,
5300.6,0.1924,1.8026,5390.6,0.1990,1.8527,
5480.6,0.2059,1.9034,5570.6,0.2128,1.9545,
5660.6,0.2199,2.0059,5750.6,0.2270,2.0576,
5840.6,0.2343,2.1095,
endd
*
*
36,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 6.002217E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.0588,1,1,0.25,2,0.25    *rods.9
3,1,1.0256,1,1,0.125,2,0.25,3,0.125    *rods.9
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4,1,1.0592,1,2,0.25,4,0.25    *rods.9
5,1,1.0262,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
6,1,1.0275,1,3,0.125,5,0.25,6,0.125    *rods.9
7,2,0,1,4,0.25,7,0.25,0,0    *rods.9
8,1,1.0602,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9
9,1,1.0629,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9
10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9
11,1,1.0587,1,7,0.25,11,0.25    *rods.9
12,1,1.0265,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9
13,1,1.0308,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9
14,1,1.0741,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9
15,1,1.0600,1,10,0.125,14,0.25,15,0.125    *rods.9
16,1,1.0561,1,11,0.25,16,0.25,0,0    *rods.9
17,1,1.0242,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9
18,1,1.0291,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9
19,1,1.0759,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9
20,1,1.0837,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9
21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9
22,2,0,1,16,0.25,22,0.25    *rods.9
23,1,1.0516,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9
24,1,1.0546,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9
25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9
26,1,1.0662,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9
27,1,1.0440,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9
28,1,0.9894,1,21,0.125,27,0.25,28,0.125    *rods.9
29,1,1.0375,1,22,0.25,29,0.25    *rods.9
30,1,1.0091,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9
31,1,1.0098,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9
32,1,1.0386,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9
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33,1,1.0047,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9
34,1,0.9825,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
35,1,0.9621,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,0.9547,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,0.9941,1,29,0.25,37,0.25    *rods.9
38,1,0.9892,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,0.9888,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,0.9918,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,0.9810,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,0.9685,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,0.9594,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,0.9602,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,0.9694,1,36,0.125,38,0.375    *rods.9
46,1,1.02131,1,37,35    *rods.9
47,1,1.02131,1,38,35.125    *rods.9
48,1,1.02131,1,39,66    *rods.9
49,1,1.02131,1,40,132    *rods.9
50,1,1.070,1,41,132    *rods.9
51,1,1.030,1,42,264    *rods.9
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
```

```
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.4809,530.6,0.0687,1.4366,
620.6,0.0698,1.3961,710.6,0.0707,1.3599,
800.6,0.0715,1.3285,890.6,0.0722,1.3023,
980.6,0.0729,1.2813,1070.6,0.0735,1.2650,
1160.6,0.0740,1.2522,1250.6,0.0745,1.2416,
1340.6,0.0750,1.2316,1430.6,0.0754,1.2211,
1520.6,0.0758,1.2093,1610.6,0.0762,1.1959,
1700.6,0.0767,1.1809,1790.6,0.0771,1.1647,
1880.6,0.0775,1.1477,1970.6,0.0779,1.1303,
2060.6,0.0783,1.1131,2150.6,0.0788,1.0963,
2240.6,0.0793,1.0805,2330.6,0.0799,1.0658,
2420.6,0.0805,1.0526,2510.6,0.0813,1.0412,
2600.6,0.0821,1.0317,2690.6,0.0830,1.0242,
2780.6,0.0840,1.0190,2870.6,0.0851,1.0162,
2960.6,0.0864,1.0158,3050.6,0.0879,1.0179,
3140.6,0.0895,1.0226,3230.6,0.0914,1.0299,
3320.6,0.0934,1.0398,3410.6,0.0956,1.0523,
3500.6,0.0980,1.0675,3590.6,0.1006,1.0851,
3680.6,0.1035,1.1053,3770.6,0.1066,1.1280,
3860.6,0.1099,1.1530,3950.6,0.1134,1.1804,
4040.6,0.1172,1.2100,4130.6,0.1212,1.2417,
4220.6,0.1254,1.2754,4310.6,0.1299,1.3110,
4400.6,0.1346,1.3485,4490.6,0.1395,1.3877,
4580.6,0.1446,1.4285,4670.6,0.1499,1.4708,
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4760.6,0.1555,1.5144,4850.6,0.1612,1.5593,
4940.6,0.1671,1.6054,5030.6,0.1732,1.6525,
5120.6,0.1794,1.7005,5210.6,0.1858,1.7494,
5300.6,0.1924,1.7990,5390.6,0.1990,1.8492,
5480.6,0.2059,1.9000,5570.6,0.2128,1.9512,
5660.6,0.2199,2.0027,5750.6,0.2270,2.0545,
5840.6,0.2343,2.1065,
endd
*
*
37,0,0,-1,0    *vipre.1
Burnup [MWd/t] at 6.292647E+04
rods,1,54,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*  Nuclear Fuel Rod Power Profile
* chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
*
*             Normal Rod input
1,2,0,1,1,0.125    *rods.9
2,1,1.0591,1,1,0.25,2,0.25    *rods.9
3,1,1.0262,1,1,0.125,2,0.25,3,0.125    *rods.9
4,1,1.0595,1,2,0.25,4,0.25    *rods.9
5,1,1.0268,1,2,0.25,3,0.25,4,0.25,5,0.25    *rods.9
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6,1,1.0281,1,3,0.125,5,0.25,6,0.125    *rods.9

7,2,0,1,4,0.25,7,0.25,0,0    *rods.9

8,1,1.0604,1,4,0.25,5,0.25,7,0.25,8,0.25    *rods.9

9,1,1.0632,1,5,0.25,6,0.25,8,0.25,9,0.25    *rods.9

10,2,0,1,6,0.125,9,0.25,10,0.125    *rods.9

11,1,1.0590,1,7,0.25,11,0.25    *rods.9

12,1,1.0271,1,7,0.25,8,0.25,11,0.25,12,0.25    *rods.9

13,1,1.0314,1,8,0.25,9,0.25,12,0.25,13,0.25    *rods.9

14,1,1.0744,1,9,0.25,10,0.25,13,0.25,14,0.25    *rods.9

15,1,1.0603,1,10,0.125,14,0.25,15,0.125    *rods.9

16,1,1.0563,1,11,0.25,16,0.25,0,0    *rods.9

17,1,1.0247,1,11,0.25,12,0.25,16,0.25,17,0.25    *rods.9

18,1,1.0296,1,12,0.25,13,0.25,17,0.25,18,0.25    *rods.9

19,1,1.0760,1,13,0.25,14,0.25,18,0.25,19,0.25    *rods.9

20,1,1.0838,1,14,0.25,15,0.25,19,0.25,20,0.25    *rods.9

21,2,0,1,15,0.125,20,0.25,21,0.125    *rods.9

22,2,0,1,16,0.25,22,0.25    *rods.9

23,1,1.0518,1,16,0.25,17,0.25,22,0.25,23,0.25    *rods.9

24,1,1.0548,1,17,0.25,18,0.25,23,0.25,24,0.25    *rods.9

25,2,0,1,18,0.25,19,0.25,24,0.25,25,0.25    *rods.9

26,1,1.0663,1,19,0.25,20,0.25,25,0.25,26,0.25    *rods.9

27,1,1.0442,1,20,0.25,21,0.25,26,0.25,27,0.25    *rods.9

28,1,0.9899,1,21,0.125,27,0.25,28,0.125    *rods.9

29,1,1.0378,1,22,0.25,29,0.25    *rods.9

30,1,1.0096,1,22,0.25,23,0.25,29,0.25,30,0.25    *rods.9

31,1,1.0103,1,23,0.25,24,0.25,30,0.25,31,0.25    *rods.9

32,1,1.0388,1,24,0.25,25,0.25,31,0.25,32,0.25    *rods.9

33,1,1.0051,1,25,0.25,26,0.25,32,0.25,33,0.25    *rods.9

34,1,0.9830,1,26,0.25,27,0.25,33,0.25,34,0.25    *rods.9
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35,1,0.9626,1,27,0.25,28,0.25,34,0.25,35,0.25    *rods.9
36,1,0.9552,1,28,0.125,35,0.25,36,0.125    *rods.9
37,1,0.9946,1,29,0.25,37,0.25    *rods.9
38,1,0.9897,1,29,0.25,30,0.25,37,0.5    *rods.9
39,1,0.9893,1,30,0.25,31,0.25,37,0.5    *rods.9
40,1,0.9923,1,31,0.25,32,0.25,37,0.5    *rods.9
41,1,0.9815,1,32,0.25,33,0.25,37,0.25,38,0.25    *rods.9
42,1,0.9690,1,33,0.25,34,0.25,38,0.5    *rods.9
43,1,0.9599,1,34,0.25,35,0.25,38,0.5    *rods.9
44,1,0.9606,1,35,0.25,36,0.25,38,0.5    *rods.9
45,1,0.9697,1,36,0.125,38,0.375    *rods.9
46,1,1.02171,1,37,35    *rods.9
47,1,1.02171,1,38,35.125    *rods.9
48,1,1.02171,1,39,66    *rods.9
49,1,1.02171,1,40,132    *rods.9
50,1,1.070,1,41,132    *rods.9
51,1,1.030,1,42,264    *rods.9
52,1,1.010,1,43,132    *rods.9
53,1,1.000,1,44,1848    *rods.9
54,1,0.989,1,45,3696    *rods.9
0    *rods.9
*              Fuel Geometry Types
*
* nuclear type geometry - used for nuclear rods
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
*
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
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*
* Fuel thermal-physical property table
1,61,651.186,UOX    *rods.70
440.6,0.0673,1.4512,530.6,0.0687,1.4087,
620.6,0.0698,1.3698,710.6,0.0707,1.3350,
800.6,0.0715,1.3049,890.6,0.0722,1.2799,
980.6,0.0729,1.2599,1070.6,0.0735,1.2445,
1160.6,0.0740,1.2326,1250.6,0.0745,1.2228,
1340.6,0.0750,1.2136,1430.6,0.0754,1.2039,
1520.6,0.0758,1.1929,1610.6,0.0762,1.1802,
1700.6,0.0767,1.1660,1790.6,0.0771,1.1504,
1880.6,0.0775,1.1341,1970.6,0.0779,1.1174,
2060.6,0.0783,1.1007,2150.6,0.0788,1.0845,
2240.6,0.0793,1.0692,2330.6,0.0799,1.0550,
2420.6,0.0805,1.0423,2510.6,0.0813,1.0313,
2600.6,0.0821,1.0222,2690.6,0.0830,1.0152,
2780.6,0.0840,1.0103,2870.6,0.0851,1.0078,
2960.6,0.0864,1.0078,3050.6,0.0879,1.0102,
3140.6,0.0895,1.0152,3230.6,0.0914,1.0227,
3320.6,0.0934,1.0329,3410.6,0.0956,1.0457,
3500.6,0.0980,1.0610,3590.6,0.1006,1.0789,
3680.6,0.1035,1.0994,3770.6,0.1066,1.1222,
3860.6,0.1099,1.1474,3950.6,0.1134,1.1750,
4040.6,0.1172,1.2047,4130.6,0.1212,1.2366,
4220.6,0.1254,1.2705,4310.6,0.1299,1.3063,
4400.6,0.1346,1.3439,4490.6,0.1395,1.3832,
4580.6,0.1446,1.4241,4670.6,0.1499,1.4665,
4760.6,0.1555,1.5103,4850.6,0.1612,1.5553,
4940.6,0.1671,1.6015,5030.6,0.1732,1.6487,
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5120.6,0.1794,1.6968,5210.6,0.1858,1.7458,
5300.6,0.1924,1.7955,5390.6,0.1990,1.8458,
5480.6,0.2059,1.8966,5570.6,0.2128,1.9479,
5660.6,0.2199,1.9995,5750.6,0.2270,2.0514,
5840.6,0.2343,2.1035,
endd
0
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B.2 Partial LOFA Analysis

```
*
* UOX 4.9% U235 17x17 Assembly Westinghouse 4-Loop PWR (Comanche Peak)
* 112%Power, T=+2C,-5%Flow, APP=CC1.55,MPEAK=2.42
1,0,0,-1,0    *vipre.1
1/8 PWR Core PLOFA Analysis  (uox1 - 02/14/09) *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, s/l ratio = 0.5 *geom.2
*      channel dimensions
1,119.0902,1087.6390,969.3384,3,2,1.054,15.41,3,2.108,11.442,?
4,2.108,11.442    *geom.4
2,38.1089,348.0445,310.1883,3,3,2.108,6.482,6,2.108,6.482,?
10,1.054,12.434    *geom.4
3,38.1089,348.0445,310.1883,2,4,2.108,8.466,?
6,2.108,8.466    *geom.4
4,38.1089,348.0445,310.1883,2,5,2.108,6.978,?
7,2.108,8.466    *geom.4
5,19.0544,174.0222,155.0941,1,8,2.108,6.482    *geom.4
6,38.1089,348.0445,310.1883,2,7,2.108,8.466,?
11,2.108,8.466    *geom.4
7,38.1089,348.0445,310.1883,2,8,2.108,8.466,?
12,2.108,8.466    *geom.4
8,38.1089,348.0445,310.1883,5,9,2.108,6.978,13,0.527,8.466,?
14,0.527,8.466    *geom.4
15,0.5270,8.4660,16,0.527,8.466    *geom.4a
```

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9,19.0544,174.0222,155.0941,1,17,2.108,6.978    *geom.4
10,19.0544,174.0222,155.0941,2,11,2.108,6.482,?
19,1.054,8.466    *geom.4
11,38.1089,348.0445,310.1883,2,12,2.108,8.466,?
20,2.108,8.466    *geom.4
12,38.1089,348.0445,310.1883,2,13,2.108,5.49,?
21,2.108,5.49    *geom.4
13,9.8440,89.4345,79.9704,5,14,2.108,1.984,25,0.122,4.746,?
26,0.122,4.746    *geom.4
27,0.1220,4.7460,28,0.122,4.746    *geom.4a
14,9.8440,89.4345,79.9704,5,15,2.108,1.984,29,0.122,4.746,?
30,0.122,4.746    *geom.4
31,0.1220,4.7460,32,0.122,4.746    *geom.4a
15,9.8440,89.4345,79.9704,5,16,2.108,1.984,33,0.122,4.746,?
34,0.122,4.746    *geom.4
35,0.1220,4.7460,36,0.122,4.746    *geom.4a
16,9.8440,89.4345,79.9704,5,17,2.108,5.49,37,0.122,4.746,?
38,0.122,4.746    *geom.4
39,0.1220,4.7460,40,0.122,4.746    *geom.4a
17,38.1089,348.0445,310.1883,2,18,2.108,6.978,?
281,2.108,5.49    *geom.4
18,19.0544,174.0222,155.0941,1,285,2.108,6.978    *geom.4
19,19.0544,174.0222,155.0941,2,20,2.108,6.482,?
286,1.054,8.466    *geom.4
20,38.1089,348.0445,310.1883,5,21,0.527,8.466,22,0.527,8.466,?
23,0.527,8.466    *geom.4
24,0.5270,8.4660,287,2.108,8.466    *geom.4a
21,9.8440,89.4345,79.9704,5,22,2.108,1.984,25,0.122,4.746,?
41,0.122,4.746    *geom.4
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57,0.1220,4.7460,73,0.122,4.746    *geom.4a
22,9.8440,89.4345,79.9704,5,23,2.108,1.984,89,0.122,4.746,?
105,0.122,4.746    *geom.4
121,0.1220,4.7460,137,0.122,4.746    *geom.4a
23,9.8440,89.4345,79.9704,5,24,2.108,1.984,153,0.122,4.746,?
169,0.122,4.746    *geom.4
185,0.1220,4.7460,201,0.122,4.746    *geom.4a
24,9.8440,89.4345,79.9704,5,217,0.122,4.746,233,0.122,4.746,?
249,0.122,4.746    *geom.4
265,0.1220,4.7460,288,2.108,5.49    *geom.4a
25,0.1362,1.1750,1.1750,2,26,0.122,0,41,0.122,0    *geom.4
26,0.1362,1.1750,1.1750,2,27,0.122,0,42,0.122,0    *geom.4
27,0.1362,1.1750,1.1750,2,28,0.122,0,43,0.122,0    *geom.4
28,0.1362,1.1750,1.1750,2,29,0.122,0,44,0.122,0    *geom.4
29,0.1362,1.1750,1.1750,2,30,0.122,0,45,0.122,0    *geom.4
30,0.1362,1.1750,1.1750,2,31,0.122,0,46,0.122,0    *geom.4
31,0.1362,1.1750,1.1750,2,32,0.122,0,47,0.122,0    *geom.4
32,0.1362,1.1750,1.1750,2,33,0.122,0,48,0.122,0    *geom.4
33,0.1362,1.1750,1.1750,2,34,0.122,0,49,0.122,0    *geom.4
34,0.1362,1.1750,1.1750,2,35,0.122,0,50,0.122,0    *geom.4
35,0.1362,1.1750,1.1750,2,36,0.122,0,51,0.122,0    *geom.4
36,0.1362,1.1750,1.1750,2,37,0.122,0,52,0.122,0    *geom.4
37,0.1362,1.1750,1.1750,2,38,0.122,0,53,0.122,0    *geom.4
38,0.1362,1.1750,1.1750,2,39,0.122,0,54,0.122,0    *geom.4
39,0.1362,1.1750,1.1750,2,40,0.122,0,55,0.122,0    *geom.4
40,0.1362,1.1750,1.1750,2,56,0.122,0,281,0.122,0    *geom.4
41,0.1362,1.1750,1.1750,2,42,0.122,0,57,0.122,0    *geom.4
42,0.1362,1.1750,1.1750,2,43,0.122,0,58,0.122,0    *geom.4
43,0.1362,1.1750,1.1750,2,44,0.122,0,59,0.122,0    *geom.4
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44,0.1362,1.1750,1.1750,2,45,0.122,0,60,0.122,0    *geom.4
45,0.1180,1.2598,0.8812,2,46,0.068,0,61,0.068,0    *geom.4
46,0.1180,1.2598,0.8812,2,47,0.122,0,62,0.068,0    *geom.4
47,0.1362,1.1750,1.1750,2,48,0.122,0,63,0.122,0    *geom.4
48,0.1180,1.2598,0.8812,2,49,0.068,0,64,0.068,0    *geom.4
49,0.1180,1.2598,0.8812,2,50,0.122,0,65,0.068,0    *geom.4
50,0.1362,1.1750,1.1750,2,51,0.122,0,66,0.122,0    *geom.4
51,0.1180,1.2598,0.8812,2,52,0.068,0,67,0.068,0    *geom.4
52,0.1180,1.2598,0.8812,2,53,0.122,0,68,0.068,0    *geom.4
53,0.1362,1.1750,1.1750,2,54,0.122,0,69,0.122,0    *geom.4
54,0.1362,1.1750,1.1750,2,55,0.122,0,70,0.122,0    *geom.4
55,0.1362,1.1750,1.1750,2,56,0.122,0,71,0.122,0    *geom.4
56,0.1362,1.1750,1.1750,2,72,0.122,0,281,0.122,0    *geom.4
57,0.1362,1.1750,1.1750,2,58,0.122,0,73,0.122,0    *geom.4
58,0.1362,1.1750,1.1750,2,59,0.122,0,74,0.122,0    *geom.4
59,0.1180,1.2598,0.8812,2,60,0.068,0,75,0.068,0    *geom.4
60,0.1180,1.2598,0.8812,2,61,0.122,0,76,0.068,0    *geom.4
61,0.1180,1.2598,0.8812,2,62,0.068,0,77,0.122,0    *geom.4
62,0.1180,1.2598,0.8812,2,63,0.122,0,78,0.122,0    *geom.4
63,0.1362,1.1750,1.1750,2,64,0.122,0,79,0.122,0    *geom.4
64,0.1180,1.2598,0.8812,2,65,0.068,0,80,0.122,0    *geom.4
65,0.1180,1.2598,0.8812,2,66,0.122,0,81,0.122,0    *geom.4
66,0.1362,1.1750,1.1750,2,67,0.122,0,82,0.122,0    *geom.4
67,0.1180,1.2598,0.8812,2,68,0.068,0,83,0.122,0    *geom.4
68,0.1180,1.2598,0.8812,2,69,0.122,0,84,0.122,0    *geom.4
69,0.1180,1.2598,0.8812,2,70,0.068,0,85,0.068,0    *geom.4
70,0.1180,1.2598,0.8812,2,71,0.122,0,86,0.068,0    *geom.4
71,0.1362,1.1750,1.1750,2,72,0.122,0,87,0.122,0    *geom.4
72,0.1362,1.1750,1.1750,2,88,0.122,0,281,0.122,0    *geom.4
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73,0.1362,1.1750,1.1750,2,74,0.122,0,89,0.122,0    *geom.4
74,0.1362,1.1750,1.1750,2,75,0.122,0,90,0.122,0    *geom.4
75,0.1180,1.2598,0.8812,2,76,0.068,0,91,0.122,0    *geom.4
76,0.1180,1.2598,0.8812,2,77,0.122,0,92,0.122,0    *geom.4
77,0.1362,1.1750,1.1750,2,78,0.122,0,93,0.122,0    *geom.4
78,0.1362,1.1750,1.1750,2,79,0.122,0,94,0.122,0    *geom.4
79,0.1362,1.1750,1.1750,2,80,0.122,0,95,0.122,0    *geom.4
80,0.1362,1.1750,1.1750,2,81,0.122,0,96,0.122,0    *geom.4
81,0.1362,1.1750,1.1750,2,82,0.122,0,97,0.122,0    *geom.4
82,0.1362,1.1750,1.1750,2,83,0.122,0,98,0.122,0    *geom.4
83,0.1362,1.1750,1.1750,2,84,0.122,0,99,0.122,0    *geom.4
84,0.1362,1.1750,1.1750,2,85,0.122,0,100,0.122,0    *geom.4
85,0.1180,1.2598,0.8812,2,86,0.068,0,101,0.122,0    *geom.4
86,0.1180,1.2598,0.8812,2,87,0.122,0,102,0.122,0    *geom.4
87,0.1362,1.1750,1.1750,2,88,0.122,0,103,0.122,0    *geom.4
88,0.1362,1.1750,1.1750,2,104,0.122,0,281,0.122,0    *geom.4
89,0.1362,1.1750,1.1750,2,90,0.122,0,105,0.122,0    *geom.4
90,0.1180,1.2598,0.8812,2,91,0.068,0,106,0.068,0    *geom.4
91,0.1180,1.2598,0.8812,2,92,0.122,0,107,0.068,0    *geom.4
92,0.1362,1.1750,1.1750,2,93,0.122,0,108,0.122,0    *geom.4
93,0.1180,1.2598,0.8812,2,94,0.068,0,109,0.068,0    *geom.4
94,0.1180,1.2598,0.8812,2,95,0.122,0,110,0.068,0    *geom.4
95,0.1362,1.1750,1.1750,2,96,0.122,0,111,0.122,0    *geom.4
96,0.1180,1.2598,0.8812,2,97,0.068,0,112,0.068,0    *geom.4
97,0.1180,1.2598,0.8812,2,98,0.122,0,113,0.068,0    *geom.4
98,0.1362,1.1750,1.1750,2,99,0.122,0,114,0.122,0    *geom.4
99,0.1180,1.2598,0.8812,2,100,0.068,0,115,0.068,0    *geom.4
100,0.1180,1.2598,0.8812,2,101,0.122,0,116,0.068,0    *geom.4
101,0.1362,1.1750,1.1750,2,102,0.122,0,117,0.122,0    *geom.4
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102,0.1180,1.2598,0.8812,2,103,0.068,0,118,0.068,0     *geom.4
103,0.1180,1.2598,0.8812,2,104,0.122,0,119,0.068,0     *geom.4
104,0.1362,1.1750,1.1750,2,120,0.122,0,282,0.122,0     *geom.4
105,0.1362,1.1750,1.1750,2,106,0.122,0,121,0.122,0     *geom.4
106,0.1180,1.2598,0.8812,2,107,0.068,0,122,0.122,0     *geom.4
107,0.1180,1.2598,0.8812,2,108,0.122,0,123,0.122,0     *geom.4
108,0.1362,1.1750,1.1750,2,109,0.122,0,124,0.122,0     *geom.4
109,0.1180,1.2598,0.8812,2,110,0.068,0,125,0.122,0     *geom.4
110,0.1180,1.2598,0.8812,2,111,0.122,0,126,0.122,0     *geom.4
111,0.1362,1.1750,1.1750,2,112,0.122,0,127,0.122,0     *geom.4
112,0.1180,1.2598,0.8812,2,113,0.068,0,128,0.122,0     *geom.4
113,0.1180,1.2598,0.8812,2,114,0.122,0,129,0.122,0     *geom.4
114,0.1362,1.1750,1.1750,2,115,0.122,0,130,0.122,0     *geom.4
115,0.1180,1.2598,0.8812,2,116,0.068,0,131,0.122,0     *geom.4
116,0.1180,1.2598,0.8812,2,117,0.122,0,132,0.122,0     *geom.4
117,0.1362,1.1750,1.1750,2,118,0.122,0,133,0.122,0     *geom.4
118,0.1180,1.2598,0.8812,2,119,0.068,0,134,0.122,0     *geom.4
119,0.1180,1.2598,0.8812,2,120,0.122,0,135,0.122,0     *geom.4
120,0.1362,1.1750,1.1750,2,136,0.122,0,282,0.122,0     *geom.4
121,0.1362,1.1750,1.1750,2,122,0.122,0,137,0.122,0     *geom.4
122,0.1362,1.1750,1.1750,2,123,0.122,0,138,0.122,0     *geom.4
123,0.1362,1.1750,1.1750,2,124,0.122,0,139,0.122,0     *geom.4
124,0.1362,1.1750,1.1750,2,125,0.122,0,140,0.122,0     *geom.4
125,0.1362,1.1750,1.1750,2,126,0.122,0,141,0.122,0     *geom.4
126,0.1362,1.1750,1.1750,2,127,0.122,0,142,0.122,0     *geom.4
127,0.1362,1.1750,1.1750,2,128,0.122,0,143,0.122,0     *geom.4
128,0.1362,1.1750,1.1750,2,129,0.122,0,144,0.122,0     *geom.4
129,0.1362,1.1750,1.1750,2,130,0.122,0,145,0.122,0     *geom.4
130,0.1362,1.1750,1.1750,2,131,0.122,0,146,0.122,0     *geom.4
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133,0.1362,1.1750,1.1750,2,134,0.122,0,149,0.122,0     *geom.4
134,0.1362,1.1750,1.1750,2,135,0.122,0,150,0.122,0     *geom.4
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136,0.1362,1.1750,1.1750,2,152,0.122,0,282,0.122,0     *geom.4
137,0.1362,1.1750,1.1750,2,138,0.122,0,153,0.122,0     *geom.4
138,0.1180,1.2598,0.8812,2,139,0.068,0,154,0.068,0     *geom.4
139,0.1180,1.2598,0.8812,2,140,0.122,0,155,0.068,0     *geom.4
140,0.1362,1.1750,1.1750,2,141,0.122,0,156,0.122,0     *geom.4
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145,0.1180,1.2598,0.8812,2,146,0.122,0,161,0.068,0     *geom.4
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156,0.1362,1.1750,1.1750,2,157,0.122,0,172,0.122,0     *geom.4
157,0.1180,1.2598,0.8812,2,158,0.068,0,173,0.122,0     *geom.4
158,0.1180,1.2598,0.8812,2,159,0.122,0,174,0.122,0     *geom.4
159,0.1362,1.1750,1.1750,2,160,0.122,0,175,0.122,0     *geom.4
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162,0.1362,1.1750,1.1750,2,163,0.122,0,178,0.122,0     *geom.4
163,0.1180,1.2598,0.8812,2,164,0.068,0,179,0.122,0     *geom.4
164,0.1180,1.2598,0.8812,2,165,0.122,0,180,0.122,0     *geom.4
165,0.1362,1.1750,1.1750,2,166,0.122,0,181,0.122,0     *geom.4
166,0.1180,1.2598,0.8812,2,167,0.068,0,182,0.122,0     *geom.4
167,0.1180,1.2598,0.8812,2,168,0.122,0,183,0.122,0     *geom.4
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172,0.1362,1.1750,1.1750,2,173,0.122,0,188,0.122,0     *geom.4
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174,0.1362,1.1750,1.1750,2,175,0.122,0,190,0.122,0     *geom.4
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176,0.1362,1.1750,1.1750,2,177,0.122,0,192,0.122,0     *geom.4
177,0.1362,1.1750,1.1750,2,178,0.122,0,193,0.122,0     *geom.4
178,0.1362,1.1750,1.1750,2,179,0.122,0,194,0.122,0     *geom.4
179,0.1362,1.1750,1.1750,2,180,0.122,0,195,0.122,0     *geom.4
180,0.1362,1.1750,1.1750,2,181,0.122,0,196,0.122,0     *geom.4
181,0.1362,1.1750,1.1750,2,182,0.122,0,197,0.122,0     *geom.4
182,0.1362,1.1750,1.1750,2,183,0.122,0,198,0.122,0     *geom.4
183,0.1362,1.1750,1.1750,2,184,0.122,0,199,0.122,0     *geom.4
184,0.1362,1.1750,1.1750,2,200,0.122,0,283,0.122,0     *geom.4
185,0.1362,1.1750,1.1750,2,186,0.122,0,201,0.122,0     *geom.4
186,0.1180,1.2598,0.8812,2,187,0.068,0,202,0.068,0     *geom.4
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188,0.1362,1.1750,1.1750,2,189,0.122,0,204,0.122,0     *geom.4
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191,0.1362,1.1750,1.1750,2,192,0.122,0,207,0.122,0     *geom.4
192,0.1180,1.2598,0.8812,2,193,0.068,0,208,0.068,0     *geom.4
193,0.1180,1.2598,0.8812,2,194,0.122,0,209,0.068,0     *geom.4
194,0.1362,1.1750,1.1750,2,195,0.122,0,210,0.122,0     *geom.4
195,0.1180,1.2598,0.8812,2,196,0.068,0,211,0.068,0     *geom.4
196,0.1180,1.2598,0.8812,2,197,0.122,0,212,0.068,0     *geom.4
197,0.1362,1.1750,1.1750,2,198,0.122,0,213,0.122,0     *geom.4
198,0.1180,1.2598,0.8812,2,199,0.068,0,214,0.068,0     *geom.4
199,0.1180,1.2598,0.8812,2,200,0.122,0,215,0.068,0     *geom.4
200,0.1362,1.1750,1.1750,2,216,0.122,0,283,0.122,0     *geom.4
201,0.1362,1.1750,1.1750,2,202,0.122,0,217,0.122,0     *geom.4
202,0.1180,1.2598,0.8812,2,203,0.068,0,218,0.122,0     *geom.4
203,0.1180,1.2598,0.8812,2,204,0.122,0,219,0.122,0     *geom.4
204,0.1362,1.1750,1.1750,2,205,0.122,0,220,0.122,0     *geom.4
205,0.1180,1.2598,0.8812,2,206,0.068,0,221,0.122,0     *geom.4
206,0.1180,1.2598,0.8812,2,207,0.122,0,222,0.122,0     *geom.4
207,0.1362,1.1750,1.1750,2,208,0.122,0,223,0.122,0     *geom.4
208,0.1180,1.2598,0.8812,2,209,0.068,0,224,0.122,0     *geom.4
209,0.1180,1.2598,0.8812,2,210,0.122,0,225,0.122,0     *geom.4
210,0.1362,1.1750,1.1750,2,211,0.122,0,226,0.122,0     *geom.4
211,0.1180,1.2598,0.8812,2,212,0.068,0,227,0.122,0     *geom.4
212,0.1180,1.2598,0.8812,2,213,0.122,0,228,0.122,0     *geom.4
213,0.1362,1.1750,1.1750,2,214,0.122,0,229,0.122,0     *geom.4
214,0.1180,1.2598,0.8812,2,215,0.068,0,230,0.122,0     *geom.4
215,0.1180,1.2598,0.8812,2,216,0.122,0,231,0.122,0     *geom.4
216,0.1362,1.1750,1.1750,2,232,0.122,0,283,0.122,0     *geom.4
217,0.1362,1.1750,1.1750,2,218,0.122,0,233,0.122,0     *geom.4
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218,0.1362,1.1750,1.1750,2,219,0.122,0,234,0.122,0     *geom.4
219,0.1180,1.2598,0.8812,2,220,0.068,0,235,0.068,0     *geom.4
220,0.1180,1.2598,0.8812,2,221,0.122,0,236,0.068,0     *geom.4
221,0.1362,1.1750,1.1750,2,222,0.122,0,237,0.122,0     *geom.4
222,0.1362,1.1750,1.1750,2,223,0.122,0,238,0.122,0     *geom.4
223,0.1362,1.1750,1.1750,2,224,0.122,0,239,0.122,0     *geom.4
224,0.1362,1.1750,1.1750,2,225,0.122,0,240,0.122,0     *geom.4
225,0.1362,1.1750,1.1750,2,226,0.122,0,241,0.122,0     *geom.4
226,0.1362,1.1750,1.1750,2,227,0.122,0,242,0.122,0     *geom.4
227,0.1362,1.1750,1.1750,2,228,0.122,0,243,0.122,0     *geom.4
228,0.1362,1.1750,1.1750,2,229,0.122,0,244,0.122,0     *geom.4
229,0.1180,1.2598,0.8812,2,230,0.068,0,245,0.068,0     *geom.4
230,0.1180,1.2598,0.8812,2,231,0.122,0,246,0.068,0     *geom.4
231,0.1362,1.1750,1.1750,2,232,0.122,0,247,0.122,0     *geom.4
232,0.1362,1.1750,1.1750,2,248,0.122,0,284,0.122,0     *geom.4
233,0.1362,1.1750,1.1750,2,234,0.122,0,249,0.122,0     *geom.4
234,0.1362,1.1750,1.1750,2,235,0.122,0,250,0.122,0     *geom.4
235,0.1180,1.2598,0.8812,2,236,0.068,0,251,0.122,0     *geom.4
236,0.1180,1.2598,0.8812,2,237,0.122,0,252,0.122,0     *geom.4
237,0.1180,1.2598,0.8812,2,238,0.068,0,253,0.068,0     *geom.4
238,0.1180,1.2598,0.8812,2,239,0.122,0,254,0.068,0     *geom.4
239,0.1362,1.1750,1.1750,2,240,0.122,0,255,0.122,0     *geom.4
240,0.1180,1.2598,0.8812,2,241,0.068,0,256,0.068,0     *geom.4
241,0.1180,1.2598,0.8812,2,242,0.122,0,257,0.068,0     *geom.4
242,0.1362,1.1750,1.1750,2,243,0.122,0,258,0.122,0     *geom.4
243,0.1180,1.2598,0.8812,2,244,0.068,0,259,0.068,0     *geom.4
244,0.1180,1.2598,0.8812,2,245,0.122,0,260,0.068,0     *geom.4
245,0.1180,1.2598,0.8812,2,246,0.068,0,261,0.122,0     *geom.4
246,0.1180,1.2598,0.8812,2,247,0.122,0,262,0.122,0     *geom.4
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247,0.1362,1.1750,1.1750,2,248,0.122,0,263,0.122,0     *geom.4
248,0.1362,1.1750,1.1750,2,264,0.122,0,284,0.122,0     *geom.4
249,0.1362,1.1750,1.1750,2,250,0.122,0,265,0.122,0     *geom.4
250,0.1362,1.1750,1.1750,2,251,0.122,0,266,0.122,0     *geom.4
251,0.1362,1.1750,1.1750,2,252,0.122,0,267,0.122,0     *geom.4
252,0.1362,1.1750,1.1750,2,253,0.122,0,268,0.122,0     *geom.4
253,0.1180,1.2598,0.8812,2,254,0.068,0,269,0.122,0     *geom.4
254,0.1180,1.2598,0.8812,2,255,0.122,0,270,0.122,0     *geom.4
255,0.1362,1.1750,1.1750,2,256,0.122,0,271,0.122,0     *geom.4
256,0.1180,1.2598,0.8812,2,257,0.068,0,272,0.122,0     *geom.4
257,0.1180,1.2598,0.8812,2,258,0.122,0,273,0.122,0     *geom.4
258,0.1362,1.1750,1.1750,2,259,0.122,0,274,0.122,0     *geom.4
259,0.1180,1.2598,0.8812,2,260,0.068,0,275,0.122,0     *geom.4
260,0.1180,1.2598,0.8812,2,261,0.122,0,276,0.122,0     *geom.4
261,0.1362,1.1750,1.1750,2,262,0.122,0,277,0.122,0     *geom.4
262,0.1362,1.1750,1.1750,2,263,0.122,0,278,0.122,0     *geom.4
263,0.1362,1.1750,1.1750,2,264,0.122,0,279,0.122,0     *geom.4
264,0.1362,1.1750,1.1750,2,280,0.122,0,284,0.122,0     *geom.4
265,0.1362,1.1750,1.1750,2,266,0.122,0,289,0.122,0     *geom.4
266,0.1362,1.1750,1.1750,2,267,0.122,0,289,0.122,0     *geom.4
267,0.1362,1.1750,1.1750,2,268,0.122,0,289,0.122,0     *geom.4
268,0.1362,1.1750,1.1750,2,269,0.122,0,289,0.122,0     *geom.4
269,0.1362,1.1750,1.1750,2,270,0.122,0,290,0.122,0     *geom.4
270,0.1362,1.1750,1.1750,2,271,0.122,0,290,0.122,0     *geom.4
271,0.1362,1.1750,1.1750,2,272,0.122,0,290,0.122,0     *geom.4
272,0.1362,1.1750,1.1750,2,273,0.122,0,290,0.122,0     *geom.4
273,0.1362,1.1750,1.1750,2,274,0.122,0,291,0.122,0     *geom.4
274,0.1362,1.1750,1.1750,2,275,0.122,0,291,0.122,0     *geom.4
275,0.1362,1.1750,1.1750,2,276,0.122,0,291,0.122,0     *geom.4
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276,0.1362,1.1750,1.1750,2,277,0.122,0,291,0.122,0    *geom.4
277,0.1362,1.1750,1.1750,2,278,0.122,0,292,0.122,0    *geom.4
278,0.1362,1.1750,1.1750,2,279,0.122,0,292,0.122,0    *geom.4
279,0.1362,1.1750,1.1750,2,280,0.122,0,292,0.122,0    *geom.4
280,0.1362,1.1750,1.1750,2,284,0.122,0,292,0.122,0    *geom.4
281,9.8440,89.4345,79.9704,2,282,2.108,1.984,?
285,0.527,8.466    *geom.4
282,9.8440,89.4345,79.9704,2,283,2.108,1.984,?
285,0.527,8.466    *geom.4
283,9.8440,89.4345,79.9704,2,284,2.108,1.984,?
285,0.527,8.466    *geom.4
284,9.8440,89.4345,79.9704,1,285,0.527,8.466    *geom.4
285,38.1089,348.0445,310.1883    *geom.4
286,19.0544,174.0222,155.0941,1,287,2.108,6.482    *geom.4
287,38.1089,348.0445,310.1883,1,288,2.108,8.466    *geom.4
288,38.1089,348.0445,310.1883,1,289,2.108,5.49    *geom.4
289,9.8440,89.4345,79.9704,1,290,2.108,1.984    *geom.4
290,9.8440,89.4345,79.9704,1,291,2.108,1.984    *geom.4
291,9.8440,89.4345,79.9704,1,292,2.108,1.984    *geom.4
292,9.8440,89.4345,79.9704    *geom.4
*
* fluid properties are generated from EPRI functions
prop,0,0,2,1    *prop.1
*
* lateral flow resistance is determined by Blasius-type relation
* from Idel'chik
drag,0,1,4    *drag.1
0.374,0.496    *drag.7
3.15,-0.2,0,3.15,-0.2,0    *drag.8
```

```
*
* 8 grid spacers, located every 20 in.
* form loss coefficient is 0.61
grid,0,1    *grid.1
0.61    *grid.2
-1,8    *grid.4
6,1,26,1,46,1,66,1,86,1,106,1,126,1,146,1    *grid.6
0    *grid.4
*
*   Correlations
corr,1,1,0    *corr.1
epri,epri,epri,none    *corr.2
0.2    *corr.3
epri,thsp,thsp,w-3l,cond,g5.7,0    *corr.6
0    *corr.7
* CHF calculations performed with W-3L correlation
w-3l    *corr.9
0.042,0.066,0.986    *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
2235,563.2,4941,5.996,640.5    *oper.5
*
* Transient forcing functions
28,28,28,28,0,0    *oper.12
*
* Core inlet pressure forcing function table
```

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0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.13
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5618,1.0008    *oper.13
6.0798,0.9996,6.6002,1.0001,7.1231,1.0005,7.5168,1.0002    *oper.13
8.0441,1.0001,8.5742,1.0005,9.1073,1.0010,9.5090,1.0014    *oper.13
10.0477,1.0001,10.5926,0.9893,11.0081,0.9828,11.5728,0.9772   *oper.13
12.0037,0.9716,12.5875,0.9622,13.0324,0.9551,13.6347,0.9463   *oper.13
14.0932,0.9401,14.5577,0.9358,15.0284,0.9308,15.5048,0.9252   *oper.13
*
* Core coolant inlet temperature forcing function table
0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.14
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5618,1.0000    *oper.14
6.0798,1.0000,6.6002,1.0000,7.1231,1.0000,7.5168,1.0000    *oper.14
8.0441,0.9999,8.5742,0.9999,9.1073,0.9998,9.5090,0.9998    *oper.14
10.0477,0.9997,10.5926,0.9996,11.0081,0.9995,11.5728,0.9994   *oper.14
12.0037,0.9993,12.5875,0.9992,13.0324,0.9991,13.6347,0.9991   *oper.14
14.0932,0.9990,14.5577,0.9990,15.0284,0.9989,15.5048,0.9989   *oper.14
*
* Core coolant mass flow rate forcing function table
0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.17
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5618,0.9991    *oper.17
6.0798,0.9953,6.6002,0.9902,7.1231,0.9850,7.5168,0.9810    *oper.17
8.0441,0.9753,8.5742,0.9694,9.1073,0.9634,9.5090,0.9588    *oper.17
10.0477,0.9535,10.5926,0.9492,11.0081,0.9440,11.5728,0.9372   *oper.17
12.0037,0.9320,12.5875,0.9239,13.0324,0.9169,13.6347,0.9071   *oper.17
14.0932,0.8992,14.5577,0.8901,15.0284,0.8820,15.5048,0.8728   *oper.17
*
* Core power forcing function table
0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.20
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5618,1.0000    *oper.20
```

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6.0798,1.0000,6.6002,1.0000,7.1231,1.0000,7.5168,1.0000    *oper.20
8.0441,1.0000,8.5742,0.9997,9.1073,0.9974,9.5090,0.9958    *oper.20
10.0477,0.4653,10.5926,0.1444,11.0081,0.1170,11.5728,0.1015   *oper.20
12.0037,0.0944,12.5875,0.0913,13.0324,0.0891,13.6347,0.0862   *oper.20
14.0932,0.0840,14.5577,0.0817,15.0284,0.0800,15.5048,0.0786   *oper.20
*
cont    *cont.1
15.0,1500,40,60,2,0,0,0    *cont.2
0.1,0.0001,0.0015,0.05,0.01,0.8,1.5,1    *cont.3
6,0,0,0,0,0,1,1,0,0,0,0,0,0,0    *cont.6
10000,0,5,0,0,0    *cont.7
*
summ,2    *summ.1
6,1,1    *summ.2
8,1,1    *summ.2
*
*  Rod Layout - mixed nuclear and control rods
*
* 325 rods with 2 geometry types (nuclear & dummy)
rods,1,325,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*             Nuclear Fuel Rod Power Profile
*  chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
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*
*             Normal Rod input
1,1,0.9232,1,1,825    *rods.9
2,1,1.025,1,2,528    *rods.9
3,1,0.86,1,3,264    *rods.9
4,1,0.8,1,4,264    *rods.9
5,1,0.79,1,5,132    *rods.9
6,1,1.08,1,6,264    *rods.9
7,1,1.02,1,7,264    *rods.9
8,1,1.07,1,8,264    *rods.9
9,1,1.15,1,9,132    *rods.9
10,1,0.82,1,10,132    *rods.9
11,1,0.88,1,11,264    *rods.9
12,1,0.86,1,12,264    *rods.9
13,1,1.07,1,13,66    *rods.9
14,1,1.07,1,14,66    *rods.9
15,1,1.07,1,15,66    *rods.9
16,1,1.07,1,16,66    *rods.9
17,1,0.95,1,17,264    *rods.9
18,1,1.25,1,18,132    *rods.9
19,1,0.93,1,19,132    *rods.9
20,1,1.36,1,20,264    *rods.9
21,1,0.92,1,21,66    *rods.9
22,1,0.92,1,22,66    *rods.9
23,1,0.92,1,23,66    *rods.9
24,1,0.92,1,24,66    *rods.9
25,1,1.3986,1,13,0.375,21,0.375,25,0.25    *rods.9
26,1,1.3836,1,13,0.5,25,0.25,26,0.25    *rods.9
27,1,1.3810,1,13,0.5,26,0.25,27,0.25    *rods.9
```

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28,1,1.3930,1,13,0.5,27,0.25,28,0.25    *rods.9
29,1,1.4103,1,13,0.25,14,0.25,28,0.25,29,0.25    *rods.9
30,1,1.4257,1,14,0.5,29,0.25,30,0.25    *rods.9
31,1,1.4205,1,14,0.5,30,0.25,31,0.25    *rods.9
32,1,1.4208,1,14,0.5,31,0.25,32,0.25    *rods.9
33,1,1.4283,1,14,0.25,15,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4208,1,15,0.5,33,0.25,34,0.25    *rods.9
35,1,1.4205,1,15,0.5,34,0.25,35,0.25    *rods.9
36,1,1.4257,1,15,0.5,35,0.25,36,0.25    *rods.9
37,1,1.4103,1,15,0.25,16,0.25,36,0.25,37,0.25    *rods.9
38,1,1.3930,1,16,0.5,37,0.25,38,0.25    *rods.9
39,1,1.3810,1,16,0.5,38,0.25,39,0.25    *rods.9
40,1,1.3836,1,16,0.5,39,0.25,40,0.25    *rods.9
41,1,1.3986,1,16,0.375,40,0.25,281,0.375    *rods.9
42,1,1.3836,1,21,0.5,25,0.25,41,0.25    *rods.9
43,1,1.3739,1,25,0.25,26,0.25,41,0.25,42,0.25    *rods.9
44,1,1.3832,1,26,0.25,27,0.25,42,0.25,43,0.25    *rods.9
45,1,1.4122,1,27,0.25,28,0.25,43,0.25,44,0.25    *rods.9
46,1,1.4444,1,28,0.25,29,0.25,44,0.25,45,0.25    *rods.9
47,1,1.4962,1,29,0.25,30,0.25,45,0.25,46,0.25    *rods.9
48,1,1.4508,1,30,0.25,31,0.25,46,0.25,47,0.25    *rods.9
49,1,1.4496,1,31,0.25,32,0.25,47,0.25,48,0.25    *rods.9
50,1,1.4940,1,32,0.25,33,0.25,48,0.25,49,0.25    *rods.9
51,1,1.4496,1,33,0.25,34,0.25,49,0.25,50,0.25    *rods.9
52,1,1.4508,1,34,0.25,35,0.25,50,0.25,51,0.25    *rods.9
53,1,1.4962,1,35,0.25,36,0.25,51,0.25,52,0.25    *rods.9
54,1,1.4444,1,36,0.25,37,0.25,52,0.25,53,0.25    *rods.9
55,1,1.4122,1,37,0.25,38,0.25,53,0.25,54,0.25    *rods.9
56,1,1.3832,1,38,0.25,39,0.25,54,0.25,55,0.25    *rods.9
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57,1,1.3739,1,39,0.25,40,0.25,55,0.25,56,0.25    *rods.9
58,1,1.3836,1,40,0.25,56,0.25,281,0.5    *rods.9
59,1,1.3810,1,21,0.5,41,0.25,57,0.25    *rods.9
60,1,1.3832,1,41,0.25,42,0.25,57,0.25,58,0.25    *rods.9
61,1,1.4227,1,42,0.25,43,0.25,58,0.25,59,0.25    *rods.9
62,1,1.5047,1,43,0.25,44,0.25,59,0.25,60,0.25    *rods.9
63,1,1.5369,1,44,0.25,45,0.25,60,0.25,61,0.25    *rods.9
64,2,0,1,45,0.25,46,0.25,61,0.25,62,0.25    *rods.9
65,1,1.5180,1,46,0.25,47,0.25,62,0.25,63,0.25    *rods.9
66,1,1.5135,1,47,0.25,48,0.25,63,0.25,64,0.25    *rods.9
67,2,0,1,48,0.25,49,0.25,64,0.25,65,0.25    *rods.9
68,1,1.5135,1,49,0.25,50,0.25,65,0.25,66,0.25    *rods.9
69,1,1.5180,1,50,0.25,51,0.25,66,0.25,67,0.25    *rods.9
70,2,0,1,51,0.25,52,0.25,67,0.25,68,0.25    *rods.9
71,1,1.5369,1,52,0.25,53,0.25,68,0.25,69,0.25    *rods.9
72,1,1.5047,1,53,0.25,54,0.25,69,0.25,70,0.25    *rods.9
73,1,1.4227,1,54,0.25,55,0.25,70,0.25,71,0.25    *rods.9
74,1,1.3832,1,55,0.25,56,0.25,71,0.25,72,0.25    *rods.9
75,1,1.3810,1,56,0.25,72,0.25,281,0.5    *rods.9
76,1,1.3930,1,21,0.5,57,0.25,73,0.25    *rods.9
77,1,1.4122,1,57,0.25,58,0.25,73,0.25,74,0.25    *rods.9
78,1,1.5047,1,58,0.25,59,0.25,74,0.25,75,0.25    *rods.9
79,2,0,1,59,0.25,60,0.25,75,0.25,76,0.25    *rods.9
80,1,1.5612,1,60,0.25,61,0.25,76,0.25,77,0.25    *rods.9
81,1,1.5486,1,61,0.25,62,0.25,77,0.25,78,0.25    *rods.9
82,1,1.4764,1,62,0.25,63,0.25,78,0.25,79,0.25    *rods.9
83,1,1.4691,1,63,0.25,64,0.25,79,0.25,80,0.25    *rods.9
84,1,1.5189,1,64,0.25,65,0.25,80,0.25,81,0.25    *rods.9
85,1,1.4691,1,65,0.25,66,0.25,81,0.25,82,0.25    *rods.9
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86,1,1.4764,1,66,0.25,67,0.25,82,0.25,83,0.25    *rods.9
87,1,1.5486,1,67,0.25,68,0.25,83,0.25,84,0.25    *rods.9
88,1,1.5612,1,68,0.25,69,0.25,84,0.25,85,0.25    *rods.9
89,2,0,1,69,0.25,70,0.25,85,0.25,86,0.25    *rods.9
90,1,1.5047,1,70,0.25,71,0.25,86,0.25,87,0.25    *rods.9
91,1,1.4122,1,71,0.25,72,0.25,87,0.25,88,0.25    *rods.9
92,1,1.3930,1,72,0.25,88,0.25,281,0.5    *rods.9
93,1,1.4103,1,21,0.25,22,0.25,73,0.25,89,0.25    *rods.9
94,1,1.4444,1,73,0.25,74,0.25,89,0.25,90,0.25    *rods.9
95,1,1.5369,1,74,0.25,75,0.25,90,0.25,91,0.25    *rods.9
96,1,1.5612,1,75,0.25,76,0.25,91,0.25,92,0.25    *rods.9
97,1,1.5226,1,76,0.25,77,0.25,92,0.25,93,0.25    *rods.9
98,1,1.5449,1,77,0.25,78,0.25,93,0.25,94,0.25    *rods.9
99,1,1.4781,1,78,0.25,79,0.25,94,0.25,95,0.25    *rods.9
100,1,1.4719,1,79,0.25,80,0.25,95,0.25,96,0.25    *rods.9
101,1,1.5222,1,80,0.25,81,0.25,96,0.25,97,0.25    *rods.9
102,1,1.4719,1,81,0.25,82,0.25,97,0.25,98,0.25    *rods.9
103,1,1.4781,1,82,0.25,83,0.25,98,0.25,99,0.25    *rods.9
104,1,1.5449,1,83,0.25,84,0.25,99,0.25,100,0.25    *rods.9
105,1,1.5226,1,84,0.25,85,0.25,100,0.25,101,0.25    *rods.9
106,1,1.5612,1,85,0.25,86,0.25,101,0.25,102,0.25    *rods.9
107,1,1.5369,1,86,0.25,87,0.25,102,0.25,103,0.25    *rods.9
108,1,1.4444,1,87,0.25,88,0.25,103,0.25,104,0.25    *rods.9
109,1,1.4103,1,88,0.25,104,0.25,281,0.25,282,0.25    *rods.9
110,1,1.4257,1,22,0.5,89,0.25,105,0.25    *rods.9
111,1,1.4962,1,89,0.25,90,0.25,105,0.25,106,0.25    *rods.9
112,2,0,1,90,0.25,91,0.25,106,0.25,107,0.25    *rods.9
113,1,1.5486,1,91,0.25,92,0.25,107,0.25,108,0.25    *rods.9
114,1,1.5449,1,92,0.25,93,0.25,108,0.25,109,0.25    *rods.9
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115,2,0,1,93,0.25,94,0.25,109,0.25,110,0.25    *rods.9
116,1,1.5280,1,94,0.25,95,0.25,110,0.25,111,0.25    *rods.9
117,1,1.5239,1,95,0.25,96,0.25,111,0.25,112,0.25    *rods.9
118,2,0,1,96,0.25,97,0.25,112,0.25,113,0.25    *rods.9
119,1,1.5239,1,97,0.25,98,0.25,113,0.25,114,0.25    *rods.9
120,1,1.5280,1,98,0.25,99,0.25,114,0.25,115,0.25    *rods.9
121,2,0,1,99,0.25,100,0.25,115,0.25,116,0.25    *rods.9
122,1,1.5449,1,100,0.25,101,0.25,116,0.25,117,0.25    *rods.9
123,1,1.5486,1,101,0.25,102,0.25,117,0.25,118,0.25    *rods.9
124,2,0,1,102,0.25,103,0.25,118,0.25,119,0.25    *rods.9
125,1,1.4962,1,103,0.25,104,0.25,119,0.25,120,0.25    *rods.9
126,1,1.4257,1,104,0.25,120,0.25,282,0.5    *rods.9
127,1,1.4205,1,22,0.5,105,0.25,121,0.25    *rods.9
128,1,1.4508,1,105,0.25,106,0.25,121,0.25,122,0.25    *rods.9
129,1,1.5180,1,106,0.25,107,0.25,122,0.25,123,0.25    *rods.9
130,1,1.4764,1,107,0.25,108,0.25,123,0.25,124,0.25    *rods.9
131,1,1.4781,1,108,0.25,109,0.25,124,0.25,125,0.25    *rods.9
132,1,1.5280,1,109,0.25,110,0.25,125,0.25,126,0.25    *rods.9
133,1,1.4729,1,110,0.25,111,0.25,126,0.25,127,0.25    *rods.9
134,1,1.4710,1,111,0.25,112,0.25,127,0.25,128,0.25    *rods.9
135,1,1.5224,1,112,0.25,113,0.25,128,0.25,129,0.25    *rods.9
136,1,1.4710,1,113,0.25,114,0.25,129,0.25,130,0.25    *rods.9
137,1,1.4729,1,114,0.25,115,0.25,130,0.25,131,0.25    *rods.9
138,1,1.5280,1,115,0.25,116,0.25,131,0.25,132,0.25    *rods.9
139,1,1.4781,1,116,0.25,117,0.25,132,0.25,133,0.25    *rods.9
140,1,1.4764,1,117,0.25,118,0.25,133,0.25,134,0.25    *rods.9
141,1,1.5180,1,118,0.25,119,0.25,134,0.25,135,0.25    *rods.9
142,1,1.4508,1,119,0.25,120,0.25,135,0.25,136,0.25    *rods.9
143,1,1.4205,1,120,0.25,136,0.25,282,0.5    *rods.9
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144,1,1.4208,1,22,0.5,121,0.25,137,0.25    *rods.9
145,1,1.4496,1,121,0.25,122,0.25,137,0.25,138,0.25    *rods.9
146,1,1.5135,1,122,0.25,123,0.25,138,0.25,139,0.25    *rods.9
147,1,1.4691,1,123,0.25,124,0.25,139,0.25,140,0.25    *rods.9
148,1,1.4719,1,124,0.25,125,0.25,140,0.25,141,0.25    *rods.9
149,1,1.5239,1,125,0.25,126,0.25,141,0.25,142,0.25    *rods.9
150,1,1.4710,1,126,0.25,127,0.25,142,0.25,143,0.25    *rods.9
151,1,1.4702,1,127,0.25,128,0.25,143,0.25,144,0.25    *rods.9
152,1,1.5219,1,128,0.25,129,0.25,144,0.25,145,0.25    *rods.9
153,1,1.4702,1,129,0.25,130,0.25,145,0.25,146,0.25    *rods.9
154,1,1.4710,1,130,0.25,131,0.25,146,0.25,147,0.25    *rods.9
155,1,1.5239,1,131,0.25,132,0.25,147,0.25,148,0.25    *rods.9
156,1,1.4719,1,132,0.25,133,0.25,148,0.25,149,0.25    *rods.9
157,1,1.4691,1,133,0.25,134,0.25,149,0.25,150,0.25    *rods.9
158,1,1.5135,1,134,0.25,135,0.25,150,0.25,151,0.25    *rods.9
159,1,1.4496,1,135,0.25,136,0.25,151,0.25,152,0.25    *rods.9
160,1,1.4208,1,136,0.25,152,0.25,282,0.5    *rods.9
161,1,1.4283,1,22,0.25,23,0.25,137,0.25,153,0.25    *rods.9
162,1,1.4940,1,137,0.25,138,0.25,153,0.25,154,0.25    *rods.9
163,2,0,1,138,0.25,139,0.25,154,0.25,155,0.25    *rods.9
164,1,1.5189,1,139,0.25,140,0.25,155,0.25,156,0.25    *rods.9
165,1,1.5222,1,140,0.25,141,0.25,156,0.25,157,0.25    *rods.9
166,2,0,1,141,0.25,142,0.25,157,0.25,158,0.25    *rods.9
167,1,1.5224,1,142,0.25,143,0.25,158,0.25,159,0.25    *rods.9
168,1,1.5219,1,143,0.25,144,0.25,159,0.25,160,0.25    *rods.9
169,2,0,1,144,0.25,145,0.25,160,0.25,161,0.25    *rods.9
170,1,1.5219,1,145,0.25,146,0.25,161,0.25,162,0.25    *rods.9
171,1,1.5224,1,146,0.25,147,0.25,162,0.25,163,0.25    *rods.9
172,2,0,1,147,0.25,148,0.25,163,0.25,164,0.25    *rods.9
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173,1,1.5222,1,148,0.25,149,0.25,164,0.25,165,0.25    *rods.9
174,1,1.5189,1,149,0.25,150,0.25,165,0.25,166,0.25    *rods.9
175,2,0,1,150,0.25,151,0.25,166,0.25,167,0.25    *rods.9
176,1,1.4940,1,151,0.25,152,0.25,167,0.25,168,0.25    *rods.9
177,1,1.4283,1,152,0.25,168,0.25,282,0.25,283,0.25    *rods.9
178,1,1.4208,1,23,0.5,153,0.25,169,0.25    *rods.9
179,1,1.4496,1,153,0.25,154,0.25,169,0.25,170,0.25    *rods.9
180,1,1.5135,1,154,0.25,155,0.25,170,0.25,171,0.25    *rods.9
181,1,1.4691,1,155,0.25,156,0.25,171,0.25,172,0.25    *rods.9
182,1,1.4719,1,156,0.25,157,0.25,172,0.25,173,0.25    *rods.9
183,1,1.5239,1,157,0.25,158,0.25,173,0.25,174,0.25    *rods.9
184,1,1.4710,1,158,0.25,159,0.25,174,0.25,175,0.25    *rods.9
185,1,1.4702,1,159,0.25,160,0.25,175,0.25,176,0.25    *rods.9
186,1,1.5219,1,160,0.25,161,0.25,176,0.25,177,0.25    *rods.9
187,1,1.4702,1,161,0.25,162,0.25,177,0.25,178,0.25    *rods.9
188,1,1.4710,1,162,0.25,163,0.25,178,0.25,179,0.25    *rods.9
189,1,1.5239,1,163,0.25,164,0.25,179,0.25,180,0.25    *rods.9
190,1,1.4719,1,164,0.25,165,0.25,180,0.25,181,0.25    *rods.9
191,1,1.4691,1,165,0.25,166,0.25,181,0.25,182,0.25    *rods.9
192,1,1.5135,1,166,0.25,167,0.25,182,0.25,183,0.25    *rods.9
193,1,1.4496,1,167,0.25,168,0.25,183,0.25,184,0.25    *rods.9
194,1,1.4208,1,168,0.25,184,0.25,283,0.5    *rods.9
195,1,1.4205,1,23,0.5,169,0.25,185,0.25    *rods.9
196,1,1.4508,1,169,0.25,170,0.25,185,0.25,186,0.25    *rods.9
197,1,1.5180,1,170,0.25,171,0.25,186,0.25,187,0.25    *rods.9
198,1,1.4764,1,171,0.25,172,0.25,187,0.25,188,0.25    *rods.9
199,1,1.4781,1,172,0.25,173,0.25,188,0.25,189,0.25    *rods.9
200,1,1.5280,1,173,0.25,174,0.25,189,0.25,190,0.25    *rods.9
201,1,1.4729,1,174,0.25,175,0.25,190,0.25,191,0.25    *rods.9
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202,1,1.4710,1,175,0.25,176,0.25,191,0.25,192,0.25    *rods.9
203,1,1.5224,1,176,0.25,177,0.25,192,0.25,193,0.25    *rods.9
204,1,1.4710,1,177,0.25,178,0.25,193,0.25,194,0.25    *rods.9
205,1,1.4729,1,178,0.25,179,0.25,194,0.25,195,0.25    *rods.9
206,1,1.5280,1,179,0.25,180,0.25,195,0.25,196,0.25    *rods.9
207,1,1.4781,1,180,0.25,181,0.25,196,0.25,197,0.25    *rods.9
208,1,1.4764,1,181,0.25,182,0.25,197,0.25,198,0.25    *rods.9
209,1,1.5180,1,182,0.25,183,0.25,198,0.25,199,0.25    *rods.9
210,1,1.4508,1,183,0.25,184,0.25,199,0.25,200,0.25    *rods.9
211,1,1.4205,1,184,0.25,200,0.25,283,0.5    *rods.9
212,1,1.4257,1,23,0.5,185,0.25,201,0.25    *rods.9
213,1,1.4962,1,185,0.25,186,0.25,201,0.25,202,0.25    *rods.9
214,2,0,1,186,0.25,187,0.25,202,0.25,203,0.25    *rods.9
215,1,1.5486,1,187,0.25,188,0.25,203,0.25,204,0.25    *rods.9
216,1,1.5449,1,188,0.25,189,0.25,204,0.25,205,0.25    *rods.9
217,2,0,1,189,0.25,190,0.25,205,0.25,206,0.25    *rods.9
218,1,1.5280,1,190,0.25,191,0.25,206,0.25,207,0.25    *rods.9
219,1,1.5239,1,191,0.25,192,0.25,207,0.25,208,0.25    *rods.9
220,2,0,1,192,0.25,193,0.25,208,0.25,209,0.25    *rods.9
221,1,1.5239,1,193,0.25,194,0.25,209,0.25,210,0.25    *rods.9
222,1,1.5280,1,194,0.25,195,0.25,210,0.25,211,0.25    *rods.9
223,2,0,1,195,0.25,196,0.25,211,0.25,212,0.25    *rods.9
224,1,1.5449,1,196,0.25,197,0.25,212,0.25,213,0.25    *rods.9
225,1,1.5486,1,197,0.25,198,0.25,213,0.25,214,0.25    *rods.9
226,2,0,1,198,0.25,199,0.25,214,0.25,215,0.25    *rods.9
227,1,1.4962,1,199,0.25,200,0.25,215,0.25,216,0.25    *rods.9
228,1,1.4257,1,200,0.25,216,0.25,283,0.5    *rods.9
229,1,1.4103,1,23,0.25,24,0.25,201,0.25,217,0.25    *rods.9
230,1,1.4444,1,201,0.25,202,0.25,217,0.25,218,0.25    *rods.9
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231,1,1.5369,1,202,0.25,203,0.25,218,0.25,219,0.25    *rods.9
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234,1,1.5449,1,205,0.25,206,0.25,221,0.25,222,0.25    *rods.9
235,1,1.4781,1,206,0.25,207,0.25,222,0.25,223,0.25    *rods.9
236,1,1.4719,1,207,0.25,208,0.25,223,0.25,224,0.25    *rods.9
237,1,1.5222,1,208,0.25,209,0.25,224,0.25,225,0.25    *rods.9
238,1,1.4719,1,209,0.25,210,0.25,225,0.25,226,0.25    *rods.9
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242,1,1.5612,1,213,0.25,214,0.25,229,0.25,230,0.25    *rods.9
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244,1,1.4444,1,215,0.25,216,0.25,231,0.25,232,0.25    *rods.9
245,1,1.4103,1,216,0.25,232,0.25,283,0.25,284,0.25    *rods.9
246,1,1.3930,1,24,0.5,217,0.25,233,0.25    *rods.9
247,1,1.4122,1,217,0.25,218,0.25,233,0.25,234,0.25    *rods.9
248,1,1.5047,1,218,0.25,219,0.25,234,0.25,235,0.25    *rods.9
249,2,0,1,219,0.25,220,0.25,235,0.25,236,0.25    *rods.9
250,1,1.5612,1,220,0.25,221,0.25,236,0.25,237,0.25    *rods.9
251,1,1.5486,1,221,0.25,222,0.25,237,0.25,238,0.25    *rods.9
252,1,1.4764,1,222,0.25,223,0.25,238,0.25,239,0.25    *rods.9
253,1,1.4691,1,223,0.25,224,0.25,239,0.25,240,0.25    *rods.9
254,1,1.5189,1,224,0.25,225,0.25,240,0.25,241,0.25    *rods.9
255,1,1.4691,1,225,0.25,226,0.25,241,0.25,242,0.25    *rods.9
256,1,1.4764,1,226,0.25,227,0.25,242,0.25,243,0.25    *rods.9
257,1,1.5486,1,227,0.25,228,0.25,243,0.25,244,0.25    *rods.9
258,1,1.5612,1,228,0.25,229,0.25,244,0.25,245,0.25    *rods.9
259,2,0,1,229,0.25,230,0.25,245,0.25,246,0.25    *rods.9
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260,1,1.5047,1,230,0.25,231,0.25,246,0.25,247,0.25    *rods.9
261,1,1.4122,1,231,0.25,232,0.25,247,0.25,248,0.25    *rods.9
262,1,1.3930,1,232,0.25,248,0.25,284,0.5    *rods.9
263,1,1.3810,1,24,0.5,233,0.25,249,0.25    *rods.9
264,1,1.3832,1,233,0.25,234,0.25,249,0.25,250,0.25    *rods.9
265,1,1.4227,1,234,0.25,235,0.25,250,0.25,251,0.25    *rods.9
266,1,1.5047,1,235,0.25,236,0.25,251,0.25,252,0.25    *rods.9
267,1,1.5369,1,236,0.25,237,0.25,252,0.25,253,0.25    *rods.9
268,2,0,1,237,0.25,238,0.25,253,0.25,254,0.25    *rods.9
269,1,1.5180,1,238,0.25,239,0.25,254,0.25,255,0.25    *rods.9
270,1,1.5135,1,239,0.25,240,0.25,255,0.25,256,0.25    *rods.9
271,2,0,1,240,0.25,241,0.25,256,0.25,257,0.25    *rods.9
272,1,1.5135,1,241,0.25,242,0.25,257,0.25,258,0.25    *rods.9
273,1,1.5180,1,242,0.25,243,0.25,258,0.25,259,0.25    *rods.9
274,2,0,1,243,0.25,244,0.25,259,0.25,260,0.25    *rods.9
275,1,1.5369,1,244,0.25,245,0.25,260,0.25,261,0.25    *rods.9
276,1,1.5047,1,245,0.25,246,0.25,261,0.25,262,0.25    *rods.9
277,1,1.4227,1,246,0.25,247,0.25,262,0.25,263,0.25    *rods.9
278,1,1.3832,1,247,0.25,248,0.25,263,0.25,264,0.25    *rods.9
279,1,1.3810,1,248,0.25,264,0.25,284,0.5    *rods.9
280,1,1.3836,1,24,0.5,249,0.25,265,0.25    *rods.9
281,1,1.3739,1,249,0.25,250,0.25,265,0.25,266,0.25    *rods.9
282,1,1.3832,1,250,0.25,251,0.25,266,0.25,267,0.25    *rods.9
283,1,1.4122,1,251,0.25,252,0.25,267,0.25,268,0.25    *rods.9
284,1,1.4444,1,252,0.25,253,0.25,268,0.25,269,0.25    *rods.9
285,1,1.4962,1,253,0.25,254,0.25,269,0.25,270,0.25    *rods.9
286,1,1.4508,1,254,0.25,255,0.25,270,0.25,271,0.25    *rods.9
287,1,1.4496,1,255,0.25,256,0.25,271,0.25,272,0.25    *rods.9
288,1,1.4940,1,256,0.25,257,0.25,272,0.25,273,0.25    *rods.9
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289,1,1.4496,1,257,0.25,258,0.25,273,0.25,274,0.25    *rods.9
290,1,1.4508,1,258,0.25,259,0.25,274,0.25,275,0.25    *rods.9
291,1,1.4962,1,259,0.25,260,0.25,275,0.25,276,0.25    *rods.9
292,1,1.4444,1,260,0.25,261,0.25,276,0.25,277,0.25    *rods.9
293,1,1.4122,1,261,0.25,262,0.25,277,0.25,278,0.25    *rods.9
294,1,1.3832,1,262,0.25,263,0.25,278,0.25,279,0.25    *rods.9
295,1,1.3739,1,263,0.25,264,0.25,279,0.25,280,0.25    *rods.9
296,1,1.3836,1,264,0.25,280,0.25,284,0.5    *rods.9
297,1,1.3986,1,24,0.375,265,0.25,289,0.375    *rods.9
298,1,1.3836,1,265,0.25,266,0.25,289,0.5    *rods.9
299,1,1.3810,1,266,0.25,267,0.25,289,0.5    *rods.9
300,1,1.3930,1,267,0.25,268,0.25,289,0.5    *rods.9
301,1,1.4103,1,268,0.25,269,0.25,289,0.25,290,0.25    *rods.9
302,1,1.4257,1,269,0.25,270,0.25,290,0.5    *rods.9
303,1,1.4205,1,270,0.25,271,0.25,290,0.5    *rods.9
304,1,1.4208,1,271,0.25,272,0.25,290,0.5    *rods.9
305,1,1.4283,1,272,0.25,273,0.25,290,0.25,291,0.25    *rods.9
306,1,1.4208,1,273,0.25,274,0.25,291,0.5    *rods.9
307,1,1.4205,1,274,0.25,275,0.25,291,0.5    *rods.9
308,1,1.4257,1,275,0.25,276,0.25,291,0.5    *rods.9
309,1,1.4103,1,276,0.25,277,0.25,291,0.25,292,0.25    *rods.9
310,1,1.3930,1,277,0.25,278,0.25,292,0.5    *rods.9
311,1,1.3810,1,278,0.25,279,0.25,292,0.5    *rods.9
312,1,1.3836,1,279,0.25,280,0.25,292,0.5    *rods.9
313,1,1.3986,1,280,0.25,284,0.375,292,0.375    *rods.9
314,1,1.1,1,281,66    *rods.9
315,1,1.1,1,282,66    *rods.9
316,1,1.1,1,283,66    *rods.9
317,1,1.1,1,284,66    *rods.9
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318,1,0.82,1,285,264    *rods.9
319,1,1.12,1,286,132    *rods.9
320,1,1.16,1,287,264    *rods.9
321,1,1.03,1,288,264    *rods.9
322,1,0.83,1,289,66    *rods.9
323,1,0.83,1,290,66    *rods.9
324,1,0.83,1,291,66    *rods.9
325,1,0.83,1,292,66    *rods.9
0    *rods.9
*             Fuel Geometry Types
*
* nuclear type geometry
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
* dummy type geometry - used for control rods
2,dumy,0.482,0,0    *rods.68
* Fuel thermal-physical property table
1,61,651.1860508,UOX    *rods.70
440.6,0.0673,2.2629,530.6,0.0687,2.1599,
620.6,0.0698,2.0671,710.6,0.0707,1.9841,
800.6,0.0715,1.9103,890.6,0.0722,1.8453,
980.6,0.0729,1.7884,1070.6,0.0735,1.7383,
1160.6,0.0740,1.6938,1250.6,0.0745,1.6529,
1340.6,0.0750,1.6144,1430.6,0.0754,1.5772,
1520.6,0.0758,1.5405,1610.6,0.0762,1.5042,
1700.6,0.0767,1.4684,1790.6,0.0771,1.4332,
1880.6,0.0775,1.3990,1970.6,0.0779,1.3661,
2060.6,0.0783,1.3348,2150.6,0.0788,1.3052,
2240.6,0.0793,1.2777,2330.6,0.0799,1.2524,
```

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2420.6,0.0805,1.2295,2510.6,0.0813,1.2091,
2600.6,0.0821,1.1913,2690.6,0.0830,1.1763,
2780.6,0.0840,1.1641,2870.6,0.0851,1.1547,
2960.6,0.0864,1.1482,3050.6,0.0879,1.1446,
3140.6,0.0895,1.1440,3230.6,0.0914,1.1464,
3320.6,0.0934,1.1516,3410.6,0.0956,1.1598,
3500.6,0.0980,1.1708,3590.6,0.1006,1.1846,
3680.6,0.1035,1.2012,3770.6,0.1066,1.2204,
3860.6,0.1099,1.2421,3950.6,0.1134,1.2664,
4040.6,0.1172,1.2930,4130.6,0.1212,1.3220,
4220.6,0.1254,1.3531,4310.6,0.1299,1.3862,
4400.6,0.1346,1.4213,4490.6,0.1395,1.4582,
4580.6,0.1446,1.4968,4670.6,0.1499,1.5370,
4760.6,0.1555,1.5787,4850.6,0.1612,1.6217,
4940.6,0.1671,1.6660,5030.6,0.1732,1.7114,
5120.6,0.1794,1.7578,5210.6,0.1858,1.8051,
5300.6,0.1924,1.8531,5390.6,0.1990,1.9019,
5480.6,0.2059,1.9512,5570.6,0.2128,2.0011,
5660.6,0.2199,2.0513,5750.6,0.2270,2.1019,
5840.6,0.2343,2.1527,
endd
0
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B.3 Complete LOFA Analysis

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*
* UOX 4.9% U235 17x17 Assembly Westinghouse 4-Loop PWR (Comanche Peak)
* 112%Power, T=+2C,-5%Flow, APP=CC1.55,MPEAK=2.42
1,0,0,-1,0    *vipre.1
1/8 PWR Core CLOFA Analysis  (uox1 - 02/14/09) *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, s/l ratio = 0.5 *geom.2
*      channel dimensions
1,119.0902,1087.6390,969.3384,3,2,1.054,15.41,3,2.108,11.442,?
4,2.108,11.442    *geom.4
2,38.1089,348.0445,310.1883,3,3,2.108,6.482,6,2.108,6.482,?
10,1.054,12.434    *geom.4
3,38.1089,348.0445,310.1883,2,4,2.108,8.466,?
6,2.108,8.466    *geom.4
4,38.1089,348.0445,310.1883,2,5,2.108,6.978,?
7,2.108,8.466    *geom.4
5,19.0544,174.0222,155.0941,1,8,2.108,6.482    *geom.4
6,38.1089,348.0445,310.1883,2,7,2.108,8.466,?
11,2.108,8.466    *geom.4
7,38.1089,348.0445,310.1883,2,8,2.108,8.466,?
12,2.108,8.466    *geom.4
8,38.1089,348.0445,310.1883,5,9,2.108,6.978,13,0.527,8.466,?
14,0.527,8.466    *geom.4
15,0.5270,8.4660,16,0.527,8.466    *geom.4a
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9,19.0544,174.0222,155.0941,1,17,2.108,6.978    *geom.4
10,19.0544,174.0222,155.0941,2,11,2.108,6.482,?
19,1.054,8.466    *geom.4
11,38.1089,348.0445,310.1883,2,12,2.108,8.466,?
20,2.108,8.466    *geom.4
12,38.1089,348.0445,310.1883,2,13,2.108,5.49,?
21,2.108,5.49    *geom.4
13,9.8440,89.4345,79.9704,5,14,2.108,1.984,25,0.122,4.746,?
26,0.122,4.746    *geom.4
27,0.1220,4.7460,28,0.122,4.746    *geom.4a
14,9.8440,89.4345,79.9704,5,15,2.108,1.984,29,0.122,4.746,?
30,0.122,4.746    *geom.4
31,0.1220,4.7460,32,0.122,4.746    *geom.4a
15,9.8440,89.4345,79.9704,5,16,2.108,1.984,33,0.122,4.746,?
34,0.122,4.746    *geom.4
35,0.1220,4.7460,36,0.122,4.746    *geom.4a
16,9.8440,89.4345,79.9704,5,17,2.108,5.49,37,0.122,4.746,?
38,0.122,4.746    *geom.4
39,0.1220,4.7460,40,0.122,4.746    *geom.4a
17,38.1089,348.0445,310.1883,2,18,2.108,6.978,?
281,2.108,5.49    *geom.4
18,19.0544,174.0222,155.0941,1,285,2.108,6.978    *geom.4
19,19.0544,174.0222,155.0941,2,20,2.108,6.482,?
286,1.054,8.466    *geom.4
20,38.1089,348.0445,310.1883,5,21,0.527,8.466,22,0.527,8.466,?
23,0.527,8.466    *geom.4
24,0.5270,8.4660,287,2.108,8.466    *geom.4a
21,9.8440,89.4345,79.9704,5,22,2.108,1.984,25,0.122,4.746,?
41,0.122,4.746    *geom.4
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57,0.1220,4.7460,73,0.122,4.746    *geom.4a
22,9.8440,89.4345,79.9704,5,23,2.108,1.984,89,0.122,4.746,?
105,0.122,4.746    *geom.4
121,0.1220,4.7460,137,0.122,4.746    *geom.4a
23,9.8440,89.4345,79.9704,5,24,2.108,1.984,153,0.122,4.746,?
169,0.122,4.746    *geom.4
185,0.1220,4.7460,201,0.122,4.746    *geom.4a
24,9.8440,89.4345,79.9704,5,217,0.122,4.746,233,0.122,4.746,?
249,0.122,4.746    *geom.4
265,0.1220,4.7460,288,2.108,5.49    *geom.4a
25,0.1362,1.1750,1.1750,2,26,0.122,0,41,0.122,0    *geom.4
26,0.1362,1.1750,1.1750,2,27,0.122,0,42,0.122,0    *geom.4
27,0.1362,1.1750,1.1750,2,28,0.122,0,43,0.122,0    *geom.4
28,0.1362,1.1750,1.1750,2,29,0.122,0,44,0.122,0    *geom.4
29,0.1362,1.1750,1.1750,2,30,0.122,0,45,0.122,0    *geom.4
30,0.1362,1.1750,1.1750,2,31,0.122,0,46,0.122,0    *geom.4
31,0.1362,1.1750,1.1750,2,32,0.122,0,47,0.122,0    *geom.4
32,0.1362,1.1750,1.1750,2,33,0.122,0,48,0.122,0    *geom.4
33,0.1362,1.1750,1.1750,2,34,0.122,0,49,0.122,0    *geom.4
34,0.1362,1.1750,1.1750,2,35,0.122,0,50,0.122,0    *geom.4
35,0.1362,1.1750,1.1750,2,36,0.122,0,51,0.122,0    *geom.4
36,0.1362,1.1750,1.1750,2,37,0.122,0,52,0.122,0    *geom.4
37,0.1362,1.1750,1.1750,2,38,0.122,0,53,0.122,0    *geom.4
38,0.1362,1.1750,1.1750,2,39,0.122,0,54,0.122,0    *geom.4
39,0.1362,1.1750,1.1750,2,40,0.122,0,55,0.122,0    *geom.4
40,0.1362,1.1750,1.1750,2,56,0.122,0,281,0.122,0    *geom.4
41,0.1362,1.1750,1.1750,2,42,0.122,0,57,0.122,0    *geom.4
42,0.1362,1.1750,1.1750,2,43,0.122,0,58,0.122,0    *geom.4
43,0.1362,1.1750,1.1750,2,44,0.122,0,59,0.122,0    *geom.4
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44,0.1362,1.1750,1.1750,2,45,0.122,0,60,0.122,0    *geom.4
45,0.1180,1.2598,0.8812,2,46,0.068,0,61,0.068,0    *geom.4
46,0.1180,1.2598,0.8812,2,47,0.122,0,62,0.068,0    *geom.4
47,0.1362,1.1750,1.1750,2,48,0.122,0,63,0.122,0    *geom.4
48,0.1180,1.2598,0.8812,2,49,0.068,0,64,0.068,0    *geom.4
49,0.1180,1.2598,0.8812,2,50,0.122,0,65,0.068,0    *geom.4
50,0.1362,1.1750,1.1750,2,51,0.122,0,66,0.122,0    *geom.4
51,0.1180,1.2598,0.8812,2,52,0.068,0,67,0.068,0    *geom.4
52,0.1180,1.2598,0.8812,2,53,0.122,0,68,0.068,0    *geom.4
53,0.1362,1.1750,1.1750,2,54,0.122,0,69,0.122,0    *geom.4
54,0.1362,1.1750,1.1750,2,55,0.122,0,70,0.122,0    *geom.4
55,0.1362,1.1750,1.1750,2,56,0.122,0,71,0.122,0    *geom.4
56,0.1362,1.1750,1.1750,2,72,0.122,0,281,0.122,0    *geom.4
57,0.1362,1.1750,1.1750,2,58,0.122,0,73,0.122,0    *geom.4
58,0.1362,1.1750,1.1750,2,59,0.122,0,74,0.122,0    *geom.4
59,0.1180,1.2598,0.8812,2,60,0.068,0,75,0.068,0    *geom.4
60,0.1180,1.2598,0.8812,2,61,0.122,0,76,0.068,0    *geom.4
61,0.1180,1.2598,0.8812,2,62,0.068,0,77,0.122,0    *geom.4
62,0.1180,1.2598,0.8812,2,63,0.122,0,78,0.122,0    *geom.4
63,0.1362,1.1750,1.1750,2,64,0.122,0,79,0.122,0    *geom.4
64,0.1180,1.2598,0.8812,2,65,0.068,0,80,0.122,0    *geom.4
65,0.1180,1.2598,0.8812,2,66,0.122,0,81,0.122,0    *geom.4
66,0.1362,1.1750,1.1750,2,67,0.122,0,82,0.122,0    *geom.4
67,0.1180,1.2598,0.8812,2,68,0.068,0,83,0.122,0    *geom.4
68,0.1180,1.2598,0.8812,2,69,0.122,0,84,0.122,0    *geom.4
69,0.1180,1.2598,0.8812,2,70,0.068,0,85,0.068,0    *geom.4
70,0.1180,1.2598,0.8812,2,71,0.122,0,86,0.068,0    *geom.4
71,0.1362,1.1750,1.1750,2,72,0.122,0,87,0.122,0    *geom.4
72,0.1362,1.1750,1.1750,2,88,0.122,0,281,0.122,0    *geom.4
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73,0.1362,1.1750,1.1750,2,74,0.122,0,89,0.122,0    *geom.4
74,0.1362,1.1750,1.1750,2,75,0.122,0,90,0.122,0    *geom.4
75,0.1180,1.2598,0.8812,2,76,0.068,0,91,0.122,0    *geom.4
76,0.1180,1.2598,0.8812,2,77,0.122,0,92,0.122,0    *geom.4
77,0.1362,1.1750,1.1750,2,78,0.122,0,93,0.122,0    *geom.4
78,0.1362,1.1750,1.1750,2,79,0.122,0,94,0.122,0    *geom.4
79,0.1362,1.1750,1.1750,2,80,0.122,0,95,0.122,0    *geom.4
80,0.1362,1.1750,1.1750,2,81,0.122,0,96,0.122,0    *geom.4
81,0.1362,1.1750,1.1750,2,82,0.122,0,97,0.122,0    *geom.4
82,0.1362,1.1750,1.1750,2,83,0.122,0,98,0.122,0    *geom.4
83,0.1362,1.1750,1.1750,2,84,0.122,0,99,0.122,0    *geom.4
84,0.1362,1.1750,1.1750,2,85,0.122,0,100,0.122,0    *geom.4
85,0.1180,1.2598,0.8812,2,86,0.068,0,101,0.122,0    *geom.4
86,0.1180,1.2598,0.8812,2,87,0.122,0,102,0.122,0    *geom.4
87,0.1362,1.1750,1.1750,2,88,0.122,0,103,0.122,0    *geom.4
88,0.1362,1.1750,1.1750,2,104,0.122,0,281,0.122,0    *geom.4
89,0.1362,1.1750,1.1750,2,90,0.122,0,105,0.122,0    *geom.4
90,0.1180,1.2598,0.8812,2,91,0.068,0,106,0.068,0    *geom.4
91,0.1180,1.2598,0.8812,2,92,0.122,0,107,0.068,0    *geom.4
92,0.1362,1.1750,1.1750,2,93,0.122,0,108,0.122,0    *geom.4
93,0.1180,1.2598,0.8812,2,94,0.068,0,109,0.068,0    *geom.4
94,0.1180,1.2598,0.8812,2,95,0.122,0,110,0.068,0    *geom.4
95,0.1362,1.1750,1.1750,2,96,0.122,0,111,0.122,0    *geom.4
96,0.1180,1.2598,0.8812,2,97,0.068,0,112,0.068,0    *geom.4
97,0.1180,1.2598,0.8812,2,98,0.122,0,113,0.068,0    *geom.4
98,0.1362,1.1750,1.1750,2,99,0.122,0,114,0.122,0    *geom.4
99,0.1180,1.2598,0.8812,2,100,0.068,0,115,0.068,0    *geom.4
100,0.1180,1.2598,0.8812,2,101,0.122,0,116,0.068,0    *geom.4
101,0.1362,1.1750,1.1750,2,102,0.122,0,117,0.122,0    *geom.4
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102,0.1180,1.2598,0.8812,2,103,0.068,0,118,0.068,0     *geom.4
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104,0.1362,1.1750,1.1750,2,120,0.122,0,282,0.122,0     *geom.4
105,0.1362,1.1750,1.1750,2,106,0.122,0,121,0.122,0     *geom.4
106,0.1180,1.2598,0.8812,2,107,0.068,0,122,0.122,0     *geom.4
107,0.1180,1.2598,0.8812,2,108,0.122,0,123,0.122,0     *geom.4
108,0.1362,1.1750,1.1750,2,109,0.122,0,124,0.122,0     *geom.4
109,0.1180,1.2598,0.8812,2,110,0.068,0,125,0.122,0     *geom.4
110,0.1180,1.2598,0.8812,2,111,0.122,0,126,0.122,0     *geom.4
111,0.1362,1.1750,1.1750,2,112,0.122,0,127,0.122,0     *geom.4
112,0.1180,1.2598,0.8812,2,113,0.068,0,128,0.122,0     *geom.4
113,0.1180,1.2598,0.8812,2,114,0.122,0,129,0.122,0     *geom.4
114,0.1362,1.1750,1.1750,2,115,0.122,0,130,0.122,0     *geom.4
115,0.1180,1.2598,0.8812,2,116,0.068,0,131,0.122,0     *geom.4
116,0.1180,1.2598,0.8812,2,117,0.122,0,132,0.122,0     *geom.4
117,0.1362,1.1750,1.1750,2,118,0.122,0,133,0.122,0     *geom.4
118,0.1180,1.2598,0.8812,2,119,0.068,0,134,0.122,0     *geom.4
119,0.1180,1.2598,0.8812,2,120,0.122,0,135,0.122,0     *geom.4
120,0.1362,1.1750,1.1750,2,136,0.122,0,282,0.122,0     *geom.4
121,0.1362,1.1750,1.1750,2,122,0.122,0,137,0.122,0     *geom.4
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124,0.1362,1.1750,1.1750,2,125,0.122,0,140,0.122,0     *geom.4
125,0.1362,1.1750,1.1750,2,126,0.122,0,141,0.122,0     *geom.4
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127,0.1362,1.1750,1.1750,2,128,0.122,0,143,0.122,0     *geom.4
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136,0.1362,1.1750,1.1750,2,152,0.122,0,282,0.122,0     *geom.4
137,0.1362,1.1750,1.1750,2,138,0.122,0,153,0.122,0     *geom.4
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139,0.1180,1.2598,0.8812,2,140,0.122,0,155,0.068,0     *geom.4
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141,0.1180,1.2598,0.8812,2,142,0.068,0,157,0.068,0     *geom.4
142,0.1180,1.2598,0.8812,2,143,0.122,0,158,0.068,0     *geom.4
143,0.1362,1.1750,1.1750,2,144,0.122,0,159,0.122,0     *geom.4
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145,0.1180,1.2598,0.8812,2,146,0.122,0,161,0.068,0     *geom.4
146,0.1362,1.1750,1.1750,2,147,0.122,0,162,0.122,0     *geom.4
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148,0.1180,1.2598,0.8812,2,149,0.122,0,164,0.068,0     *geom.4
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154,0.1180,1.2598,0.8812,2,155,0.068,0,170,0.122,0     *geom.4
155,0.1180,1.2598,0.8812,2,156,0.122,0,171,0.122,0     *geom.4
156,0.1362,1.1750,1.1750,2,157,0.122,0,172,0.122,0     *geom.4
157,0.1180,1.2598,0.8812,2,158,0.068,0,173,0.122,0     *geom.4
158,0.1180,1.2598,0.8812,2,159,0.122,0,174,0.122,0     *geom.4
159,0.1362,1.1750,1.1750,2,160,0.122,0,175,0.122,0     *geom.4
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170,0.1362,1.1750,1.1750,2,171,0.122,0,186,0.122,0     *geom.4
171,0.1362,1.1750,1.1750,2,172,0.122,0,187,0.122,0     *geom.4
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178,0.1362,1.1750,1.1750,2,179,0.122,0,194,0.122,0     *geom.4
179,0.1362,1.1750,1.1750,2,180,0.122,0,195,0.122,0     *geom.4
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182,0.1362,1.1750,1.1750,2,183,0.122,0,198,0.122,0     *geom.4
183,0.1362,1.1750,1.1750,2,184,0.122,0,199,0.122,0     *geom.4
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185,0.1362,1.1750,1.1750,2,186,0.122,0,201,0.122,0     *geom.4
186,0.1180,1.2598,0.8812,2,187,0.068,0,202,0.068,0     *geom.4
187,0.1180,1.2598,0.8812,2,188,0.122,0,203,0.068,0     *geom.4
188,0.1362,1.1750,1.1750,2,189,0.122,0,204,0.122,0     *geom.4
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191,0.1362,1.1750,1.1750,2,192,0.122,0,207,0.122,0     *geom.4
192,0.1180,1.2598,0.8812,2,193,0.068,0,208,0.068,0     *geom.4
193,0.1180,1.2598,0.8812,2,194,0.122,0,209,0.068,0     *geom.4
194,0.1362,1.1750,1.1750,2,195,0.122,0,210,0.122,0     *geom.4
195,0.1180,1.2598,0.8812,2,196,0.068,0,211,0.068,0     *geom.4
196,0.1180,1.2598,0.8812,2,197,0.122,0,212,0.068,0     *geom.4
197,0.1362,1.1750,1.1750,2,198,0.122,0,213,0.122,0     *geom.4
198,0.1180,1.2598,0.8812,2,199,0.068,0,214,0.068,0     *geom.4
199,0.1180,1.2598,0.8812,2,200,0.122,0,215,0.068,0     *geom.4
200,0.1362,1.1750,1.1750,2,216,0.122,0,283,0.122,0     *geom.4
201,0.1362,1.1750,1.1750,2,202,0.122,0,217,0.122,0     *geom.4
202,0.1180,1.2598,0.8812,2,203,0.068,0,218,0.122,0     *geom.4
203,0.1180,1.2598,0.8812,2,204,0.122,0,219,0.122,0     *geom.4
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207,0.1362,1.1750,1.1750,2,208,0.122,0,223,0.122,0     *geom.4
208,0.1180,1.2598,0.8812,2,209,0.068,0,224,0.122,0     *geom.4
209,0.1180,1.2598,0.8812,2,210,0.122,0,225,0.122,0     *geom.4
210,0.1362,1.1750,1.1750,2,211,0.122,0,226,0.122,0     *geom.4
211,0.1180,1.2598,0.8812,2,212,0.068,0,227,0.122,0     *geom.4
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214,0.1180,1.2598,0.8812,2,215,0.068,0,230,0.122,0     *geom.4
215,0.1180,1.2598,0.8812,2,216,0.122,0,231,0.122,0     *geom.4
216,0.1362,1.1750,1.1750,2,232,0.122,0,283,0.122,0     *geom.4
217,0.1362,1.1750,1.1750,2,218,0.122,0,233,0.122,0     *geom.4
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224,0.1362,1.1750,1.1750,2,225,0.122,0,240,0.122,0     *geom.4
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237,0.1180,1.2598,0.8812,2,238,0.068,0,253,0.068,0     *geom.4
238,0.1180,1.2598,0.8812,2,239,0.122,0,254,0.068,0     *geom.4
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275,0.1362,1.1750,1.1750,2,276,0.122,0,291,0.122,0     *geom.4
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276,0.1362,1.1750,1.1750,2,277,0.122,0,291,0.122,0    *geom.4
277,0.1362,1.1750,1.1750,2,278,0.122,0,292,0.122,0    *geom.4
278,0.1362,1.1750,1.1750,2,279,0.122,0,292,0.122,0    *geom.4
279,0.1362,1.1750,1.1750,2,280,0.122,0,292,0.122,0    *geom.4
280,0.1362,1.1750,1.1750,2,284,0.122,0,292,0.122,0    *geom.4
281,9.8440,89.4345,79.9704,2,282,2.108,1.984,?
285,0.527,8.466    *geom.4
282,9.8440,89.4345,79.9704,2,283,2.108,1.984,?
285,0.527,8.466    *geom.4
283,9.8440,89.4345,79.9704,2,284,2.108,1.984,?
285,0.527,8.466    *geom.4
284,9.8440,89.4345,79.9704,1,285,0.527,8.466    *geom.4
285,38.1089,348.0445,310.1883    *geom.4
286,19.0544,174.0222,155.0941,1,287,2.108,6.482    *geom.4
287,38.1089,348.0445,310.1883,1,288,2.108,8.466    *geom.4
288,38.1089,348.0445,310.1883,1,289,2.108,5.49    *geom.4
289,9.8440,89.4345,79.9704,1,290,2.108,1.984    *geom.4
290,9.8440,89.4345,79.9704,1,291,2.108,1.984    *geom.4
291,9.8440,89.4345,79.9704,1,292,2.108,1.984    *geom.4
292,9.8440,89.4345,79.9704    *geom.4
*
* fluid properties are generated from EPRI functions
prop,0,0,2,1    *prop.1
*
* lateral flow resistance is determined by Blasius-type relation
* from Idel'chik
drag,0,1,4    *drag.1
0.374,0.496    *drag.7
3.15,-0.2,0,3.15,-0.2,0    *drag.8
```

```
*
* 8 grid spacers, located every 20 in.
* form loss coefficient is 0.61
grid,0,1    *grid.1
0.61    *grid.2
-1,8    *grid.4
6,1,26,1,46,1,66,1,86,1,106,1,126,1,146,1    *grid.6
0    *grid.4
*
*   Correlations
corr,1,1,0    *corr.1
epri,epri,epri,none    *corr.2
0.2    *corr.3
epri,thsp,thsp,w-3l,cond,g5.7,0    *corr.6
0    *corr.7
* CHF calculations performed with W-3L correlation
w-3l    *corr.9
0.042,0.066,0.986    *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
2235,563.2,4941,5.996,640.5    *oper.5
*
* Transient forcing functions
28,28,28,28,0,0    *oper.12
*
* Core inlet pressure forcing function table
```

```
0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.13
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5620,1.0008    *oper.13
6.0837,0.9998,6.6146,1.0008,7.0200,1.0016,7.5715,1.0029    *oper.13
8.1374,1.0053,8.5724,1.0078,9.0175,1.0108,9.6285,1.0158    *oper.13
10.1017,1.0205,10.5893,1.0250,11.0951,1.0211,11.6264,1.0133   *oper.13
12.1885,1.0001,12.5823,0.9840,13.1823,0.9716,13.5823,0.9692   *oper.13
14.1823,0.9631,14.5823,0.9570,15.1823,0.9493,15.5823,0.9451   *oper.13
*
* Core coolant inlet temperature forcing function table
0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.14
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5620,1.0000    *oper.14
6.0837,1.0000,6.6146,1.0000,7.0200,1.0000,7.5715,1.0000    *oper.14
8.1374,1.0000,8.5724,1.0000,9.0175,0.9999,9.6285,0.9999    *oper.14
10.1017,0.9999,10.5893,0.9998,11.0951,0.9996,11.6264,0.9994   *oper.14
12.1885,0.9991,12.5823,0.9988,13.1823,0.9985,13.5823,0.9983   *oper.14
14.1823,0.9980,14.5823,0.9978,15.1823,0.9974,15.5823,0.9972   *oper.14
*
* Core coolant mass flow rate function table
0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.17
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5620,0.9955    *oper.17
6.0837,0.9802,6.6146,0.9602,7.0200,0.9443,7.5715,0.9217    *oper.17
8.1374,0.8980,8.5724,0.8794,9.0175,0.8601,9.6285,0.8330    *oper.17
10.1017,0.8115,10.5893,0.7894,11.0951,0.7678,11.6264,0.7440   *oper.17
12.1885,0.7176,12.5823,0.7010,13.1823,0.6644,13.5823,0.6415   *oper.17
14.1823,0.6063,14.5823,0.5819,15.1823,0.5429,15.5823,0.5192   *oper.17
*
* Core power forcing function table
0.0000,1.0000,0.0446,1.0000,1.0446,1.0000,2.0446,1.0000    *oper.20
3.0446,1.0000,4.0446,1.0000,5.0446,1.0000,5.5620,1.0000    *oper.20
```

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6.0837,1.0000,6.6146,1.0000,7.0200,1.0000,7.5715,1.0000    *oper.20
8.1374,1.0000,8.5724,0.9977,9.0175,0.9958,9.6285,0.6664    *oper.20
10.1017,0.1731,10.5893,0.1180,11.0951,0.1028,11.6264,0.0948   *oper.20
12.1885,0.0915,12.5823,0.0896,13.1823,0.0867,13.5823,0.0847   *oper.20
14.1823,0.0818,14.5823,0.0802,15.1823,0.0785,15.5823,0.0773   *oper.20
*
cont    *cont.1
15.0,1500,40,60,2,0,0,0    *cont.2
0.1,0.0001,0.0015,0.05,0.01,0.8,1.5,1    *cont.3
6,0,0,0,0,0,1,1,0,0,0,0,0,0,0    *cont.6
10000,0,5,0,0,0    *cont.7
*
summ,2    *summ.1
6,1,1    *summ.2
8,1,1    *summ.2
*
*  Rod Layout - mixed nuclear and control rods
*
* 325 rods with 2 geometry types (nuclear & dummy)
rods,1,325,1,2,1,0,0,0,0,0,0,0    *rods.1
*
* heated length is 144 in.
144,4,0,0,0.0    *rods.2
*
*             Nuclear Fuel Rod Power Profile
*  chopped cosine axial profile with 1.55 peak
-1,3    *rods.3
*
1.55    *rods.5
```

```
*
*             Normal Rod input
1,1,0.9232,1,1,825    *rods.9
2,1,1.025,1,2,528    *rods.9
3,1,0.86,1,3,264    *rods.9
4,1,0.8,1,4,264    *rods.9
5,1,0.79,1,5,132    *rods.9
6,1,1.08,1,6,264    *rods.9
7,1,1.02,1,7,264    *rods.9
8,1,1.07,1,8,264    *rods.9
9,1,1.15,1,9,132    *rods.9
10,1,0.82,1,10,132    *rods.9
11,1,0.88,1,11,264    *rods.9
12,1,0.86,1,12,264    *rods.9
13,1,1.07,1,13,66    *rods.9
14,1,1.07,1,14,66    *rods.9
15,1,1.07,1,15,66    *rods.9
16,1,1.07,1,16,66    *rods.9
17,1,0.95,1,17,264    *rods.9
18,1,1.25,1,18,132    *rods.9
19,1,0.93,1,19,132    *rods.9
20,1,1.36,1,20,264    *rods.9
21,1,0.92,1,21,66    *rods.9
22,1,0.92,1,22,66    *rods.9
23,1,0.92,1,23,66    *rods.9
24,1,0.92,1,24,66    *rods.9
25,1,1.3986,1,13,0.375,21,0.375,25,0.25    *rods.9
26,1,1.3836,1,13,0.5,25,0.25,26,0.25    *rods.9
27,1,1.3810,1,13,0.5,26,0.25,27,0.25    *rods.9
```

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28,1,1.3930,1,13,0.5,27,0.25,28,0.25    *rods.9
29,1,1.4103,1,13,0.25,14,0.25,28,0.25,29,0.25    *rods.9
30,1,1.4257,1,14,0.5,29,0.25,30,0.25    *rods.9
31,1,1.4205,1,14,0.5,30,0.25,31,0.25    *rods.9
32,1,1.4208,1,14,0.5,31,0.25,32,0.25    *rods.9
33,1,1.4283,1,14,0.25,15,0.25,32,0.25,33,0.25    *rods.9
34,1,1.4208,1,15,0.5,33,0.25,34,0.25    *rods.9
35,1,1.4205,1,15,0.5,34,0.25,35,0.25    *rods.9
36,1,1.4257,1,15,0.5,35,0.25,36,0.25    *rods.9
37,1,1.4103,1,15,0.25,16,0.25,36,0.25,37,0.25    *rods.9
38,1,1.3930,1,16,0.5,37,0.25,38,0.25    *rods.9
39,1,1.3810,1,16,0.5,38,0.25,39,0.25    *rods.9
40,1,1.3836,1,16,0.5,39,0.25,40,0.25    *rods.9
41,1,1.3986,1,16,0.375,40,0.25,281,0.375    *rods.9
42,1,1.3836,1,21,0.5,25,0.25,41,0.25    *rods.9
43,1,1.3739,1,25,0.25,26,0.25,41,0.25,42,0.25    *rods.9
44,1,1.3832,1,26,0.25,27,0.25,42,0.25,43,0.25    *rods.9
45,1,1.4122,1,27,0.25,28,0.25,43,0.25,44,0.25    *rods.9
46,1,1.4444,1,28,0.25,29,0.25,44,0.25,45,0.25    *rods.9
47,1,1.4962,1,29,0.25,30,0.25,45,0.25,46,0.25    *rods.9
48,1,1.4508,1,30,0.25,31,0.25,46,0.25,47,0.25    *rods.9
49,1,1.4496,1,31,0.25,32,0.25,47,0.25,48,0.25    *rods.9
50,1,1.4940,1,32,0.25,33,0.25,48,0.25,49,0.25    *rods.9
51,1,1.4496,1,33,0.25,34,0.25,49,0.25,50,0.25    *rods.9
52,1,1.4508,1,34,0.25,35,0.25,50,0.25,51,0.25    *rods.9
53,1,1.4962,1,35,0.25,36,0.25,51,0.25,52,0.25    *rods.9
54,1,1.4444,1,36,0.25,37,0.25,52,0.25,53,0.25    *rods.9
55,1,1.4122,1,37,0.25,38,0.25,53,0.25,54,0.25    *rods.9
56,1,1.3832,1,38,0.25,39,0.25,54,0.25,55,0.25    *rods.9
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57,1,1.3739,1,39,0.25,40,0.25,55,0.25,56,0.25    *rods.9
58,1,1.3836,1,40,0.25,56,0.25,281,0.5    *rods.9
59,1,1.3810,1,21,0.5,41,0.25,57,0.25    *rods.9
60,1,1.3832,1,41,0.25,42,0.25,57,0.25,58,0.25    *rods.9
61,1,1.4227,1,42,0.25,43,0.25,58,0.25,59,0.25    *rods.9
62,1,1.5047,1,43,0.25,44,0.25,59,0.25,60,0.25    *rods.9
63,1,1.5369,1,44,0.25,45,0.25,60,0.25,61,0.25    *rods.9
64,2,0,1,45,0.25,46,0.25,61,0.25,62,0.25    *rods.9
65,1,1.5180,1,46,0.25,47,0.25,62,0.25,63,0.25    *rods.9
66,1,1.5135,1,47,0.25,48,0.25,63,0.25,64,0.25    *rods.9
67,2,0,1,48,0.25,49,0.25,64,0.25,65,0.25    *rods.9
68,1,1.5135,1,49,0.25,50,0.25,65,0.25,66,0.25    *rods.9
69,1,1.5180,1,50,0.25,51,0.25,66,0.25,67,0.25    *rods.9
70,2,0,1,51,0.25,52,0.25,67,0.25,68,0.25    *rods.9
71,1,1.5369,1,52,0.25,53,0.25,68,0.25,69,0.25    *rods.9
72,1,1.5047,1,53,0.25,54,0.25,69,0.25,70,0.25    *rods.9
73,1,1.4227,1,54,0.25,55,0.25,70,0.25,71,0.25    *rods.9
74,1,1.3832,1,55,0.25,56,0.25,71,0.25,72,0.25    *rods.9
75,1,1.3810,1,56,0.25,72,0.25,281,0.5    *rods.9
76,1,1.3930,1,21,0.5,57,0.25,73,0.25    *rods.9
77,1,1.4122,1,57,0.25,58,0.25,73,0.25,74,0.25    *rods.9
78,1,1.5047,1,58,0.25,59,0.25,74,0.25,75,0.25    *rods.9
79,2,0,1,59,0.25,60,0.25,75,0.25,76,0.25    *rods.9
80,1,1.5612,1,60,0.25,61,0.25,76,0.25,77,0.25    *rods.9
81,1,1.5486,1,61,0.25,62,0.25,77,0.25,78,0.25    *rods.9
82,1,1.4764,1,62,0.25,63,0.25,78,0.25,79,0.25    *rods.9
83,1,1.4691,1,63,0.25,64,0.25,79,0.25,80,0.25    *rods.9
84,1,1.5189,1,64,0.25,65,0.25,80,0.25,81,0.25    *rods.9
85,1,1.4691,1,65,0.25,66,0.25,81,0.25,82,0.25    *rods.9
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86,1,1.4764,1,66,0.25,67,0.25,82,0.25,83,0.25    *rods.9
87,1,1.5486,1,67,0.25,68,0.25,83,0.25,84,0.25    *rods.9
88,1,1.5612,1,68,0.25,69,0.25,84,0.25,85,0.25    *rods.9
89,2,0,1,69,0.25,70,0.25,85,0.25,86,0.25    *rods.9
90,1,1.5047,1,70,0.25,71,0.25,86,0.25,87,0.25    *rods.9
91,1,1.4122,1,71,0.25,72,0.25,87,0.25,88,0.25    *rods.9
92,1,1.3930,1,72,0.25,88,0.25,281,0.5    *rods.9
93,1,1.4103,1,21,0.25,22,0.25,73,0.25,89,0.25    *rods.9
94,1,1.4444,1,73,0.25,74,0.25,89,0.25,90,0.25    *rods.9
95,1,1.5369,1,74,0.25,75,0.25,90,0.25,91,0.25    *rods.9
96,1,1.5612,1,75,0.25,76,0.25,91,0.25,92,0.25    *rods.9
97,1,1.5226,1,76,0.25,77,0.25,92,0.25,93,0.25    *rods.9
98,1,1.5449,1,77,0.25,78,0.25,93,0.25,94,0.25    *rods.9
99,1,1.4781,1,78,0.25,79,0.25,94,0.25,95,0.25    *rods.9
100,1,1.4719,1,79,0.25,80,0.25,95,0.25,96,0.25    *rods.9
101,1,1.5222,1,80,0.25,81,0.25,96,0.25,97,0.25    *rods.9
102,1,1.4719,1,81,0.25,82,0.25,97,0.25,98,0.25    *rods.9
103,1,1.4781,1,82,0.25,83,0.25,98,0.25,99,0.25    *rods.9
104,1,1.5449,1,83,0.25,84,0.25,99,0.25,100,0.25    *rods.9
105,1,1.5226,1,84,0.25,85,0.25,100,0.25,101,0.25    *rods.9
106,1,1.5612,1,85,0.25,86,0.25,101,0.25,102,0.25    *rods.9
107,1,1.5369,1,86,0.25,87,0.25,102,0.25,103,0.25    *rods.9
108,1,1.4444,1,87,0.25,88,0.25,103,0.25,104,0.25    *rods.9
109,1,1.4103,1,88,0.25,104,0.25,281,0.25,282,0.25    *rods.9
110,1,1.4257,1,22,0.5,89,0.25,105,0.25    *rods.9
111,1,1.4962,1,89,0.25,90,0.25,105,0.25,106,0.25    *rods.9
112,2,0,1,90,0.25,91,0.25,106,0.25,107,0.25    *rods.9
113,1,1.5486,1,91,0.25,92,0.25,107,0.25,108,0.25    *rods.9
114,1,1.5449,1,92,0.25,93,0.25,108,0.25,109,0.25    *rods.9
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115,2,0,1,93,0.25,94,0.25,109,0.25,110,0.25    *rods.9
116,1,1.5280,1,94,0.25,95,0.25,110,0.25,111,0.25    *rods.9
117,1,1.5239,1,95,0.25,96,0.25,111,0.25,112,0.25    *rods.9
118,2,0,1,96,0.25,97,0.25,112,0.25,113,0.25    *rods.9
119,1,1.5239,1,97,0.25,98,0.25,113,0.25,114,0.25    *rods.9
120,1,1.5280,1,98,0.25,99,0.25,114,0.25,115,0.25    *rods.9
121,2,0,1,99,0.25,100,0.25,115,0.25,116,0.25    *rods.9
122,1,1.5449,1,100,0.25,101,0.25,116,0.25,117,0.25    *rods.9
123,1,1.5486,1,101,0.25,102,0.25,117,0.25,118,0.25    *rods.9
124,2,0,1,102,0.25,103,0.25,118,0.25,119,0.25    *rods.9
125,1,1.4962,1,103,0.25,104,0.25,119,0.25,120,0.25    *rods.9
126,1,1.4257,1,104,0.25,120,0.25,282,0.5    *rods.9
127,1,1.4205,1,22,0.5,105,0.25,121,0.25    *rods.9
128,1,1.4508,1,105,0.25,106,0.25,121,0.25,122,0.25    *rods.9
129,1,1.5180,1,106,0.25,107,0.25,122,0.25,123,0.25    *rods.9
130,1,1.4764,1,107,0.25,108,0.25,123,0.25,124,0.25    *rods.9
131,1,1.4781,1,108,0.25,109,0.25,124,0.25,125,0.25    *rods.9
132,1,1.5280,1,109,0.25,110,0.25,125,0.25,126,0.25    *rods.9
133,1,1.4729,1,110,0.25,111,0.25,126,0.25,127,0.25    *rods.9
134,1,1.4710,1,111,0.25,112,0.25,127,0.25,128,0.25    *rods.9
135,1,1.5224,1,112,0.25,113,0.25,128,0.25,129,0.25    *rods.9
136,1,1.4710,1,113,0.25,114,0.25,129,0.25,130,0.25    *rods.9
137,1,1.4729,1,114,0.25,115,0.25,130,0.25,131,0.25    *rods.9
138,1,1.5280,1,115,0.25,116,0.25,131,0.25,132,0.25    *rods.9
139,1,1.4781,1,116,0.25,117,0.25,132,0.25,133,0.25    *rods.9
140,1,1.4764,1,117,0.25,118,0.25,133,0.25,134,0.25    *rods.9
141,1,1.5180,1,118,0.25,119,0.25,134,0.25,135,0.25    *rods.9
142,1,1.4508,1,119,0.25,120,0.25,135,0.25,136,0.25    *rods.9
143,1,1.4205,1,120,0.25,136,0.25,282,0.5    *rods.9
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144,1,1.4208,1,22,0.5,121,0.25,137,0.25    *rods.9
145,1,1.4496,1,121,0.25,122,0.25,137,0.25,138,0.25    *rods.9
146,1,1.5135,1,122,0.25,123,0.25,138,0.25,139,0.25    *rods.9
147,1,1.4691,1,123,0.25,124,0.25,139,0.25,140,0.25    *rods.9
148,1,1.4719,1,124,0.25,125,0.25,140,0.25,141,0.25    *rods.9
149,1,1.5239,1,125,0.25,126,0.25,141,0.25,142,0.25    *rods.9
150,1,1.4710,1,126,0.25,127,0.25,142,0.25,143,0.25    *rods.9
151,1,1.4702,1,127,0.25,128,0.25,143,0.25,144,0.25    *rods.9
152,1,1.5219,1,128,0.25,129,0.25,144,0.25,145,0.25    *rods.9
153,1,1.4702,1,129,0.25,130,0.25,145,0.25,146,0.25    *rods.9
154,1,1.4710,1,130,0.25,131,0.25,146,0.25,147,0.25    *rods.9
155,1,1.5239,1,131,0.25,132,0.25,147,0.25,148,0.25    *rods.9
156,1,1.4719,1,132,0.25,133,0.25,148,0.25,149,0.25    *rods.9
157,1,1.4691,1,133,0.25,134,0.25,149,0.25,150,0.25    *rods.9
158,1,1.5135,1,134,0.25,135,0.25,150,0.25,151,0.25    *rods.9
159,1,1.4496,1,135,0.25,136,0.25,151,0.25,152,0.25    *rods.9
160,1,1.4208,1,136,0.25,152,0.25,282,0.5    *rods.9
161,1,1.4283,1,22,0.25,23,0.25,137,0.25,153,0.25    *rods.9
162,1,1.4940,1,137,0.25,138,0.25,153,0.25,154,0.25    *rods.9
163,2,0,1,138,0.25,139,0.25,154,0.25,155,0.25    *rods.9
164,1,1.5189,1,139,0.25,140,0.25,155,0.25,156,0.25    *rods.9
165,1,1.5222,1,140,0.25,141,0.25,156,0.25,157,0.25    *rods.9
166,2,0,1,141,0.25,142,0.25,157,0.25,158,0.25    *rods.9
167,1,1.5224,1,142,0.25,143,0.25,158,0.25,159,0.25    *rods.9
168,1,1.5219,1,143,0.25,144,0.25,159,0.25,160,0.25    *rods.9
169,2,0,1,144,0.25,145,0.25,160,0.25,161,0.25    *rods.9
170,1,1.5219,1,145,0.25,146,0.25,161,0.25,162,0.25    *rods.9
171,1,1.5224,1,146,0.25,147,0.25,162,0.25,163,0.25    *rods.9
172,2,0,1,147,0.25,148,0.25,163,0.25,164,0.25    *rods.9
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173,1,1.5222,1,148,0.25,149,0.25,164,0.25,165,0.25    *rods.9
174,1,1.5189,1,149,0.25,150,0.25,165,0.25,166,0.25    *rods.9
175,2,0,1,150,0.25,151,0.25,166,0.25,167,0.25    *rods.9
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177,1,1.4283,1,152,0.25,168,0.25,282,0.25,283,0.25    *rods.9
178,1,1.4208,1,23,0.5,153,0.25,169,0.25    *rods.9
179,1,1.4496,1,153,0.25,154,0.25,169,0.25,170,0.25    *rods.9
180,1,1.5135,1,154,0.25,155,0.25,170,0.25,171,0.25    *rods.9
181,1,1.4691,1,155,0.25,156,0.25,171,0.25,172,0.25    *rods.9
182,1,1.4719,1,156,0.25,157,0.25,172,0.25,173,0.25    *rods.9
183,1,1.5239,1,157,0.25,158,0.25,173,0.25,174,0.25    *rods.9
184,1,1.4710,1,158,0.25,159,0.25,174,0.25,175,0.25    *rods.9
185,1,1.4702,1,159,0.25,160,0.25,175,0.25,176,0.25    *rods.9
186,1,1.5219,1,160,0.25,161,0.25,176,0.25,177,0.25    *rods.9
187,1,1.4702,1,161,0.25,162,0.25,177,0.25,178,0.25    *rods.9
188,1,1.4710,1,162,0.25,163,0.25,178,0.25,179,0.25    *rods.9
189,1,1.5239,1,163,0.25,164,0.25,179,0.25,180,0.25    *rods.9
190,1,1.4719,1,164,0.25,165,0.25,180,0.25,181,0.25    *rods.9
191,1,1.4691,1,165,0.25,166,0.25,181,0.25,182,0.25    *rods.9
192,1,1.5135,1,166,0.25,167,0.25,182,0.25,183,0.25    *rods.9
193,1,1.4496,1,167,0.25,168,0.25,183,0.25,184,0.25    *rods.9
194,1,1.4208,1,168,0.25,184,0.25,283,0.5    *rods.9
195,1,1.4205,1,23,0.5,169,0.25,185,0.25    *rods.9
196,1,1.4508,1,169,0.25,170,0.25,185,0.25,186,0.25    *rods.9
197,1,1.5180,1,170,0.25,171,0.25,186,0.25,187,0.25    *rods.9
198,1,1.4764,1,171,0.25,172,0.25,187,0.25,188,0.25    *rods.9
199,1,1.4781,1,172,0.25,173,0.25,188,0.25,189,0.25    *rods.9
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201,1,1.4729,1,174,0.25,175,0.25,190,0.25,191,0.25    *rods.9
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218,1,1.5280,1,190,0.25,191,0.25,206,0.25,207,0.25    *rods.9
219,1,1.5239,1,191,0.25,192,0.25,207,0.25,208,0.25    *rods.9
220,2,0,1,192,0.25,193,0.25,208,0.25,209,0.25    *rods.9
221,1,1.5239,1,193,0.25,194,0.25,209,0.25,210,0.25    *rods.9
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223,2,0,1,195,0.25,196,0.25,211,0.25,212,0.25    *rods.9
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227,1,1.4962,1,199,0.25,200,0.25,215,0.25,216,0.25    *rods.9
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229,1,1.4103,1,23,0.25,24,0.25,201,0.25,217,0.25    *rods.9
230,1,1.4444,1,201,0.25,202,0.25,217,0.25,218,0.25    *rods.9
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254,1,1.5189,1,224,0.25,225,0.25,240,0.25,241,0.25    *rods.9
255,1,1.4691,1,225,0.25,226,0.25,241,0.25,242,0.25    *rods.9
256,1,1.4764,1,226,0.25,227,0.25,242,0.25,243,0.25    *rods.9
257,1,1.5486,1,227,0.25,228,0.25,243,0.25,244,0.25    *rods.9
258,1,1.5612,1,228,0.25,229,0.25,244,0.25,245,0.25    *rods.9
259,2,0,1,229,0.25,230,0.25,245,0.25,246,0.25    *rods.9
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267,1,1.5369,1,236,0.25,237,0.25,252,0.25,253,0.25    *rods.9
268,2,0,1,237,0.25,238,0.25,253,0.25,254,0.25    *rods.9
269,1,1.5180,1,238,0.25,239,0.25,254,0.25,255,0.25    *rods.9
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275,1,1.5369,1,244,0.25,245,0.25,260,0.25,261,0.25    *rods.9
276,1,1.5047,1,245,0.25,246,0.25,261,0.25,262,0.25    *rods.9
277,1,1.4227,1,246,0.25,247,0.25,262,0.25,263,0.25    *rods.9
278,1,1.3832,1,247,0.25,248,0.25,263,0.25,264,0.25    *rods.9
279,1,1.3810,1,248,0.25,264,0.25,284,0.5    *rods.9
280,1,1.3836,1,24,0.5,249,0.25,265,0.25    *rods.9
281,1,1.3739,1,249,0.25,250,0.25,265,0.25,266,0.25    *rods.9
282,1,1.3832,1,250,0.25,251,0.25,266,0.25,267,0.25    *rods.9
283,1,1.4122,1,251,0.25,252,0.25,267,0.25,268,0.25    *rods.9
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285,1,1.4962,1,253,0.25,254,0.25,269,0.25,270,0.25    *rods.9
286,1,1.4508,1,254,0.25,255,0.25,270,0.25,271,0.25    *rods.9
287,1,1.4496,1,255,0.25,256,0.25,271,0.25,272,0.25    *rods.9
288,1,1.4940,1,256,0.25,257,0.25,272,0.25,273,0.25    *rods.9
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291,1,1.4962,1,259,0.25,260,0.25,275,0.25,276,0.25    *rods.9
292,1,1.4444,1,260,0.25,261,0.25,276,0.25,277,0.25    *rods.9
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299,1,1.3810,1,266,0.25,267,0.25,289,0.5    *rods.9
300,1,1.3930,1,267,0.25,268,0.25,289,0.5    *rods.9
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302,1,1.4257,1,269,0.25,270,0.25,290,0.5    *rods.9
303,1,1.4205,1,270,0.25,271,0.25,290,0.5    *rods.9
304,1,1.4208,1,271,0.25,272,0.25,290,0.5    *rods.9
305,1,1.4283,1,272,0.25,273,0.25,290,0.25,291,0.25    *rods.9
306,1,1.4208,1,273,0.25,274,0.25,291,0.5    *rods.9
307,1,1.4205,1,274,0.25,275,0.25,291,0.5    *rods.9
308,1,1.4257,1,275,0.25,276,0.25,291,0.5    *rods.9
309,1,1.4103,1,276,0.25,277,0.25,291,0.25,292,0.25    *rods.9
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311,1,1.3810,1,278,0.25,279,0.25,292,0.5    *rods.9
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314,1,1.1,1,281,66    *rods.9
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316,1,1.1,1,283,66    *rods.9
317,1,1.1,1,284,66    *rods.9
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318,1,0.82,1,285,264    *rods.9
319,1,1.12,1,286,132    *rods.9
320,1,1.16,1,287,264    *rods.9
321,1,1.03,1,288,264    *rods.9
322,1,0.83,1,289,66    *rods.9
323,1,0.83,1,290,66    *rods.9
324,1,0.83,1,291,66    *rods.9
325,1,0.83,1,292,66    *rods.9
0    *rods.9
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* nuclear type geometry
1,nucl,0.374,0.3252,6,0.0,0.02244    *rods.62
0,1,0,0,0,2000,0.95,0    *rods.63
* dummy type geometry - used for control rods
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620.6,0.0698,2.0671,710.6,0.0707,1.9841,
800.6,0.0715,1.9103,890.6,0.0722,1.8453,
980.6,0.0729,1.7884,1070.6,0.0735,1.7383,
1160.6,0.0740,1.6938,1250.6,0.0745,1.6529,
1340.6,0.0750,1.6144,1430.6,0.0754,1.5772,
1520.6,0.0758,1.5405,1610.6,0.0762,1.5042,
1700.6,0.0767,1.4684,1790.6,0.0771,1.4332,
1880.6,0.0775,1.3990,1970.6,0.0779,1.3661,
2060.6,0.0783,1.3348,2150.6,0.0788,1.3052,
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4580.6,0.1446,1.4968,4670.6,0.1499,1.5370,
4760.6,0.1555,1.5787,4850.6,0.1612,1.6217,
4940.6,0.1671,1.6660,5030.6,0.1732,1.7114,
5120.6,0.1794,1.7578,5210.6,0.1858,1.8051,
5300.6,0.1924,1.8531,5390.6,0.1990,1.9019,
5480.6,0.2059,1.9512,5570.6,0.2128,2.0011,
5660.6,0.2199,2.0513,5750.6,0.2270,2.1019,
5840.6,0.2343,2.1527,
endd
0
```

APPENDIX C
MELCOR INPUT DECKS

The following are the input decks for MELCOR version 1.8.5 described in Section 3.4.2. An existing MELCOR input deck that models a station blackout event for a Westinghouse 4-Loop PWR plant similar to the selected reference core design has been modified to induce complete and partial LOFAs. All original input decks come from reference [38]. The 4 modified files included in this appendix are:

sbo.gen General MELGEN input, intializes calculation

sbo.cor General MELCOR input, for time advancement

z_trips.gen Control functions governing plant trip logic

Z_ic.gen Control function intial conditions, and records of heat structures, flowpaths, and control volumes

Due to the length of each input file, only the modified segments of each file are shown below.

C.1 sbo.gen

```
title     'zion NC MODEL'
jobid     'zion NC MODEL'
*
restartf  'sbo.rst'
outputf   'sbog.out'
diagf     'sbog.dia'
stopf     'sbo.stp'
*
*allowreplace
*
*************************************
```

```
* Read in data from external files   *
**************************************
******************
*    Active      *
******************
*
r*i*f original\accum.gen
r*i*f original\block.gen
r*i*f creep.gen
r*i*f original\eccs.gen
r*i*f loops.gen
r*i*f original\mp.gen
r*i*f original\nc_hl.gen
r*i*f original\nc_logic.gen
r*i*f original\nc_sg.gen
r*i*f przr.gen
r*i*f original\reltank.gen
r*i*f original\rnplots.gen
r*i*f sg.gen
r*i*f sg_ht.gen
r*i*f ss_pres.gen
r*i*f original\vessel.gen
r*i*f original\vessel_hs.gen
*
r*i*f z_cav.gen
r*i*f z_core.gen
r*i*f original\z_fcl.gen
r*i*f original\z_fw.gen
r*i*f original\z_rhr.gen
```

```
r*i*f original\z_rwst.gen
r*i*f z_trips.gen
*
r*i*f original\z_cont.gen
r*i*f z_cvtype.gen
r*i*f original\z_par.gen
r*i*f z_rn.gen
r*i*f original\z_spray.gen
******************
*  In-active     *
******************
*
* r*i*f original\z_burn.gen
* r*i*f original\s_seals.gen
bur000   1
*
******************
* Initialization *
******************
*
tstart    -200.0
r*i*f z_loop_k.gen
r*i*f z_ic.gen
r*i*f original\h2800.gen
*
sc44001   4400  0.9   1  * Courant of 90%
sc44013   4401  25.0  3  * Max number of vel. iterations
sc44151   4415  1.0   1  * Use "fast" (iterative, sparse)
*
```

```
******************
*  Trips         *
******************
*
*  Trip   Description
*  ----   -------------
*   1     Steady/Transient toggle
*   2     No Power available
*
* transient initiation time changed to begin at 5 s - Adam
*
cf00100  'Transient'  equals  1   1.0  0.0
cf00110   0.0  5.0    time
*
*  Loss-of-power
*
* time changed to begin at 10000 s
* to prevent TMLB during transient - Adam
*
cf00200  'TMLB'    equals  1   1.0  0.0
cf00210   0.0  10000.0    time
*
*  This particular scenario (i.e., at least as portrayed in S/R5)
*  does have battery power available for the pressurizer PORV
*
CF69411  0.0  1.0  CFVALU.042   * Power available to PORV
CF69511  0.0  1.0  CFVALU.042   * Power available to PORV
.
```

C.2 sbo.cor

```
title     'zion NC MODEL'
jobid     'zion NC MODEL'
*
restartf  'sbo.rst'
outputf   'sbo1.out'
diagf     'sbo1.dia'
stopf     'sbo1.stp'
plotf     'sbo1.ptf'
messagef  'sbo1.mes'
*
crtout
*
cymesf      1        1
softdtmin   1.0e-6   500
*
restart    -1* time 9000
*
* 'time3' inserted to create finer temporal discretization
* for VIPRE calculations following transient initiation at
* 5.0 seconds. Plot time is 0.3. -Adam
*
*         time    dtmax    dtmin     dtedit   dtplot   dtrest
time1     -1.e6   0.1      0.00001   2000.0    10.0   15000.0
time2      -5.0   0.1      0.00001   2000.0     1.0   15000.0
time3       5.0   0.1      0.000001  2000.0     0.3    1000.0
time4     100.0   0.1      0.000001  2000.0     5.0    1000.0
time5    9000.0   0.2      0.000001  2000.0    30.0    1000.0
```

```
time6   10000.0   0.3      0.000001  2000.0    60.0    2000.0
time7   11000.0   0.5      0.000001  2000.0    60.0    2000.0
time8   25000.0   0.8      0.00001   2000.0   120.0    5000.0
*
tend       25000.0
*tend          -190.0
cpulim   2000000.0
cpuleft       30.0
comtc            3
*
*  core edit information
*
*         itemp  imass   ivol  iasur   ipmv   ipow
coredv01      1      1      1      0      1      0
*
*  rn edit information
*
* rnedtflg    1  1  1
*
* sc40552   4055  5.e-1 2    * HS convergence
* sc44001   4400  0.9   1    * Courant of 90%
sc44013   4401  25.0  3    * Max number of vel. iterations
* sc44131   4413  1.e-1 5    * Ergun equation, minimum porosity
sc44151   4415  1.0   1    * Use "fast" (iterative, sparse)
* cvhtrace
*CF99700 double EQUALS 1 -1.0 *0.5
.
```

C.3 z_trips.gen

```
*  ----------
*  Trip Index
*  ----------
*  30 -  32  Transient/Steady State
*  35 -  39  Limited availability dc power during SBO
*  40 -  41  Station blackout IE
*  43 -  49  ECCS Signal
*  50 -  53  Turbine Control Valve (TCV) closure logic
*  60 -  65  RCP trip logic
*  70 -  76  Feedwater (FW)/Auxillary FW (AFW)
*            trip/actuation logic
*  80 -  91  LPI, HPI, and Charging actuation logic
*  95        ECCS availability on shift to recirculation
* 123        Sprays availability on shift to recirculation
* 100 - 110  Reactor trip logic
* 120 - 124  Containment spray actuation logic
* 126 - 129  RHR and Spray HX availability
* 135 - 139  Recirculation Fan actuation
* 140 - 141  Recombiners availability
* 142 - 143  Fan coolers (not in Sequoyah)
*
*  Trip   Description
*  ----   -------------
*   1     Steady/Transient toggle
*   2     Power available
*   3     Manual SCRAM
*
```

```
cf00100  'Transient'  equals  1   1.0  0.0
cf00110   0.0  0.0    time
*
cf00200  'Onsite Pwr' equals  1   1.0  0.0
cf00210   0.0  1.e9   time
*
* additive in CF00310 set to zero to prevent
* manual scram, original 1.e9 - Adam
*
cf00300  'Man. SCRAM' equals  1   1.0  0.0
cf00310   0.0  0.0   time
*****************************************************
*****************************************************
              Skipped to Next Segment
*****************************************************
*****************************************************
*  Pump Trip
*    1. Initiating transient event -Adam
*    2. Steam voiding (i.e., > 10%)
*
cf06000  'Pump 1 Void' l-gt   2   1.0  0.0
cf06005  'LATCH'
cf06006   2  'High Void Trips Pump 1'
cf06010   1.0    0.0  fl-void.522
cf06011   0.0    0.1  time
*
* cfvalu.40 changed to cfvalue.30 at CF06110 so that
* transient would initiate pump trip and not TMLB - Adam
*
```

```
cf06100  'Pump 1 Trip'  l-or   2   1.0  0.0
cf06105  'LATCH'
cf06106   2  'Single Loop Pump tripped'
cf06110   1.0    0.0  cfvalu.30
cf06111   1.0    0.0  cfvalu.60
*
cf06200  'Pump 1 Trip'  trip   1   1.0  0.0
cf06202   1   0.0
cf06210   1.0    0.0  cfvalu.61
*
cf06300  'Pump 3 Void' l-gt   2   1.0  0.0
cf06305  'LATCH'
cf06306   2  'High Void Trips Pump 3'
cf06310   1.0    0.0  fl-void.622
cf06311   0.0    0.1  time
*
* Pump 3 trip modified by Adam
* The use of cfvalu.40 at CF06410 induces a partial LOFA when
* the transient is initiated
* The use of cfvalu.30 at CF06410 induces a complete LOFA when
* the transient is initiated
*
cf06400  'Pump 3 Trip'  l-or   2   1.0  0.0
cf06405  'LATCH'
cf06406   2  'Triple Loop Pumps tripped'
cf06410   1.0    0.0  cfvalu.40  * PLOFA option -Adam
*cf06410   1.0    0.0  cfvalu.30  * CLOFA option -Adam
cf06411   1.0    0.0  cfvalu.63
*
```

```
cf06500  'Pump 3 Trip'  trip   1   1.0  0.0
cf06502   1   0.0
cf06510   1.0    0.0  cfvalu.64
*
*  Main Feedwater Pump Trip
*    1. Loss of power trip
*    2. Manual signal
*    3. SCRAM
*
* Set to true to manually fail FW and false to have available
cf07000  'FW Failure' l-gt   2   1.0  0.0
cf07006   2   'FW failed' * added by adam
cf07010   0.0    0.0  time
cf07011   0.0    1.0  time
*
* FW Trip averted for LOFA with normal plant response - Adam
* (FW trip due to transient initiation at CF07110 deleted
*  and 3 arguments changed to 2 at CF07100. cfvalu.101
*  at CF07112 changed to cfvalu.70 to prevent FW trip when
*  reactor is tripped.) -Adam
*
cf07100  'FW Trip'    l-or   2   0.0  0.0
cf07105  'LATCH'
cf07106   2  'FW tripped'
* cf07110   1.0    0.0  cfvalu.40
cf07111   0.0    0.0  cfvalu.70
cf07112   1.0    0.0  cfvalu.70
*
cf07200  'FW Trip'    trip   1   1.0  0.0
```

```
cf07202   3   0.0   1.0
cf07210   0.1    0.0  cfvalu.71  * isolate over 10 seconds
*
cf07300  ’FW On’      equals 1   1.0  0.0
cf07302   3   0.0   1.0
cf07310  -1.0    1.0  cfvalu.72
*****************************************************
*****************************************************
              Skipped to Next Segment
*****************************************************
*****************************************************
*  Reactor Trip
*    1. Loss of power trip
*    2. FW trip
*    3. TCV closure
*    4. Pump trip (low flow)
*    5. LPI/HPI actuation (ECCS actuation signal)
*    5. High Pressure ( 2400 psia)
*    6. Low Pressure ( 1815 psia)
*    7. High pressurizer level (44.97 feet)
*    8. Low pressurizer level (12.51 feet)
*    9. High loop Delta T (75 F)
*   10. Must be in transient mode (not a steady state
*       initialization)
*
* Initial reactor trip due to TMLB, Loss of pump, and
* High pressurizer level trips deleted so that transient
* could take place. The loss of pump trip was replaced by
* the more realistic 87% loop flow trip point with
```

```
* CF10014. The number of arguments for CF10000 was changed
* from 14 to 12 since two other options were deleted. -Adam


cf10000  'React Trp'  l-or  12   1.0  0.0
cf10010   1.0    0.0  cfvalu.40  * Loss of power
cf10011   1.0    0.0  cfvalu.49  * ECCS actuation
cf10012   1.0    0.0  cfvalu.71  * FW trip
cf10013   1.0    0.0  cfvalu.51  * TCV closure
*
* 87% loop flow trip changed from cfvalu.61 to cfvalu.111
* for low flow trip instead of pump trip - adam
cf10014   1.0    0.0  cfvalu.111  *
* cf10015   1.0    0.0  cfvalu.64  * Pump 3 trip deleted by adam
cf10016   1.0    0.0  cfvalu.82  * HPI Activation
cf10017   1.0    0.0  cfvalu.86  * LPI Activation
cf10018   1.0    0.0  cfvalu.103 * High RPV Pressure
cf10019   1.0    0.0  cfvalu.104 * Low RPV Pressure
*cf10020  1.0    0.0  cfvalu.105 * High przr level deleted by adam
cf10021   1.0    0.0  cfvalu.106 * Low przr level
cf10022   1.0    0.0  cfvalu.109 * High loop delta_T
cf10023   1.0    0.0  cfvalu.110 * Manual trip
*
cf10100  'React Trp' l-and   3   1.0  0.0
cf10105  'LATCH'
cf10106   2  'Reactor Trip'
cf10110   1.0    0.0  cfvalu.100  * Reactor
cf10111   1.0    0.0  cfvalu.030  * Must be a transient
*
```

```
* Added by adam to delay reactor trip
cf10112   1.0    0.0  cfvalu.97
*
*
* CF096 and CF097 added to induce a 1 second delay
* between 87% loop flow signal and a reactor trip -Adam
*
* added by adam
cf09600  'Trip Time'  trip   1   1.0  0.0
cf09602   1   0.0
cf09610   1.0    0.0  cfvalu.100
*
* added by adam
cf09700  'Trip delay' l-gt 2 1.0 0.0
cf09705  'LATCH'
*cf09706   2   'Reactor Trip delayed'
cf09710   1.0    0.0   cfvalu.96
cf09711   0.0    1.0   time
*
cf10200  'React Trp'  trip   1   1.0  0.0
cf10202   1   0.0
cf10210   1.0    0.0  cfvalu.101
*
cf10300  'High Press' l-gt   2   1.0  0.0
cf10305  'LATCH'
cf10306   2  'High RPV Pressure Trip'
*vierow: change CV numbering for new pressurizer nodalization
*cf10310   1.0    0.0       cvh-p.400
cf10310   1.0    0.0       cvh-p.407
```

```
cf10311   0.0    1.655e+07 time       * 2400 psia (16.55 MPa)
*
cf10400  'Low Press'  l-gt   2   1.0  0.0
cf10405  'LATCH'
cf10406   2  'Low RPV Pressure Trip'
cf10410   0.0    1.251e+07 time       * 1815 psia (12.51 MPa)
*vierow: change CV numbering for new pressurizer nodalization
*cf10411   1.0    0.0       cvh-p.400
cf10411   1.0    0.0       cvh-p.407
*
*  Nominal level is 31 ft (22 m in MELCOR model)
cf10500  'High Przr Level' l-gt   2   1.0  0.0
cf10505  'LATCH'
cf10506   2  'High Pressurizer Level Trip'
*vierow: change CV numbering for new pressurizer nodalization
*cf10510   1.0    0.0       cvh-liqlev.400
cf10510   1.0    0.0       cvh-liqlev.407
*vierow: new pressurizer nodalization
*cf10511   0.0    26.26     time
cf10511   0.0    1.79     time
*
cf10600  'Low Przr Level'  l-gt   2   1.0  0.0
cf10605  'LATCH'
cf10606   2  'Low Pressurizer Level Trip'
*vierow: new pressurizer nodalization
*cf10610   0.0    16.36     time
cf10610   0.0    1.564     time
*vierow: change CV numbering for new pressurizer nodalization
*cf10611   1.0    0.0        cvh-liqlev.400
```

```
cf10611   1.0    0.0        cvh-liqlev.404
*
*  High Delta T
cf10700  'Loop Delta_T'    add    2   1.0  0.0
cf10710   1.0    0.0       cvh-tliq.523
cf10711  -1.0    0.0       cvh-tliq.623
*
cf10800  'Loop Delta_T'    abs    1   1.0  0.0
cf10810   1.0    0.0       cfvalu.107
*
cf10900  'High Delta_T'    l-gt   2   1.0  0.0
cf10905  'LATCH'
cf10906   2  'High Loop Temperature Difference'
cf10910   1.0    0.0       cfvalu.108
cf10911   0.0   41.67      time       * 75 F (41.67 C)
*
*
* At CF11010 TIME changed to cfvalu.003 and the additive at
* CF11011 is changed from 1.0 to 10.0 to prevent manual
* scram of the reactor -Adam
*
*  Set to true to create a manual SCRAM
cf11000  'Manual SCRAM'  l-gt   2   1.0  0.0
cf11005  'LATCH'
cf11006   2   'Manual SCRAM Initiated' * message added by adam
cf11010   1.0    1.0  cfvalu.003
cf11011   1.0    10.0  cfvalu.003
*
*
```

```
* CF111 added to create a 87% loop flow reactor trip signal
* for LOFA analysis. CF11111 references flow-path 524 (Cold leg 1)
* and compares the mass flow to a value representing 87% of its
* nominal mass flow rate. CF111 becomes true when the mass flow
* rate in flow-path 524 becomes less than or equal to 3721 kg/s.
* -Adam
*
* Low Flow trip added by Adam
cf11100  '87% Loop Flow'  l-gt   2   1.0  0.0
cf11105  'LATCH'
cf11106   2  'Low Loop Flow Trip'
cf11110   0.0    3.721e+03 time   * 87% Loop 1 Flow 3721 KG/S
cf11111   1.0    0.0       fl-mflow.1.524
```

C.4 z_ic.gen

Initial conditions for new control functions CF96, CF97, and CF111 are added.

```
CF09601     0.00000 *added by adam
CF09701     .False. *added by adam
CF10001     .False.
CF10101     .False.
CF10201     0.00000
CF10301     .False.
CF10401     .False.
CF10501     .False.
CF10601     .False.
CF10701     0.00512695
CF10801     0.00512695
CF10901     .False.
CF11001     .False.
CF11101     .False. *added by adam
```

APPENDIX D

THERMAL CONDUCTIVITY MODELS AND DATA

The material discussed herein provides supporting information for Section 4. The thermal conductivity models of Ronchi et al. [45,47] and Popov et al. [48] are described in detail. Thermal conductivity measurements for fresh UO_2 taken by Gibby [46] and Hobson [52] are listed. FRAPCON-3 thermal conductivity model parameters for $(U,Pu)O_2$ are listed, as well.

D.1 Ronchi et al. Model for Temperatures up to 2900K

The thermal conductivity model developed by Ronchi et al. [45] from the combined contribution of the lattice and ambipolar components is

$$k(t) = \left(\frac{10^2}{6.548 + 23533t} + \frac{6400e^{-16.35/t}}{t^{5/2}} \right) \tag{D.1}$$

where $t = T/1000$ K.

D.2 Ronchi et al. Model for Burnup up to 100 GWd/tHM

Ronchi et al. [47] suggested that the thermal conductivity of the fuel be represented by Equation D.2. The following discussion will cover the formulation of the model deduced by Ronchi et al. and concentrate on defining the coefficients, A and B.

$$k = \left[A(T_{\text{irr}}, T_{\text{ann}}, \text{Bu}) + B(T_{\text{irr}}, T_{\text{ann}}, \text{Bu})T\right]^{-1} \tag{D.2}$$

The constant coefficient A is the sum of the thermal resistance due to phonon scattering by individual point defects and dislocations and extended defects [47]. Many defects, such as those caused by vacancies, interstitial atoms, and impurities, already exist in the fuel matrix at BOL conditions. Additional defects are created through radiation damage and the formation of fission products in the lattice structure as a result of the fission process. The value of A is largely dependent on a scattering coefficient, Γ, known as the phonon diffusion cross-section. The calculation of Γ was

Table D.1
List of variables from Ronchi et al. thermal conductivity model for burnup up to 100 GWd/tHM (from [47])

Variable	Meaning
k	thermal conductivity of UO_2, $W/m \cdot K$
T	instant application temperature (300-1500 K)
T_{irr}	irradiation temperature (700-1450 K)
T_{ann}	maximum temperature reached during annealing following irradiation at T_{irr} (700-1450 K)
T_m	largest temperature of T_{irr} and T_{ann} ($T_m = \max(T_{\mathrm{irr}}, T_{\mathrm{ann}})$)
Bu	Burnup (0-100 GWd/tHM)

performed using fission product concentrations calculated by the ORIGEN2 code, and the values of Γ were found to be linearly dependent on both the amount of dissolved fission products and dynamically dissolved volatile fission products. The amount of dissolved fission products is proportional to burnup, while the amount of dynamically dissolved volatile fission products is proportional to the product of burnup and the parameter GIS (Gas-in-Solid), which represents the ratio of the gas amount present in the dynamical solution to the total produced inventory [47]. The expression for GIS was found by fitting an interpolating spline function to a set of parametric evaluations calculated from a gas diffusion/precipitation/release model, and is shown in Equation D.3 along with the expression for Γ in Equation D.4.

$$\mathrm{GIS}(\mathrm{Bu},T_{\mathrm{irr}},T_{\mathrm{ann}}) = \frac{1-0.9\left[1+\exp\left(\frac{T_{\mathrm{irr}}-950}{30}\right)\right]^{-1}\left[1+\exp\left(\frac{73-\mathrm{Bu}}{2}\right)\right]^{-1}}{\left[1+\exp\left(\frac{T_{\mathrm{irr}}-1350}{200}\right)\right]\left[1+\exp\left(\frac{T_{\mathrm{ann}}-1350}{200}\right)\right]} \tag{D.3}$$

$$\Gamma(\mathrm{Bu},\mathrm{GIS}) = 9.02\times10^{-4}\ \mathrm{Bu}\ \mathrm{GIS} + 1.74\times10^{-3}\ \mathrm{Bu} + 7.51\times10^{-3} \tag{D.4}$$

During laboratory annealing analyses, the irradiated samples showed signs of a slight recovery at annealing temperatures below T_{irr}. The recovery corresponds to a healing of self-irradiation defects produced between EOL extraction and the time of laboratory measurements (typically a few years) [47]. The self-irradiation effect was prevalent among the samples, indicated by the fact that the values of A at EOL were always lower than those measured in the lab, and the following compensation was made:

$$\delta A_{\mathrm{Self}}(T_{\mathrm{ann}},\mathrm{Bu}) = \begin{cases} 0.02F(\mathrm{Bu}) & \text{if } T_{\mathrm{ann}} \leq 900\mathrm{K}, \\ 0.02F(\mathrm{Bu})\frac{1450-T_{\mathrm{ann}}}{1450-900} & \text{if } 1450\mathrm{K} > T_{\mathrm{ann}} > 900\mathrm{K}, \\ 0 & \text{if } T_{\mathrm{ann}} > 1450\mathrm{K} \end{cases} \tag{D.5}$$

where

$$F(\mathrm{Bu}) = \left(\left(1+\exp\left(\frac{20-\mathrm{Bu}}{6}\right)\right)^{-1} - 0.015267\right) \tag{D.6}$$

The factor F(Bu) accounts for the differences between fresh fuel and irradiated fuel by weakening the effect described by Equation D.5 as burnup decreases. It was also observed that samples with low burnup and low irradiation temperatures experienced a thermal conductivity recovery due to a decrease in A at temperatures between 800 and 1000 K and 1200 and 1350 K. The expression for the variation of A due to the effective concentration of irradiation defects at EOL as a function of burnup is shown by Equation D.7.

$$\begin{aligned}\delta A_{\mathrm{EOL}}(T_m,\mathrm{Bu}) =& \frac{\mathrm{Bu}}{850}\left[\left(1+\exp\left(\frac{T_m-950}{25}\right)\right)^{-1}+\left(1+\exp\left(\frac{T_m-1300}{35}\right)\right)^{-1}\right.\\ &\left. -\,0.0525\right]\end{aligned} \tag{D.7}$$

where T_m is the larger temperature of T_{irr} and T_{ann} ($T_m = \max(T_{\mathrm{irr}}, T_{\mathrm{ann}})$). The total effect of irradiation defects on A is given by the sum of the effective concentration of irradiation defects at EOL and the contribution from the self-irradiation effect from EOL to the time the samples were measured in lab:

$$\delta A = \delta A_{\mathrm{Self}}(T_{\mathrm{ann}},\mathrm{Bu}) + \delta A_{\mathrm{EOL}}(T_m,\mathrm{Bu}) \tag{D.8}$$

The final combined formulation for coefficient A found in Equation D.2, which represents the phonon-defect scattering mechanism of the lattice contribution to thermal conductivity, is given by

$$A(T_{\mathrm{irr}}, T_{\mathrm{ann}}, \mathrm{Bu}) = 0.046 + \Gamma(\mathrm{Bu{,}GIS}) + \delta A. \tag{D.9}$$

The product BT in Equation D.2 represents the intrinsic lattice thermal resistivity caused by phonon-phonon scattering [47]. The variations of B at EOL and after annealing are opposite to those of A. The general variations of B with temperature and the effects of burnup are fitted by Equation D.10 and the effect of irradiation defects on the value of B is expressed in Equation D.11.

$$\begin{aligned}\delta B_{\mathrm{EOL}}(T_m,\mathrm{Bu}) =& \frac{\mathrm{Bu}}{34}\left[\left(1+\exp\left(\frac{T_m-950}{25}\right)\right)^{-1}\right.\\ &\left. +2.5\times10^{-5}\left(1+\exp\left(\frac{T_m-1300}{35}\right)\right)^{-1}\right]\end{aligned} \tag{D.10}$$

$$\delta B = F(\mathrm{Bu})\delta B_{\mathrm{EOL}} \tag{D.11}$$

The final formulation for coefficient B found in Equation D.2, as interpolated from experimental measurements, is

$$B(T_{\text{irr}}, T_{\text{ann}}, \text{Bu}) = B_0 + (B_1 - B_0)\frac{6.5 \times 10^{-5} - \delta B}{6.5 \times 10^{-5}} \tag{D.12}$$

where B_0 and B_1 are the values of B at the EOL and after annealing at 1450 K, respectively, and are shown in Equations D.13 and D.14.

$$B_0 = -1.65 \times 10^{-6}\ \text{Bu} + 2.55 \times 10^{-4} - 3.6 \times 10^{-5}\ \text{IRIM} \tag{D.13}$$

$$B_1 = 4.2 \times 10^{-7}\ \text{Bu} + 2.75 \times 10^{-4} \tag{D.14}$$

The factor IRIM is a correction term associated with the effect of rim restructuring during irradiation, which results in a substantial decrease in the fission gas concentration dissolved in the matrix (a positive effect on lattice portion of the thermal conductivity).

$$\text{IRIM} = \left[1 + \exp\left(\frac{T_{\text{irr}} - 950}{30}\right)\right]^{-1} \times \left[1 + \exp\left(\frac{73 - \text{Bu}}{2}\right)\right]^{-1} \tag{D.15}$$

D.3 Popov et al. Model for Thermal Conductivity of UO_2

The thermal conductivity model developed by Popov et al. [48] is based primarily on previous work by Lucuta et al. [49] with SIMFUEL. The Lucuta et al. analytical model accounts for effects produced by the buildup of solid fission products, pores and fission-gas-bubble formation, radiation damage, and changes in the oxygen-to-metal ratio. Equation D.16 shows the form of the Lucuta et al. model and the meaning of each effect factor is given in Table D.2.

$$k(T, \text{Bu}_{\text{at}}, \text{p}) = k_0(T) \times \text{FD} \times \text{FP} \times \text{FM} \times \text{FR} \tag{D.16}$$

After a review of the open literature on thermal conductivity, Popov et al. selected a correlation for fully dense, unirradiated UO_2. Equation D.17 represents the final equation for the Popov et al. model, and consists of a characteristic lattice term and

Table D.2

Lucuta et al. thermal conductivity model variables (from [49])

Variable	Meaning
k_0	thermal conductivity of unirradiated, fully dense UO_2, $W/m \cdot K$
FD	factor describing the effect of the dissolved solid fission products in fuel matrix
FP	factor describing effect of precipitated solid fission products in fuel matrix
FM	factor describing effect of fuel porosity
FR	factor describing effect of radiation damage
T	temperature, K
$\mathrm{Bu_{at}}$	burnup, at.% (1 at.% = 9375 MWd/tHM)
p	porosity (1 - %th. d.)

an additional term suggested by Ronchi et al. [45] to account for the small-polaron ambipolar contribution to the thermal conductivity.

$$k_0(T) = \frac{115.8}{7.5408 + 17.692t + 3.6142t^2} + 7410.5t^{-5/2}\exp(-16.35/t) \tag{D.17}$$

where $t = T/1000$ K.

Based on the work performed by Lucuta et al. [49], the effect of dissolved fission products is represented by a burnup and temperature-dependent parameter FD:

$$\mathrm{FD} = \omega \times \arctan(1/\omega) \tag{D.18}$$

where

$$\omega = 1.09/{\mathrm{Bu_{at}}}^{3.265} + 0.0643(T/\mathrm{Bu_{at}})^{1/2} \tag{D.19}$$

The factor FP represents the effect of precipitated fission products:

$$\mathrm{FP} = 1 + \frac{0.019\mathrm{Bu_{at}}}{3 - 0.019\mathrm{Bu_{at}}} \times \left[1 + \exp\left(\frac{1200 - T}{100}\right)\right]^{-1} \tag{D.20}$$

Porosity's effect on thermal conductivity is given by the Maxwell-Eucken factor [48], FM, in Equation D.21, and the radiation effect is represented by the factor, FR, in Equation D.22.

$$\mathrm{FM} = \frac{(1 - \mathrm{p})}{(1 + 2\mathrm{p})} \tag{D.21}$$

$$\mathrm{FR} = 1 - \frac{0.2}{\left[1 + \exp\left(\frac{T-900}{80}\right)\right]} \tag{D.22}$$

D.4 FRAPCON-3 Model for MOX Fuel

The FRAPCON MOX thermal conductivity model is given by Equation D.23, with a brief explanation of the terms in Table D.3.

$$\begin{aligned} k = &\frac{1}{A(x) + a \cdot gad + B(x)T + f(\mathrm{Bu}) + (1 - 0.9\exp(-0.04\mathrm{Bu}))\, g(\mathrm{Bu})h(T)} \\ &+ \frac{E}{T^2}\exp(-F/T) \end{aligned} \tag{D.23}$$

Table D.3
FRAPCON-3 Thermal conductivity model variables for MOX fuel (from [28])

Variable	Meaning
k	thermal conductivity, $\mathrm{W/m \cdot K}$
x	$=2.00 - \mathrm{O/M}$ (i.e., oxygen-to-metal ratio)
a	$=1.1599$
gad	gadolinia weight fraction
T	temperature, K
Bu	burnup in GWd/tHM
$f(\mathrm{Bu})$	effect of fission products in crystal matrix (solution)
	$= 0.00187 \cdot \mathrm{Bu}$
$g(\mathrm{Bu})$	effect of irradiation defects
	$= 0.038 \cdot \mathrm{Bu}^{0.28}$
$h(\mathrm{T})$	temperature dependence of annealing on irradiation defects
	$= \dfrac{1}{1 + 396e^{-Q/T}}$
Q	temperature dependence parameter ("Q/R") $= 6380\mathrm{K}$
$A(x)$	$= 2.85x + 0.035\ \mathrm{m \cdot K/W}$
$B(x)$	$= (2.86 - 7.15x) \times 10^{-4}\ \mathrm{m \cdot K/W/K}$
E	$= 1.5 \times 10^{9}\ \mathrm{W \cdot K/m}$
F	$= 13520\mathrm{K}$

D.5 Thermal Conductivity Measurements

Table D.4: Thermal Conductivity Measurements of UO_2 by Gibby (from [46])

T (K)	k (W/m·K)
575	6.24
578	6.36
586	6.28
587	5.87
588	5.63
665	5.12
675	5.20
679	5.31
690	5.12
846	4.30
846	4.40
852	4.53
853	4.65
865	4.30
865	4.40
893	4.29
908	4.29
907	4.20
964	3.84
964	3.92
969	4.02
969	5.12
1000	3.70

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T (K)	k (W/m · K)
1031	3.94
1031	3.84
1071	3.66
1080	3.47
1204	3.55
1204	3.55
1280	3.24
1288	3.34
1288	3.13
1289	2.99
1323	3.01
1335	2.90
1384	2.92
1390	2.80
1395	2.70
1399	2.80
1412	2.95

Table D.5
Thermal Conductivity Measurements of UO_2 by Hobson (from [52])

T (K)	k (W/m · K)
547	5.76
607	5.41
642	5.33
732	4.96
788	4.63
834	4.45
885	4.26
944	4.13
995	4.01
1046	3.86
1083	3.75
1133	3.62
1150	3.51
1175	3.53
1279	3.23
1330	3.15
1392	3.04
1449	2.97

APPENDIX E

THERMAL CONDUCTIVITY SENSITIVITY STUDIES

The material discussed herein provides supporting information for Section 4. The results from a sensitivity study on the effects of the oxygen-to-metal ratio and theoretical density parameters in the FRAPCON MOX thermal conductivity model to VIPRE maximum fuel centerline temperatures are reported within this appendix. The general observations from this study are as follows:

1. Induced variations in the fuel oxygen-to-metal ratio and theoretical density within the FRAPCON MOX thermal conductivity model have essentially no effect on the fluid flow solution in VIPRE
2. Variations only affect the heat transfer solution in `nuclear` fuel rods
3. Cladding temperatures are generally unaffected by the selected oxygen-to-metal ratio and theoretical density values
4. The VIPRE heat transfer solution has a strong dependence on the oxygen-to-metal ratio and theoretical density

Sensitivity studies for the fuel oxygen-to-metal ratio and theoretical density are conducted by selecting multiple points over a range of interest for each parameter. At each point within the selected range, several VIPRE steady-state calculations are performed while inducing small variations in the parameter of interest about the selected data point while maintaining all other parameters at a constant value. The percentage of induced variations about a selected data point and the resulting changes in the VIPRE steady-state maximum fuel centerline temperatures are recorded.

The sensitivity of VIPRE calculations to the parameter of interest at each selected data point is defined as the percent change in the maximum fuel temperature divided by the percent change in the parameter of interest. A sensitivity value of 1 represents a one-to-one (‘strong’) relationship between the VIPRE results and the parameter of interest. Sensitivity values less than 1, but still close to 1, indicate a fairly strong relationship between VIPRE results and the parameter of interest, with large changes in the selected parameter resulting in relatively smaller changes in the maximum fuel centerline temperatures. Sensitivity values greater than 1 or much closer to 0 represent very strong and negligible relationships, respectively, to the selected parameter for VIPRE results.

PWR fuel pellets are fabricated with an initial oxygen-to-metal ratio of 2.00. After burnup effects begin to take place, the fuel becomes hyperstoichiometric with oxygen migrating and diffusing in the fuel matrix due to steep temperature gradients within the fuel pellet, and due to the presence of added free oxygen as a result of uranium fissioning within a UO_2 molecule. The hyperstoichiometric oxygen-to-metal ratio decreases the thermal conductivity of the fuel and causes maximum fuel temperatures to increase. The sensitivity of VIPRE maximum fuel centerline temperature calculations to the oxygen-to-metal ratio as it is varied from 1.95 to 2.05 is shown in Figure E.1.

As can be seen from Figure E.1, there is a very strong relationship between

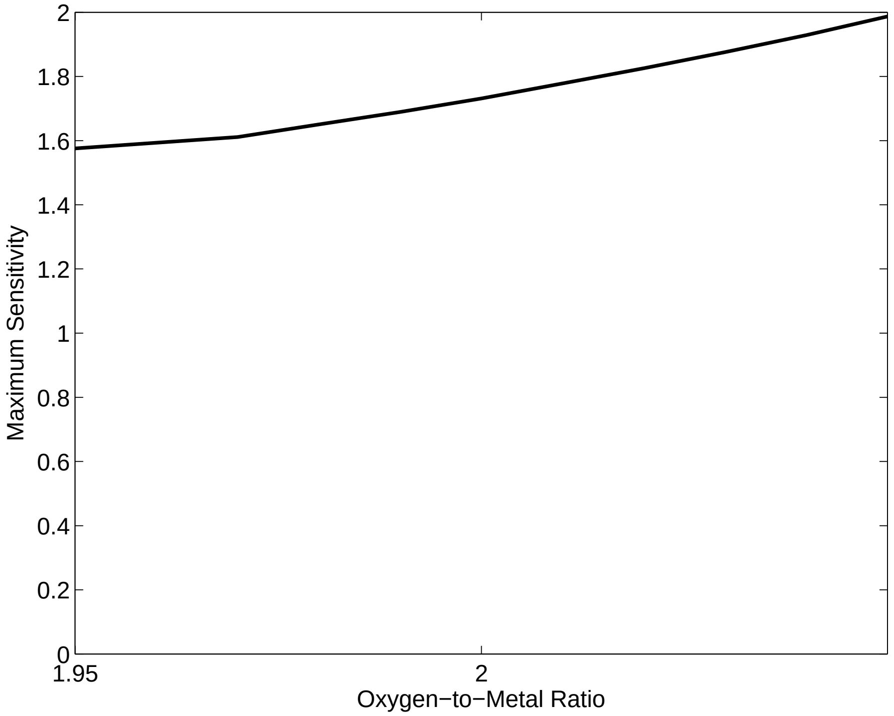

Figure E.1. VIPRE Fuel temperature stoichiometry sensitivity the oxygen-to-metal ratio and VIPRE maximum fuel centerline temperatures. While the initial oxygen-to-metal ratio is a set parameter from the fabrication process and is assumed constant for the neutronic calculations that drive the thermal-hydraulic analyses within this thesis, the oxygen-to-metal ratio will increase over time due to irradiation, burnup, and temperature effects. The FRAPCON MOX thermal conductivity model has stoichiometry and burnup dependencies; however, it does not take into account changes in stoichiometry once the fuel has undergone irradiation and thermal annealing. At extremely high temperatures below the melting point of UO2, the fuel's hyperstoichiometry can be as high as $UO_{2.25}$. Considering VIPRE's strong dependence on the oxygen-to-metal ratio, a great deal of care must be exercised in selecting appropriate fuel stoichiometric values in future research where the effect of burnup on the fuel oxygen-to-metal ratio is modeled.

Fuel pellets are fabricated with an initial theoretical density. The initial theoretical density value is selected to provide cavities within the pellet which collect fission product gases and minimize the effects of fuel swelling and densification that occur after the first few days of full power operation. A typical initial theoretical density value for PWR fuel is approximately 95%. For the sensitivity study the theoretical density was varied from 90% to 100%. The sensitivity of VIPRE maximum fuel centerline temperatures to the fuel pellet theoretical density is plotted in Figure E.2.

Figure E.2 shows that VIPRE maximum fuel centerline temperatures have a fairly strong dependence on the fuel pellet theoretical density. As the theoretical density is increased, the thermal conductivity increases which reduces the fuel temperature in the core. While the results indicate that the VIPRE heat transfer solution is fairly sensitive to the fuel pellet theoretical density, within this thesis the initial pellet theoretical density is set at the beginning of each fuel assembly analysis by the neutronic analysts for burnup-dependent neutronic calculations. For higher discharge burnup levels, the initial theoretical density can be altered in order to provide better fuel performance by providing more space within the pellet to accommodate higher concentrations of fission product gases.

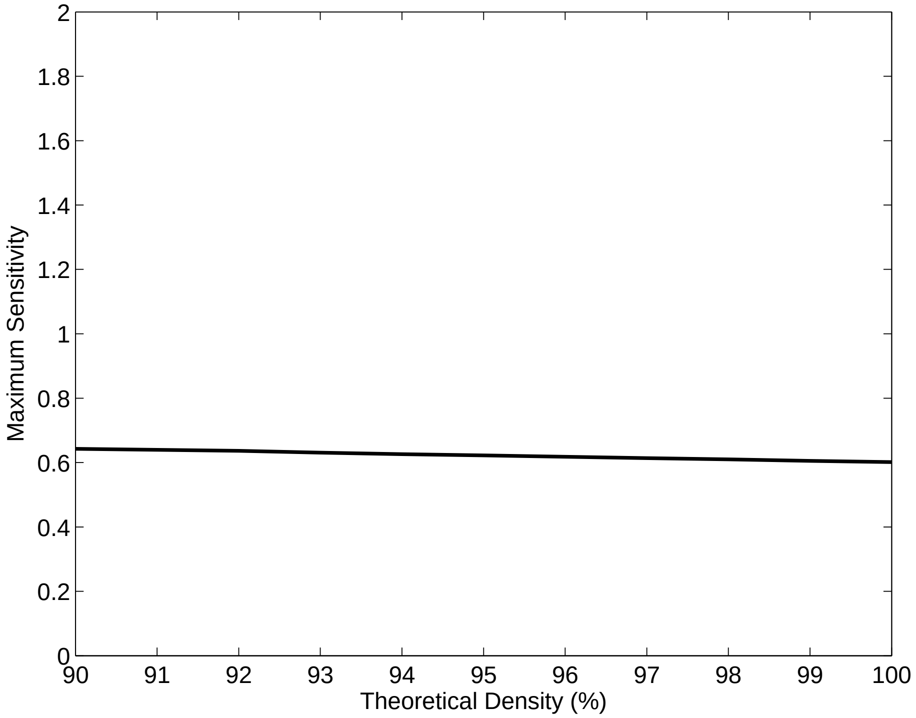

Figure E.2. VIPRE Fuel temperature theoretical density sensitivity

VITA

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