# OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
# CALCULATION COVER SHEET

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Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package

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# 1. PURPOSE

The purpose of this calculation is to evaluate the transient behavior and consequences of a worst-case criticality event involving intact pressurized water reactor (PWR) mixed-oxide (MOX) spent nuclear fuel (SNF) in a degraded basket configuration inside a 21 PWR waste package (WP). This calculation will provide information necessary for demonstrating that the consequences of a worst-case criticality event involving intact PWR MOX SNF are insignificant in their effect on the overall radioisotopic inventory and on the integrity of the repository. This calculation includes results obtained by maximizing postulated rates of reactivity insertion to assure no synergistic reactions could occur among waste packages from hypothetical criticality events. Another variable, potentially influencing the criticality consequences, is the exit area of the leakage path(s) from the WP. If the leakage area through the WP is sufficiently small, inflow rates will be restricted, lengthening the time required for flooding the WP and thus delaying potential criticality events, which require flooded conditions. However, if a criticality event does occur, a limited leakage area will reduce the exit flow volume. The immediate effect on the system from a limited leakage area is to reduce the negative reactivity effect of voiding the WP because the water/vapor escape rate may be lowered. This, in turn, leads to higher heat output, higher internal pressure, and higher temperatures. The higher pressure and density of the water vapor will increase the mass flow out of the WP, so that eventually the negative reactivity from voiding the system becomes dominant, and the criticality event shuts down.

This calculation was performed under the AP-3.12Q Revision 0, ICN 0 Procedure and will support WP design and analysis activities.

# 2. METHOD

## 2.1. TIME-DEPENDENT METHODS

The method for analyzing transient criticality consequences involving intact PWR SNF in a degraded WP has been documented previously (Ref. 1). The same methodology was followed for calculations to determine the criticality consequences of PWR MOX SNF in a degraded WP. The analysis deck (Case: r5wp2d.c103c) from the initial consequence analysis (Ref. 1, Attachment IV) was used as the basis for this calculation with the fuel element parameters adjusted for the MOX fuel assemblies. This file is included in the electronic data files on a compact disk (CD) (Ref. 7). The light water reactor (LWR) transient analysis code, RELAP5/MOD3.2 (Ref. 2) was used to calculate the time evolution of the power level and other characteristics of a criticality event involving PWR MOX SNF.

The simulated criticality event is driven by a linear rate of reactivity insertion until a maximum reactivity of 14.18 $ is reached (Ref. 1, Section 7); the reactivity is held constant thereafter. The 14.18-$ reactivity value was derived from the low-enriched uranium (LEU) SNF WP reactivity change between a homogeneous and settled distribution of $Fe_2O_3$ (hematite) (Refs. 1 and 21), and used in this calculation to maintain a consistent basis for purposes of comparison. The calculation was performed for time scales corresponding to a rapid reactivity insertion rate of

0.158 $/s and a much slower rate of 0.0004 $/s. The rapid reactivity insertion rate was derived from the time required (≅ 90 seconds) for a spherical particle of $Fe_2O_3$ to fall one meter in water at a Reynolds number of ≅ 1.0 (Ref. 1, Attachment III), hence the value 0.158 $/s = 14.18 $/90s. This time provides an upper bound on the rate at which the reactivity in the WP can be increased through absorber redistribution. The low reactivity insertion rate approximates a more likely gradual shift in conditions conducive to criticality. One possible mechanism is a sudden increase in the flow rate into the WP, which could cover all the assemblies in approximately 10 hours, starting from a partially covered (30%-35%) condition for the top fuel assemblies, corresponding to the 14.18 $ total reactivity addition.

Reactivity tables based on changes in the effective neutron multiplication factor ($k_{eff}$) from a baseline configuration must be included in the RELAP5/MOD3.2 input data file. The Monte Carlo N-Particle computer code, MCNP4B2 (Ref. 3), is used to calculate a baseline $k_{eff}$ for criticality safety evaluations and to determine the change in reactivity from one configuration to another. MCNP4B2 does not have an associated cross-section library with sufficient temperature-dependent data to calculate the reactivity changes associated with the fuel and moderator temperature changes required for this calculation. SCALE4.3 and its SAS2H sequence do have the necessary cross sections. SAS2H employs a one-dimensional (1-D) assembly-cell discrete-ordinates technique (XSDRNPM) for calculation of the $k_{eff}$ for a configuration. A correction for finite dimensions can be made using various buckling terms. Initially, infinite MCNP4B2 cases were run with which to compare the results from infinite SAS2H cases to develop the appropriate SAS2H data file to match MCNP4B2 results. Corrections were then made to the SAS2H input file to account for finite dimensions using the appropriate buckling terms based on the baseline MCNP4B2 finite case. The resulting SAS2H input data file incorporating the buckling terms is then used for calculating temperature and density reactivity effects. The reactivity changes calculated by MCNP4B2 and SAS2H are used as input to RELAP5/MOD3.2 to evaluate the transient behavior of a criticality event.

## 2.2. STEADY-STATE METHODS

A low reactivity insertion rate approximates a more likely gradual shift in conditions conducive to criticality. Consequences of low reactivity addition rates are calculated by two different methods, one using the transient criticality consequence methodology (RELAP5/MOD3.2) with a low reactivity addition rate of 0.0004 $/s and the second from a steady-state equilibrium condition. This section describes the computational method used for a steady-state event.

If a WP reaches a $k_{eff}$ of 1 through a gradual process, continued small positive reactivity insertions will cause the power output of the WP to begin rising slowly (i.e., a long reactor period). If the power exceeds a certain limit, the rate at which water is subsequently removed from the WP will exceed the rate of input, and the resulting water level drop will provide a negative reactivity insertion driving the WP back towards a subcritical condition. Conversely, if insufficient power is produced, the water level will be maintained and the processes contributing to the reactivity will continue, thus providing a continued source of positive reactivity insertions until the point of equilibrium is achieved. The maximum steady-state power for such a scenario can be estimated by determining the power required to maintain the WP bulk water temperature at the point where water is removed at the same rate that it drips into the WP. The WP must produce sufficient power to raise the temperature of the incoming water to this equilibrium value, as well as account for heat losses to the environment by radiation and/or conduction.

Unqualified (existing) data were used as input for this calculation and the RELAP5/MOD3.2 basis data file is unqualified data per AP-SIII.2Q.

## 3. ASSUMPTIONS

The following assumptions were used in the reactivity consequence calculation:

3.1 It is assumed that the reactivity feedback mechanism for the point kinetics calculation can be represented by separable effects. The bases for this assumption are as follows:

(1) Doppler reactivity depends upon intrinsic fuel parameters with temperature being the only time-dependent variable.

(2) Moderator reactivity effects depend only upon the fluid density.

(3) No soluble poisons are included.

(4) The settled iron oxide residue is not redistributed in the WP.

This assumption is used throughout Section 5.2.

3.2 The WP is assumed to be filled with water at the start of the postulated reactivity-driven scenarios. The basis for this assumption is that it is conservative and is an assumption in a previous probabilistic analyses (Ref. 20, p. 17). This assumption is used throughout Section 5.

3.3 Thermal properties of MOX fuel pellets are assumed to be similar to LEU fuel pellets. The basis for this assumption is that the pellets are ~ 95 wt% $UO_2$ (Ref. 5, p. 18). This assumption is used throughout Section 5.4.

3.4 It is assumed that the $Fe_2O_3$ in the WP from degradation of internal components can be neglected for hydraulic calculations. The basis for this assumption is that it is conservative since it results in a larger water inventory in the WP. This assumption is used throughout Section 5.4.

3.5 It is assumed that the pure water region (above the settled iron oxide region in the WP) is the principal contributor to reflector effects. The basis for this assumption is the much greater importance (more than twice) of the pure water region contribution to the combined $k_{eff}$. This assumption is used in Section 5.2.

3.6 It is assumed for the reactivity calculations that the instrument tube can be replaced with a guide tube. The basis for this assumption is that the SAS2H Path-B geometry is based on the fuel pin-to-water rod ratio and that the fuel assemblies have 24 guide tubes versus one instrument tube. This assumption is used in Section 5.1.

# 4. USE OF COMPUTER SOFTWARE AND MODELS

## 4.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE (QA) WORK

### 4.1.1 RELAP5/MOD3.2

The transient simulation of criticality events is performed using the transient thermal-hydraulic code RELAP5/MOD3.2 (Refs. 2 and 25-30). RELAP5/MOD3.2 was developed for the U.S. Nuclear Regulatory Commission for simulations of operational transients in PWR systems such as loss of coolant. The transient criticality events involving PWR SNF within a WP are similar to the situations for which RELAP5/MOD3.2 was developed to analyze. The software specifications are as follows:

- Software name: RELAP5/MOD3.2
- Software version/revision number: Version V1.0
- Software activity number: LV-1999-047
- Software tracking number: 10091-1.0-00
- Software media number: 10091-MED-1.0-00
- Computer type: Hewlett Packard (HP) 9000 Series Workstations

The RELAP5/MOD3.2 software used is: (a) appropriate for the application of WP transient criticality consequence calculations, (b) used within the range of the software validation, and (c) obtained from the Software Configuration Secretariat in accordance with appropriate procedures.

### 4.1.2 MCNP

The MCNP code (Ref. 3) was used to calculate the $k_{eff}$ of the MOX PWR SNF WP. The software specifications are as follows:

- Software name: MCNP
- Software version/revision number: Version 4B2
- Software tracking number: 30033 V4B2LV
- Computer type: HP 9000 Series Workstations

The MCNP software used is: (a) appropriate for the application of WP $k_{eff}$ calculations, (b) used only within the range of validation, and (c) obtained from the Software Configuration Manager in accordance with appropriate procedures.

### 4.1.3 SCALE

The SAS2H module of the SCALE modular code (Ref. 6) was used to calculate the reactivity values for the PWR MOX SNF assemblies. The software specifications are as follows:

- Software name: SCALE/SAS2H
- Software version/revision number: Version 4.3
- Software tracking number: 30011 V4.3
- Computer type: HP 9000 Series Workstations

The SCALE software used is: (a) appropriate for the application of WP reactivity calculations, (b) used only within the range of validation, and (c) obtained from the Software Configuration Manager in accordance with appropriate procedures.

## 4.2 SOFTWARE ROUTINES

### 4.2.1 Excel

The Excel spreadsheet program was used to generate graphical representations of various parameters calculated by RELAP5/MOD3.2 and to identify maximum values. No additional calculations were performed on the data files. The software specifications are as follows:

- Software name: Excel
- Software version/revision number: 97
- Computer type: Personal Computer (PC).

### 4.2.2 Strip

The RELAP5/MOD3.2 program writes two files as output as follows:

(1) A formatted print file containing "major edits" at specified times

(2) A binary "restart" file to enable a case to resume.

The RELAP5/MOD3.2 code also has an option to collect minor edits (a history of particular variables) at each time point from the restart file and put them into a formatted strip file. The FORTRAN-90 program, "Strip", reads a RELAP5/MOD3.2 strip file and writes the information in a series of more compact files for use in later calculation. The output of the code can be readily checked against the strip files by visual inspection. The source code with sample input and output files are included in Attachment II. The source and executable files are included as part of the electronic data on a CD (Ref. 7). The software specifications are as follows:

- Software name: Strip
- Software version/revision number: V00
- Computer type: PC.

## 4.3 MODELS

There were no models used in this calculation.

# 5. CALCULATION

As stated in Section 1, the purpose of this calculation is to evaluate the transient behavior and consequences of a worst-case criticality event involving intact PWR MOX SNF in a degraded basket configuration inside a 21 PWR WP. The calculation was performed for hypothetical criticality events where a reactivity insertion rate of 0.158 $/s was used to approximate the maximum rate of change in the available reactivity due to absorber redistribution within the WP. A much slower insertion rate of 0.0004 $/s and a steady-state condition were used to approximate a gradual shift in the system reactivity. Additionally, this calculation investigated the relationship between reduction in the leakage area and possible increases in peak pressures and temperatures for such hypothetical criticality events.

The basic RELAP5/MOD3.2 data file from the initial consequence analysis (Ref. 1, Attachment IV) was used as a basis for this calculation. The input deck was modified for the use of MOX SNF in place of low enriched uranium (LEU) SNF and is listed in Attachment IV of this document. These sections included the reactivity feedback tables, fluid volume dimensions, junction areas, and heat conductor dimensions. The area of the junction exiting the WP was varied for the sensitivity calculation.

## 5.1 DESIGN PARAMETERS

### 5.1.1 Spent Fuel Assembly Parameters

The fuel assembly upon which this calculation is based is the Westinghouse Vantage 5 17x17 assembly (Ref. 8, Section 5.1). Design parameters for calculating input data for the SAS2H cases of MOX SNF assemblies are given in this section. The reactivity coefficient data are developed in Section 5.2, the steady-state description in Section 5.3, and the RELAP5 WP description in Section 5.4.

### 5.1.2 MOX Assembly Design Parameters

The MOX Westinghouse Vantage 5 PWR assembly parameters are given in Table 5.1.2-1 (Ref. 9, pp. 2A-355 through 2A-358 and Ref. 10, p. 37). Assembly dimensions are given primarily in English units and converted into metric units. The number of digits in the corresponding metric value column results from the units conversion and is not indicative of precision. The zero-burnup density of the 4.0 wt% heavy metal (HM) fissile Pu MOX is 10.28 $g/cm^3$ (Ref. 8, p. 14). The initial heavy metal isotopic content of the Westinghouse Vantage 5 assembly fuel is given in Table 5.1.2-2 (Ref. 5, p. 17).

Table 5.1.2-1. Mechanical Parameters for Westinghouse 17x17 Fuel Assemblies

| Parameter | Vantage 5 Assembly | |
|---|---|---|
| | **Value in Metric Units** | **Value in English Units** |
| Fuel Rods/Assembly | 264 | N/A[1] |
| Fuel Assembly Width | 21.4172 cm | 8.432 in. |
| Cladding Material | Zirc-4 | N/A |
| Cladding Outside Diameter (OD) | 0.9144 cm | 0.360 in. |
| Cladding Thickness | 0.05715 cm | 0.0225 in. |
| Fuel Pellet OD | 0.784352 cm | 0.3088 in. |
| Fuel Length | 365.76 cm | 144 in. |
| Pitch | 1.25984 cm | 0.496 in. |
| Guide Tube Material | Zirc-4 | N/A |
| Guide Tube OD[2] | 1.22428 cm | 0.482 in. |
| Guide Tube Inside Diameter (ID) | 1.143 cm | 0.45 in. |
| Number of Guide Tubes | 24 | N/A |
| Instrument Tube OD[3] | 1.22428 cm | 0.482 in. |
| Instrument Tube ID | 1.143 cm | 0.45 in. |
| Number of Instrument Tubes | 1 | N/A |

[1] Not Applicable.
[2] Guide tube dimensions are from Westinghouse Standard 17x17 assemblies.
[3] Assumption 3.6.

Table 5.1.2-2. Initial Heavy Metal Isotopic Content of Fuel Assemblies

| Isotopes | Isotopic Mass (g/mole) | 1996 Design for Vantage 5 Assemblies |
|---|---|---|
| **Uranium** | | **(wt% of U)** |
| U234 | 234.040904 | 0.002 |
| U235 | 235.043915 | 0.200 |
| U236 | 236.045637 | 0.001 |
| U238 | 238.05077 | 99.797 |
| **Plutonium** | | **(wt% of Pu)** |
| Pu238 | 238.049511 | 0.000 |
| Pu239 | 239.052146 | 93.600 |
| Pu240 | 240.053882 | 5.900 |
| Pu241 | 241.056737 | 0.400 |
| Pu242 | 242.058725 | 0.100 |

### 5.1.3 Intact Waste Package Geometry Parameters

The intact WP geometry parameters used in this calculation were unchanged from the LEU reactivity consequence analysis (Ref. 1, Table 4.1-2) which was based on the 21 PWR uncannistered fuel (UCF) WP design (Ref. 24, p. I-17). These parameters are used in the MCNP V4B2LV calculations and in the geometric input data for RELAP5/MOD3.2.

### 5.1.4 Material Properties

The atom densities for the PWR MOX SNF are taken from a previous SAS2H/ORIGEN-S calculation (Ref. 11, Case w3_35-5gwd_2cy-6stps) of assembly burnup to 35.6 GWd/MTHM (gigawatt-days/metric ton heavy metal). The ORIGEN-S isotopic distribution at 25,000 years decay time is the reference condition on which reactivity calculations are made and the RELAP5 reactivity tables developed. The isotopic concentration and number density for the nuclides important for criticality are listed in Table 5.1.4-1. The input for this case is included in Attachment III.

Table 5.1.4-1. Atom Densities for 4.0 wt% HM Fissile Pu Westinghouse 17x17 MOX SNF with 35.6 GWd/MTHM Burnup and 25,000 Years Decay Time

| Isotopic ID | MCNP4B2 Nuclide ID | Number Density (atoms/bn⋅cm) | Isotopic Concentration (g/assembly) |
|---|---|---|---|
| U233 | 92233.50C | 8.308600E-07 | 1.50E+01 |
| U234 | 92234.50C | 3.386430E-06 | 6.14E+01 |
| U235 | 92235.50C | 2.169270E-04 | 3.95E+03 |
| U236 | 92236.50C | 1.848360E-04 | 3.38E+03 |
| U238 | 92238.50C | 2.136450E-02 | 3.94E+05 |
| Np237 | 93237.55C | 1.105420E-04 | 2.03E+03 |
| Pu239 | 94239.55C | 1.868310E-04 | 3.46E+03 |
| Pu240 | 94240.50C | 1.381940E-05 | 2.57E+02 |
| Pu241 | 94241.50C | 2.099100E-11 | 3.92E-04 |
| Pu242 | 94242.50C | 2.490360E-05 | 4.67E+02 |
| Am241 | 95241.50C | 6.586460E-10 | 1.23E-02 |
| Am243 | 95243.50C | 5.576220E-07 | 1.05E+01 |
| O16 | 8016.50C | 5.003520E-02 | 6.20E+04 |
| Mo95 | 42095.50C | 3.876310E-05 | 2.85E+02 |
| Tc99 | 43099.50C | 4.254610E-05 | 3.26E+02 |
| Ru101 | 44101.50C | 4.720380E-05 | 3.69E+02 |
| Rh103 | 45103.50C | 4.214700E-05 | 3.36E+02 |
| Ag109 | 47109.50C | 1.040670E-05 | 8.78E+01 |
| Nd143 | 60143.50C | 3.224570E-05 | 3.57E+02 |
| Nd145 | 60145.50C | 2.342700E-05 | 2.63E+02 |
| Sm147 | 62147.50C | 1.001630E-05 | 1.14E+02 |
| Sm149 | 62149.50C | 1.898300E-07 | 2.19E+00 |
| Sm150 | 62150.50C | 1.291530E-05 | 1.50E+02 |
| Sm152 | 62152.50C | 6.372550E-06 | 7.50E+01 |
| Eu151 | 63151.50C | 1.197420E-06 | 1.40E+01 |
| Eu153 | 63153.50C | 5.824350E-06 | 6.90E+01 |
| Gd155 | 64155.50C | 2.891220E-07 | 3.47E+00 |

### 5.1.5 Neutronic Data Description

The Westinghouse Vantage 5 assemblies have 24 guide tubes and one instrument tube per assembly (Table 5.1-2). The SAS2H Path-B representation of the assembly (Ref. 7, Spreadsheet MOX_96_sas2h.xls, Sheet "Path-B geom") incorporates a water-filled guide tube at the center, water (plus $Fe_2O_3$ as required), and a fuel mixture having an area scaled to the number of fuel pins per guide tube ((289-25)/25 = 10.56). This was increased to ~ 11 pins/guide tube since the guide tubes are not uniformly distributed over the assembly cross section. The Path-B dimensions and compositions are given in Table 5.1.5-1.

Table 5.1.5-1. SAS2H Path-B Parameters

| Composition | Outside Radius (cm) | Area ($cm^2$) |
|---|---|---|
| 5 (water) | 0.57150 | 1.02610 |
| 4 (Zirc-4) | 0.61214 | 0.15112 |
| 3 (water $Fe_2O_3$) | 0.71079 | 0.40999 |
| 500 (fuel) | 2.4665 | 12.0415 |

Kinetics parameters required for the RELAP5 calculation are given in Table 5.1.5-2.

Table 5.1.5-2. RELAP5 MOX Kinetics Parameters

| Parameter | Value | |
|---|---|---|
| End-of-Life (EOL) Effective Delayed Neutron Fraction[1] - β | 0.00371 | |
| EOL Prompt Neutron Lifetime[1] - Λ (s) | 9.58e-06 | |
| β/Λ -(1/s) | 387.3 | |
| **Delayed Neutron Group[2]** | **Relative Yield** | **Decay Constant** |
| 1 | 0.038 | 0.0129 |
| 2 | 0.280 | 0.0311 |
| 3 | 0.216 | 0.1336 |
| 4 | 0.328 | 0.33165 |
| 5 | 0.103 | 1.2626 |
| 6 | 0.035 | 3.2090 |

[1] (Ref. 5, p. 24).
[2] (Ref. 23, p. 64).

## 5.2 NEUTRONICS CALCULATIONS AND REACTIVITY COEFFICIENTS

The effects on reactivity due to changes in the system are shown to be separable into leakage effects and material effects in this section. Leakage effects are primarily dependent on boundary conditions, such as water level in the WP, and must be calculated using finite WP representations. Material effects such as changes to fuel temperature, moderator temperature, or moderator density are primarily localized and can be approximated using infinite-assembly representations with a constant buckling (leakage) term.

Reactivity is defined as in the commercial LEU reactivity consequence analysis (Ref. 1, p. 18):

$$\boldsymbol{r} = \frac{k_{eff} - 1.0}{k_{eff}}$$

and a change in reactivity (Δρ) was defined as:

$$\Delta\rho = \rho_{Change} - \rho_{Base} = \frac{1}{k_{eff\ -Base}} - \frac{1}{k_{eff\ -Change}}$$

Thus, a positive reactivity change results when $\rho_{Change}$ is greater than $\rho_{Base}$. In the RELAP5/MOD3.2 input, $\rho$ and $\Delta\rho$ are noted in terms of dollars ($) which is defined as:

$$\rho(\$) = \frac{\rho}{\beta_{eff}} \quad and \quad \Delta\rho(\$) = \frac{\Delta\rho}{\beta_{eff}}$$

where

$\beta_{eff}$ is the effective delayed neutron fraction.

### 5.2.1 Reactivity Effect of Temperature and Density Changes

MCNP V4B2LV does not have an associated cross-section library with sufficient temperature-dependant data to calculate the reactivity changes required for this calculation. SCALE4.3 and its SAS2H sequence do have the necessary cross sections. SAS2H employs a 1-D assembly-cell discrete-ordinates technique (XSDRNPM) for calculation of the $k_{eff}$ for a configuration. A correction for finite dimensions can be made through use of buckling (leakage) correction terms. Initially, MCNP cases (infinite through use of reflective boundary conditions) were run with which to compare the results from SAS2H cases (also infinite) in order to develop the appropriate SAS2H representation to match MCNP results. Corrections were then made to the SAS2H representation to account for finite dimensions using the appropriate buckling terms for inclusion in the SAS2H representations determined by comparisons with the finite baseline MCNP cases. The resulting SAS2H representation incorporating the buckling terms is then used for calculating temperature and density reactivity effects.

### 5.2.2 SAS2H Setup and Reactivity Feedback Development

The equation for the buckling (*B*) in the XSDRNPM-S computer software portion of the SAS2H code system is as follows (Ref. 12, Vol. 2, pp. F3.2.24-25):

$$B^2 = \left(\frac{\pi}{Axial\ length + f\ (0.710446)\ \lambda_m}\right)^2 + \left(\frac{\pi}{Radial\ length + f\ (0.710446)\ \lambda_m}\right)^2$$

The above equation for the buckling of the three-dimensional WP representations is based on the separability of the geometrical configuration into an axial coordinate and radial plane. The reflector effects are treated by the term:

$$\text{Reflector Effects} = f\ (0.710446)\ \lambda_m$$

where $f$ is a factor greater or equal to 0.0 and $\lambda_m$ is the effective neutron mean free path in the reflector region. The neutron mean free path is determined by the XSDRNPM internal calculations from the properties of the fuel region. The product of $f$ and 0.710446 is a constant input to the SAS2H representation to give the reflector effects indicated by the MCNP results. To determine the appropriate reflector effects constant ( $f$ ( 0.710446), MCNP representations of the WP are evaluated. The $k_{eff}$ values from MCNP and the $k_4$ values from the SAS2H representations are used to determine the SAS2H buckling values. The buckling values are then used to determine the constant, $f$ ( 0.710446. This process is performed iteratively with the SAS2H representation because the analytic solution of the equation involves multiple unknowns.

The separation of the independent neutron variables into an infinite assembly cell coupled with a buckling correction is assessed by first benchmarking the SAS2H infinite (4) representation (buckling = 0.0) with three MCNP $k_4$ results. The MCNP $k_4$ represents a fuel region with complete reflection on all finite surfaces. The complete reflection of the MCNP fuel representation represents a buckling of 0.0 and a $k_{eff}$ equal to $k_4$.

The base finite MCNP representation represents Westinghouse 17x17 fuel assemblies, 4.0 wt% HM fissile Pu, 35.6 GWd/MTHM burnup, and 25,000 years of isotopic decay. In the degraded state, for a WP that has been breached by water and that has 58% iron oxide by volume settled in the bottom of it, the MCNP $k_{eff}$ is 0.8659 " 0.0058 ("2σ) (Ref. 13, Table 6.2-2).

This MCNP representation has two separate fuel regions: (1) the upper region of fuel in the WP that has no iron oxide in the water, and (2) the lower region of fuel in the WP that has 58% iron oxide by volume in the water. To be consistent, the SAS2H infinite representation must be able to calculate the same $k_4$ as MCNP (within a small deviation) for each independent fuel region. Note that the MCNP results are reported "2σ (~ 95% confidence interval). Filenames for cases (output included on a data CD [Ref. 7]) are reported in parenthesis beside or below the case results.

| | MCNP-$k_4$ | SAS2H-$k_4$ | $\Delta r$ Difference |
|---|---|---|---|
| No Iron | 1.06583 " 0.00086 (infh2o.mox.inp) | 1.06732 (out.e49.mox1d.inp) | +0.00148 |
| Iron | 0.79878 " 0.00080 (infox.mox.inp) | 0.799214 (out.fe.mox1f.inp) | +0.00068 |

The above results show that the reactivity change between SAS2H and the MCNP reference $k_4$ is between 15/10,000 and 7/10,000. This difference is sufficiently small and indicates that results from the SAS2H representation is in good agreement with the MCNP representation. A comparison of the SAS2H input with the MCNP input shows that the SAS2H pin cell and assembly cell have the same geometrical and material characteristics as the MCNP pin and assembly lattice arrays.

The third SAS2H $k_4$ evaluation in comparison to MCNP was used to determine the SAS2H neutron flux and volume weighting of the upper fuel region with pure water and the lower fuel region with 58% iron oxide in water. The MCNP representation used a square array of 16 fuel assemblies (4 by 4) with 12 containing 58% iron oxide by volume in water and 4 containing pure water. This volume fraction of 0.25 pure water and 0.75 iron oxide in water is representative of the volume fraction of the 58% settled iron oxide in water representation of the degraded WP. The weighting of upper and lower regions was defined as follows:

$k_4$ (MCNP) - $\Delta r$ bias = (x) $k_4$ (SAS2H pure water) + (1 - x) $k_4$ (SAS2H 58% iron oxide by volume in water).

The x is the combined flux and volume weighting factor, and the $\Delta r$ bias is defined by the $\Delta r$ difference in the table of iron and no-iron $k_4$ values. The parameters for the above equation are:

$k_4$ (MCNP) = 0.99575 " 0.00096 (influx2.mox1a.inp)
$\Delta r$ bias = 0.00072
$k_4$ (SAS2H pure water) = 1.06710 (out.e49.mox1d.inp)
$k_4$ (SAS2H 58% iron oxide in water) = 0.799214 (out.fe.mox1f.inp)
x = 0.730

This value of x is used in the final calculation (out.wp.mox.inp) as a weighting factor for the fraction of water in the moderator and (1-x) is the weighting factor for the fraction of 58% iron oxide by volume/water mix in the moderator.

The comparison of MCNP and SAS2H results are shown in the following table:

| | MCNP-$k_4$ | SAS2H-$k_4$ | $\Delta r$ Difference |
|---|---|---|---|
| Infinite Waste Package | 0.99575 " 0.00096 (influx2.mox1a.inp) | 0.996098 (wpi.mox1a.inp) | 0.00035 |

**Axial Leakage Correction**–The SAS2H axial buckling equation for the degraded WP is as follows (Ref. 12, Vol. 2, pp. F3.2.24-25):

$$B_{Axial}\,(SAS2H) = \frac{\pi}{Axial\ length + f\,(0.710446)\,\lambda_m}$$

with the assumption that the axial coordinate and radial plane may be separated by a constant buckling eigenvalue. The infinite-cell SAS2H-$k_4$ results for the pure water in the upper region of the degraded WP and the $k_4$ results for the 58% iron oxide by volume in water in the lower region of the degraded WP indicated that the SAS2H separability is valid. The flux-volume weighting of the upper and lower regions indicated that the importance of the upper region relative to the lower region is a factor greater than 2 to 1. Therefore, the pure-water upper region was used to establish the constants for the theoretical reflector effects.

The pure-water axial representation of the degraded WP was computed with MCNP and SAS2H. The MCNP case used reflective radial boundary conditions on the radial surfaces of the fuel. Thus, the boundary conditions represented an infinite radial case. The MCNP axial description however represented the appropriate geometry and compositions in the degraded WP with appropriate boundary conditions at the end of the WP outer metal surfaces. The SAS2H case used a radial buckling of zero ( $B_{Radial} = 0.0$ ) to represent an infinite radial description. The SAS2H axial description represented the axial fuel length as 365.76 cm. The solution of the reflector effects constant, ( $f$ ( 0.710446 ), was iterative. However, the theoretical solution of $f$ = 2 gave a reasonable comparison between the MCNP- and SAS2H-$k_{eff}$ results as shown below:

$$\text{Reflector Effects Axial Constant} = f * 0.710446 = 1.420892$$

$$f = 2$$

| | MCNP - $k_{eff}$ | SAS2H - $k_{eff}$ | $\Delta\rho$ Difference |
|---|---|---|---|
| Waste Package | 1.06300 $\pm$ 0.00092 | 1.06489 | 0.0017 |
| | (infh2oa.mox.inp) | (out.fin.mox.inp) | |

**Radial Leakage Correction**–In the 1-D SAS2H cases, the leakage from the SNF configuration may be represented with either a cylindrical or rectangular geometry. Both options are investigated to identify the better one. There are three theoretical equations that are appropriate to evaluate the radial buckling (Ref. 12, pp. F3.2.24-25 and Ref. 23, pp. 205-214) given by:

$$B_{Cylinder} = \frac{J_0\ (0\ )\ Bessel\ Function}{Radius\ +\ f_C\,(0.710446)\ \lambda_m}$$

$$B_{Square} = \frac{\left(\pi/2\right)^2}{Radial\ length\ +\ f_S\,(0.710446)\ \lambda_m}$$

$$B_{\substack{Separable\\Square}} = \frac{\sqrt{2}\ \pi}{(2)\,Radial\ length\ +\ f_{SS}\,(0.710446)\ \lambda_m}$$

In the radial buckling for a cylinder, the radial length for the WP representation is the radius of a cylinder, which has a planar area equal to the area of the 21 fuel assemblies in the degraded WP. The width of the fuel lattice in the MCNP baseline degraded case is 21.42 cm (10.7086 x 2) (Spreadsheet Vantage 5 Specs.xls, D19). The radius is given by:

$$Radius = \left\{\frac{\left(21.42\,cm\right)^2\ 21}{\pi}\right\}^{1/2} = 55.3729\ \text{cm}$$

In the radial buckling for a square, the radial length for the WP representation is either the above radius or one-half the length of a side of a square having a planar area equal to the area of the fuel assemblies in the degraded WP. This radial length is given by:

$$Radial\ length = \frac{\left\{\left(21.42\,cm\right)^2\ 21\right\}^{1/2}}{2} = 49.0730\ \text{cm}$$

In the radial buckling for a separable square, the radial length for the WP representation is the above radial length.

**Reflector Effects**–The three radial buckling equations were evaluated in combination with the axial buckling equation to determine the appropriate constant for the reflector effects on the combined axial and radial leakage for the degraded WP. The SAS2H radial equation was used to determine the effective radial length with the reflector effects constant set to zero. For example, the effective radial length in the SAS2H radial buckling equation to reproduce the radial buckling of the separable square equation was determined as follows:

$$\frac{p}{Effective\ Radial\ Length} = \frac{p}{\sqrt{2}\quad Radial\ Length}$$

where

*Effective Radial Length* = 69.3997 cm.

Iterations with the radial buckling equations and reflector effects constant in the SAS2H representation with comparisons to MCNP-$k_{eff}$ results indicated that the separable square radial buckling equation gave the more consistent overall results. The effective radial length is that shown above. The combined (axial and radial) reflector effects constant is given by:

Reflector Effects Constant = *f* * 0.710446 = 0.815.

The comparison of the MCNP-$k_{eff}$ and SAS2H-$k_{eff}$ values shown below indicates that the iterative solution of the reflector effects constant (0.815) is appropriately converged.

| | MCNP-$k_{eff}$ | SAS2H-$k_{eff}$ | $\Delta r$ Difference |
|---|---|---|---|
| Waste Package | 1.00799 " 0.00052 | 1.00818 | 0.00019 |
| | (h2oh13f.mox.inp) | (out.wpn.mox.inp) | |

Based on the results of the axial buckling evaluation of the reflector effects constant, it would be expected that "*f*" would be between 1 and 2 for the combined axial and radial reflector effects with a probable value nearer to 1. The above calculation results in an *f* of 1.15 = 0.815/0.710446, which is consistent with expectations.

**SAS2H Effective Radial Length of Fuel Stack**–The last step in the development of a SAS2H representation for the WP reactivity coefficients is to determine the effective radial length. Ideally, the effective radial length for the degraded WP with separate regions of pure-water and of 58% iron oxide by volume and water would be the effective radial length for the pure water region. If this were the situation, it would mean that the effects of the spatial flux shape could adequately be defined by the importance weighting of the two water regions. There would be no additional leakage effects. Unfortunately, the SAS2H-$k_{eff}$ results, with an effective radial length of 69.3997 cm and a reflector constant of 0.815, did not agree with the MCNP-$k_{eff}$ (0.8659 " 0.0058). To obtain agreement between the MCNP- and SAS2H-$k_{eff}$ values, the SAS2H effective radial length had to be decreased. The revised value is given by:

Effective Radial Length (MCNP-$k_{eff}$) = 43.870 cm

The decrease in the effective radial length significantly increased the radial leakage and decreased the $k_{eff}$. The iteration to determine the effective radial length of 43.870 cm gave the following SAS2H $k_{eff}$ in comparison to MCNP:

| | MCNP-$k_{eff}$ | SAS2H-$k_{eff}$ | $\Delta r$ Difference |
|---|---|---|---|
| Waste Package | 0.86585 " 0.00143<br>(21MS1F) | 0.866196<br>(out.mox1e.wp.inp) | 0.00046 |

This agreement supports making the appropriate adjustments in the SAS2H-$k_4$ representation.

**Summary**–With the buckling corrections developed in this section and the SAS2H assembly representation giving the same $k_4$ and $k_{eff}$ results as MCNP, the SAS2H representation is appropriate to evaluate reactivity changes in the degraded WP fuel region. Three values are required for the buckling correction to the SAS2H representation: (1) axial length (dz) = 365.76 cm; (2) reflector effects constant (bkl) = 0.815; and (3) effective radial length (dy) = 43.870 cm.

The reactivity effects of changes in the fuel temperatures and water densities are calculated with SAS2H to evaluate the RELAP5 functional relations between the thermodynamic state points and the respective reactivity values. The input file for the SAS2H base reactivity case (out.mox1e.wp) is included as Attachment I. The RELAP5 representation of reactivity used in this evaluation is based on two reactivity variables: (1) fuel temperature, and (2) water density. These two reactivity variables are treated as separable entities and combined in the RELAP5 representation to define a total reactivity for the WP.

The development of the RELAP5 reactivity input data included the dependent relationship between the fuel temperature and water density variables. The dependent effects were represented using the following constraints and approximations:

(1) The fuel temperature would lead in time the water density.

(2) The water temperature effect on reactivity is insignificant compared to the water density.

(3) The water pressure effect on reactivity is insignificant compared to the water density.

(4) The onset of vapor (steam void fraction) formation would occur in the temperature range around 373 K (212 EF).

(5) The fuel temperature does not exceed 813 K (1004 EF).

Steam void fractions in the 10% range were assumed to be generated by fuel temperatures of 543 K (518 EF). Greater void fractions were assumed to be caused by fuel temperatures of

813 K (1004 EF). Table 5.2.2-1 provides a case listing of 20 SAS2H calculations forming the bases for the RELAP5 reactivity values. The water density factor is the water density reduction factor relative to the 300 K value.

Table 5.2.2-1. SAS2H Reactivity Input For RELAP5

| Case | Water Density Factor | Fuel Temperature (K) | Fuel Temperature (°F) | $k_{eff}$ |
|---|---|---|---|---|
| out.mox1e.wp | 1.000 | 300 | 80.33 | 0.866196 |
| out.mox1.122 | 1.000 | 323.15 | 122 | 0.865423 |
| out.mox2.122 | 0.988 | 323.15 | 122 | 0.863406 |
| out.mox2.212 | 0.988 | 373.15 | 212 | 0.861854 |
| out.mox1.212 | 0.973 | 373.15 | 212 | 0.859113 |
| out.mox1.320 | 0.973 | 433.15 | 320 | 0.857437 |
| out.mox5.518 | 0.973 | 543.15 | 518 | 0.854514 |
| out.mox4.518 | 0.958 | 543.15 | 518 | 0.85168 |
| out.mox3.518 | 0.940 | 543.15 | 518 | 0.846952 |
| out.mox2.518 | 0.920 | 543.15 | 518 | 0.841404 |
| out.mox1.518 | 0.900 | 543.15 | 518 | 0.835624 |
| out.mox9.100 | 0.900 | 813.15 | 1004 | 0.829274 |
| out.mox8.100 | 0.875 | 813.15 | 1004 | 0.821654 |
| out.mox7.100 | 0.850 | 813.15 | 1004 | 0.813638 |
| out.mox6.100 | 0.825 | 813.15 | 1004 | 0.805201 |
| out.mox5.100 | 0.800 | 813.15 | 1004 | 0.796323 |
| out.mox4.100 | 0.775 | 813.15 | 1004 | 0.786977 |
| out.mox3.100 | 0.750 | 813.15 | 1004 | 0.777141 |
| out.mox2.100 | 0.725 | 813.15 | 1004 | 0.766783 |
| out.mox1.100 | 0.700 | 813.15 | 1004 | 0.755879 |

## 5.3 STEADY-STATE DESCRIPTION

The steady-state calculation for a postulated criticality event is developed from a thermal equilibrium basis. It is conservatively assumed that airflow is stagnant in a drift during postclosure, and evaporation can be represented as diffusion of water vapor into air. The following expression (Ref. 14, p. 601) provides an approximation for the diffusion coefficient of water into air as a function of temperature:

$$D(T) = [435.7 \cdot T^{3/2} \cdot (M_1^{-1} + M_2^{-1})^{1/2}]/[P_{atm} \cdot (V_1^{1/3} + V_2^{1/3})^2] \qquad (1)$$

where

| | |
|---|---|
| D(T) | Diffusion coefficient at temperature T ($cm^2/s$) |
| T | Temperature (K) |
| $P_{atm}$ | Atmospheric pressure (Pa) |
| $V_1$, $V_2$ | Molecular volumes of substances 1 and 2 ($cm^3$/mole) (in this case, water and air, respectively) |
| $M_1$, $M_2$ | Molecular weights of substances 1 and 2 (g/mole) (water and air). |

Atmospheric pressure is taken to be 101,325 Pa (Ref. 14, p. 669). The molecular volumes of water and air are 18.8 $cm^3$/mole and 29.9 $cm^3$/mole, respectively (Ref. 14, p. 602). The molecular weights of water and air are 18.02 g/mole (Ref. 16, p. 50) and 28.964 g/mole (Ref. 15, p. F-13), respectively. An additional factor of 0.056 $cm^2/s$ has been added to values calculated with Equation 1 to correspond to empirical measurements of the diffusion coefficient of water vapor into air at 8 °C and 25 °C (Ref. 14, Table A-8).

With the diffusion coefficient determined, the volumetric flow rate of water out of the WP due to evaporation is determined using the integrated form of Stefan's law (Ref. 14, p. 606):

$$V_{evap}(T) = [(D(T) \cdot P_{atm} \cdot M_1 \cdot A \cdot \nu(T))/(R_0 \cdot T \cdot z)] \cdot \ln[(P_{atm} - p(T) \cdot RH)/(P_{atm} - p(T))] \quad (2)$$

where

| | |
|---|---|
| $V_{evap}(T)$ | Volumetric evaporation rate ($m^3/s$) |
| D(T) | Diffusion coefficient at temperature T ($m^2/s$) |
| T | Temperature (K) |
| $P_{atm}$ | Atmospheric pressure (Pa) |
| p(T) | Saturation pressure of water at temperature T (Pa) |
| $R_0$ | Universal Gas Constant (J/mole·K) |
| z | Distance from the water surface to the bulk environment (m) |
| ν(T) | Specific volume of the water at temperature T ($kg/m^3$) |
| A | Surface area of the water in the WP ($m^2$) |
| RH | is the drift relative humidity |
| $M_1$ | Molecular weight of water (kg/mole). |

The approximate mean rate of water dripping onto a WP during the long-term average climate in Total System Performance Assessment-Viability Assessment (TSPA-VA) was approximately 0.5 $m^3$/y (Ref. 17, pp. 3-15 and 3-23). Using Equation 2, the WP would have to produce sufficient power to maintain the water in the WP at a temperature of 73 °C, as well as compensate for other mechanisms of heat loss, to match this drip rate. The 73 °C value is the temperature derived from Equation 1 where the evaporation rate balances the inflow rate of 0.5 $m^3$/y. The above estimate used the following input values: p(73 °C) = 0.3546 bars (Ref. 18, pp. 219-221), ν(73 °C) = 1.025 $cm^3$/g (Ref. 18, pp. 219-221), $R_0$ = 8.315 J/mole·K (Ref. 16, p. 57), RH = 0.96 (Ref. 17, p. 3-37). The surface area of the water just above the upper row of assemblies (~ 8 cm from inner barrier inner surface) is taken to be 3 $m^2$ (Ref. 20, p. VI-4). This indicates that evaporation alone will be sufficient to remove the incoming water, and bulk boiling will not occur.

The amount of reactor heat dissipated by heating the incoming water, which is assumed to be at a temperature of 30 °C, to a temperature of 73 °C is given by the following expression:

$$q_{water} = [Cp(30\ °C)\cdot V_{drip}\cdot \Delta T]/\ \nu\ (30\ °C) \qquad (3)$$

where

| | |
|---|---|
| $q_{water}$ | Heat rate required to raise the water temperature 43 K (J/s) |
| $V_{drip}$ | Rate of water dripping into the WP ($m^3/s$) |
| Cp(30 °C) | Specific heat of water at 30 °C (4.179 kJ/kg·K; (Ref. 14, Table A-9) |
| ν(30 °C) | Specific gravity of water at 30 °C (1.004 $cm^3/g$; Ref. 18, p. 221) |
| ΔT | Temperature increase (43 K). |

Using Equation 3, only 2.8 W are required to raise the temperature of the water to the point where the evaporation rate is equal to the rate of influx.

Once at 73 °C, the power level required to vaporize water at a rate of 0.5 $m^3/y$ must be included. This is equal to the product of the heat of vaporization at 73 °C, 2346 kJ/kg (interpolated from Ref. 18, pp. 219-221), the volume of water to be evaporated, 0.5 $m^3/y$, and the density of water at 73 °C, 975.9 $kg/m^3$. Multiplying the above three values and performing the appropriate unit conversions yield an additional 37 W.

As stated above, additional heat losses will also occur due to radiation and/or conduction heat transfer to the local environment. The actual configuration of the drift thousands of years after emplacement cannot be defined sufficiently to allow a detailed heat transfer estimate. It is highly likely that a portion of the WP may be covered with rubble, possibly as a result of the gradual collapse of the drift, and both radiation and conduction mechanisms will be active. However, examination of ideal radiation-only and conduction-only systems should respectively provide an upper and lower bound on the heat loss from a WP with a bulk water temperature of 73 °C. Heat losses due to radiation alone can be estimated by treating the WP and drift as a system of concentric cylinders, with the WP surface at 73 °C, and the drift wall assumed to maintain a constant temperature of 30 °C. The radiation heat transfer rate is then given by (for concentric cylinders) (Ref. 14, p. 420):

$$q_{rad} = [\sigma\cdot A_1\cdot(T_1^4 - T_2^4)]/[\varepsilon_1^{-1} + (A_1/A_2)(\varepsilon_2^{-1} - 1)] \qquad (4)$$

where

| | |
|---|---|
| $q_{rad}$ | Radiation heat transfer rate (J/s) |
| $T_1$ | WP surface temperature (K) |
| $T_2$ | Drift wall temperature (K) |
| $A_1$ | WP surface area (26.0 $m^2$ [Ref. 8.20, Attachment VII]) |
| $A_2$ | Drift surface area (77.0 $m^2$ [Ref. 8.20, Attachment VII]) |
| $\varepsilon_1$ | Emissivity of oxidized carbon steel (0.8; Ref. 19, p. 9) |
| $\varepsilon_2$ | Emissivity of tuff rock (0.85; Ref. 19, p. 34) |
| $\sigma$ | Stephan-Boltzman constant ($5.669\times10^{-8}$ $W/m^2 \cdot K^4$, (Ref. 14, p. 14). |

Using the above equation, the radiation heat loss from a 73-°C WP is estimated to be 6,558 W. Again assuming the system of concentric cylinders and a drift wall temperature of 30 °C, a WP entirely covered by crushed tuff would lose heat by conduction according to (Ref. 14, p. 31):

$$q_{cond} = [2\pi kL(T_1 - T_2)]/[\ln(d_2/d_1)] \qquad (5)$$

where

| | |
|---|---|
| $q_{cond}$ | Conduction heat transfer rate (J/s) |
| k | Average thermal conductivity of crushed tuff (0.66 $J/s \cdot m^2 \cdot K/m$, [Ref. 8.20, Attachment VII]) |
| L | WP outer length less that of the skirts (4.885 m, Ref. 17) |
| $T_1$ | WP surface temperature (73 °C) |
| $T_2$ | Drift wall temperature (30 °C) |
| $d_1$ | WP outer diameter (1.7 m, Ref. 17) |
| $d_2$ | Drift diameter (5.5 m; Ref. 17). |

Solving the above equation for a WP surface temperature of 73 °C indicates that 728 W will be lost if all heat transfer occurs by conduction through crushed tuff.

The steady-state criticality calculation was performed with the SAS2H-ORIGEN-S modules from the SCALE4.3 code system (Ref. 6) for the PWR MOX assembly with a fissile Pu content of 4.0 wt% HM and burnup of 35.6 GWD/MTHM. A baseline case was run with only the decay option and a criticality case was run with a burn subcase included in the ORIGEN-S data at 25,000 years through 35,000 years followed by decay to one million years. For a conservative calculation, the larger estimated power source ((6558 + 37)/21 = 314 W/assembly) was used for the ORIGEN-S burn subcase.

## 5.4 RELAP5 WP DESCRIPTION

### 5.4.1 RELAP5/MOD3.2 Component Descriptions

The purpose of this section is to describe the RELAP5 representation used for the coupled neutronic-thermal-hydraulic analyses of a criticality event in a WP where the outer barrier has been compromised leading to a fully degraded basket assembly. The RELAP5 representation of the WP, illustrated as a block diagram in Figure 5.4.1-1, consisted of 27 control volumes, 43 junctions, and 35 heat conductors. The spatial orientation of the WP is such that the cylindrical WP axis and long fuel assembly dimension are in the horizontal plane. The representation represents one-half of the WP cross-sectional cylinder since the system has left-right symmetry.

The RELAP5 code is designed to be used with fundamentally 1-D hydraulic systems, but does include multi-directional flow representation under restricted conditions (Ref. 22, pp. 2-14 through 2-16). The RELAP5 representation for the degraded WP contains flow connections in the two directions normal to the WP cylinder axis, but not parallel to the axis. For this quasi-2-D representation, the fuel bundles were represented at one-fifth their actual length with appropriate adjustments to the representation parameters. The principal elements of the representation description include the geometric representation, flow connections, friction factors, and heat conductors. These elements are described in the following sections. Note that RELAP5 input quantities are specified in English units. The calculational worksheets are included as Attachment VIII.

Frictional effects are important in the hydraulic calculations to maintain computational stability. These effects were simulated in the RELAP5/MOD3.2 representation of WP fluid volumes containing SNF by applying loss coefficients in the connecting junctions. A prior sensitivity calculation (Ref. 21, Section 5) showed that reactivity consequences in the WP were not sensitive to loss coefficient values over the range of $K_f$ between 20 and 40 in junctions connecting volumes not containing SNF. Consequently, a $K_f$ of 20 was used for these junctions.

The particular WP configuration used for the RELAP5 studies was the fully degraded basket condition with intact fuel assemblies. The iron oxide was assumed to have settled to the bottom of the WP covering the lower 3.5 rows of assemblies. The presence of oxide material was included in the development of the reactivity parameters but not specifically included in the hydrodynamic or thermodynamic representation. The fluid volume in each fuel assembly is represented by one RELAP5 volume. The presence of the metal fuel rods in assemblies was represented by connecting powered heat conductors to appropriate volume components. As stated previously, the WP is designed to hold fuel assemblies in a horizontal arrangement limiting the gravity contributions to the volume pressures in the WP representation to elevations of 21.42 cm, the assembly width (Table 5.1.2-1). Control volumes representing SNF assemblies have IDs from 010010000 through 130010000, where control volumes 010010000-050010000 represent half assemblies. The remaining space in the WP interior was described by the control volumes labeled 140010000-250010000. Two time-dependent control volumes (ID 260010000 and ID 360010000), representing the external boundary WP environment, complete the RELAP5 geometry setup. The block diagram of the RELAP5 representation displayed in Figure 5.4.1-1, while not to scale, shows the relative control volume arrangement. Initial conditions for the RELAP5 control volumes were specified as water filled at 50 EC (122.0 EF) and 1.01325e+5 Pa (14.696 psia) except for the time-dependent control volume (ID 260010000), representing the external environment, which was initialized as steam at 220.0 EF and 14.696 psia to approximate a non-condensing gas environment.

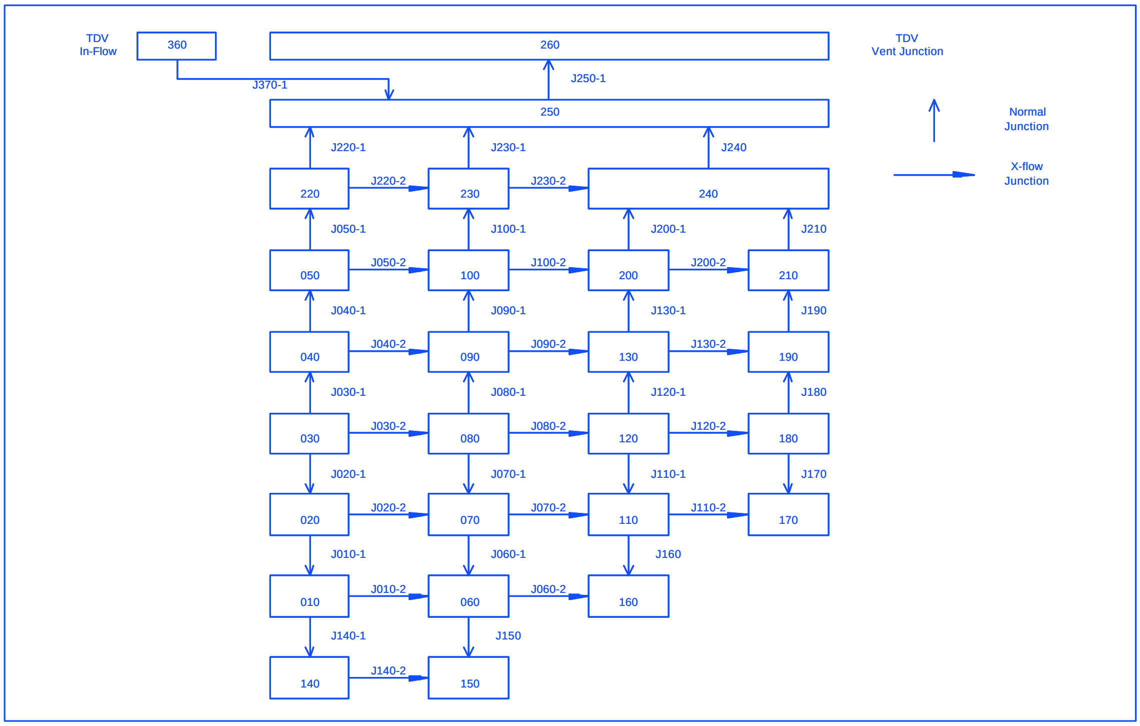


Figure 5.4.1-1. RELAP5 Component Diagram for the MOX PWR Reactivity Consequence Calculation

Time-dependent volumes were included in the representation to represent the drift space outside the WP, where the out-flowing water inventory from the WP accumulates, and to provide a low temperature flow path into the WP representing the drift flow leaking into the WP. Time-dependent volumes are used as boundary conditions providing sinks and sources for the fluid inventory. Thermodynamic conditions in these control volumes are specified as functions of time and are not dependent upon the mass or enthalpy of connecting volumes.

The control volume dimensions for the RELAP5 WP representation are listed in Table 5.4.1-1 (Spreadsheet: Vantage 5 specs.xls). With the exception of volumes 140 and 150, the non-fuel volume dimensions were unchanged from the base representation (Ref. 1). This has a minor effect on the WP water inventory that is already represented in a conservative manner (Assumption 3.4). The total volume contained in the fluid component volumes is 0.4654 $m^3$ (16.437 $ft^3$) resulting in an initial inventory of 458.15 kg (1010.04 $lb_m$) of water.

Table 5.4.1-1. RELAP5 Fluid Component Volume Description

| Component ID[1] | Volume (ft$^3$) | Vertical Flow Area (ft$^2$) | Elevation (ft) (Center-line) | Pressure (psia) | Temperature (EF) |
|---|---|---|---|---|---|
| 010010000 | 0.37035853 | 0.5271757 | 0.0 | 14.696 | 122.0 |
| 020010000 | 0.37035853 | 0.5271757 | 0.702667 | 14.696 | 122.0 |
| 030010000 | 0.37035853 | 0.5271757 | 1.40533 | 14.696 | 122.0 |
| 040010000 | 0.37035853 | 0.5271757 | 2.10800 | 14.696 | 122.0 |
| 050010000 | 0.37035853 | 0.5271757 | 2.81067 | 14.696 | 122.0 |
| 060010000 | 0.74071706 | 1.0541514 | 0.0 | 14.696 | 122.0 |
| 070010000 | 0.74071706 | 1.0541514 | 0.702667 | 14.696 | 122.0 |
| 080010000 | 0.74071706 | 1.0541514 | 1.40533 | 14.696 | 122.0 |
| 090010000 | 0.74071706 | 1.0541514 | 2.10800 | 14.696 | 122.0 |
| 100010000 | 0.74071706 | 1.0541514 | 2.81067 | 14.696 | 122.0 |
| 110010000 | 0.74071706 | 1.0541514 | 0.702667 | 14.696 | 122.0 |
| 120010000 | 0.74071706 | 1.0541514 | 1.40533 | 14.696 | 122.0 |
| 130010000 | 0.74071706 | 1.0541514 | 2.10800 | 14.696 | 122.0 |
| 140010000 | 0.20454480 | 0.8135505 | -0.477045 | 14.696 | 122.0 |
| 150010000 | 0.22424063 | 0.9973376 | -0.463753 | 14.696 | 122.0 |
| 160010000 | 0.7989270 | 1.1369929 | 0.0 | 14.696 | 122.0 |
| 170010000 | 0.5438773 | 0.7740189 | 0.702667 | 14.696 | 122.0 |
| 180010000 | 0.8980821 | 1.278105 | 1.40533 | 14.696 | 122.0 |
| 190010000 | 0.8738187 | 1.243575 | 2.10800 | 14.696 | 122.0 |
| 200010000 | 0.8633786 | 1.228717 | 2.81067 | 14.696 | 122.0 |
| 210010000 | 0.7822260 | 1.113225 | 2.81067 | 14.696 | 122.0 |
| 220010000 | 0.8633786 | 2.477844 | 3.33622 | 14.696 | 122.0 |
| 230010000 | 0.8633786 | 2.477844 | 3.33622 | 14.696 | 122.0 |
| 240010000 | 0.4918077 | 1.411458 | 3.33622 | 14.696 | 122.0 |
| 250010000 | 1.2517607 | 2.384604 | 3.77291 | 14.696 | 122.0 |
| 260010000 | 238.468 | 238.468 | 4.03537 | 14.696 | 220.0 |
| 360010000 | 238.468 | 238.468 | 3.51044 | 14.696 | 122.0 |

Notes : [1] First 3 digits correspond to the component volume labels in Figure 5.4.1-1.

### 5.4.2 RELAP5 Junction Description

The spatial orientation of the WP cylindrical axis is in the horizontal direction with the fuel assemblies stacked on their sides. The assemblies used for the MCNP analyses (Ref. 13) were Westinghouse 17x17 assemblies with open-pin arrays. This allows cross flow between assemblies since the internal WP structure is assumed to be fully degraded. The Anormal@ flow direction in the representation (normal with respect to the 1-D hydraulic characteristic of the RELAP5 code) is vertical through the assemblies normal to the fuel rod long dimension. RELAP5 junctions define the cross-sectional flow area between two fluid component volumes that must intersect both volumes. These junctions are labeled as xxx010000, where xxx is the identifier (ID) of all junctions originating in a control volume. (Note that junction label prefixes Axxx@ and volume labels prefixes form independent sets.) A second flow direction was defined horizontally across the assemblies and is likewise normal to the long fuel rod dimension. The horizontal flow paths were labeled as xxx020000. Physical constraints on flow paths in the WP are incorporated into the junction flow areas and frictional loss coefficients. A study on the effect of loss coefficient values on the transient criticality results (Ref. 21, Section 5) showed that results were relatively insensitive over the range of values as given. All junction flow rates were initialized at zero (0) kg/s ($lb_m$/s). Junction parameters used for the WP input file are listed in Table 5.4.2-1.

Table 5.4.2-1. RELAP5 Fluid Component Junction Description

| Component ID[1] | Area ($ft^2$) | Orientation (referenced to horizontal) (deg) | Connecting Volume IDs From To | Forward Loss Coefficient | Reverse Loss Coefficient | Choke Flag | Face Position (ft) |
|---|---|---|---|---|---|---|---|
| 010010 | 0.2312 | 90.0 | 01000000<br>02001000 | 68.7 | 68.7 | No | 0.351333 |
| 010020 | 0.4624 | 0.0 | 010000000<br>060000000 | 68.7 | 68.7 | No | 0.351333 |
| 020010 | 0.2312 | 90.0 | 020000000<br>030000000 | 68.7 | 68.7 | No | 1.05400 |
| 020020 | 0.4624 | 0.0 | 020000000<br>070000000 | 68.7 | 68.7 | No | 1.05400 |
| 030010 | 0.2312 | 90.0 | 030010000<br>040000000 | 68.7 | 68.7 | No | 1.75667 |
| 030020 | 0.4624 | 0.0 | 030000000<br>080000000 | 68.7 | 68.7 | No | 1.05400 |
| 040010 | 0.2312 | 90.0 | 040010000<br>050000000 | 68.7 | 68.7 | No | 2.45933 |
| 040020 | 0.4624 | 0.0 | 040000000<br>090000000 | 68.7 | 68.7 | No | 1.75667 |
| 050010 | 0.2312 | 90.0 | 050010000<br>220000000 | 68.7 | 68.7 | No | 3.16200 |
| 050020 | 0.4624 | 0.0 | 050000000<br>100000000 | 68.7 | 68.7 | No | 2.45933 |
| 060010 | 0.4624 | 90.0 | 060000000<br>070010000 | 68.7 | 68.7 | No | 0.351333 |
| 060020 | 0.4624 | 0.0 | 060000000<br>160000000 | 68.7 | 68.7 | No | 0.351333 |
| 070010 | 0.4624 | 90.0 | 070000000<br>080000000 | 68.7 | 68.7 | No | 1.05400 |
| 070020 | 0.4624 | 0.0 | 070000000<br>110000000 | 68.7 | 68.7 | No | 1.05400 |
| 080010 | 0.4624 | 0.0 | 080010000<br>09000000 | 68.7 | 68.7 | No | 1.75667 |
| 080020 | 0.4624 | 0.0 | 080000000<br>120000000 | 68.7 | 68.7 | No | 1.05400 |
| 090010 | 0.4624 | 90.0 | 090000000<br>100000000 | 68.7 | 68.7 | No | 2.5933 |

| Component ID[1] | Area (ft$^2$) | Orientation (referenced to horizontal) (deg) | Connecting Volume IDs From To | Forward Loss Coefficient | Reverse Loss Coefficient | Choke Flag | Face Position (ft) |
|---|---|---|---|---|---|---|---|
| 090020 | 0.4624 | 0.0 | 090000000 130000000 | 68.7 | 68.7 | No | 1.75667 |
| 100010 | 0.4624 | 90.0 | 100010000 230000000 | 68.7 | 68.7 | No | 3.16200 |
| 100020 | 0.4624 | 0.0 | 100000000 200000000 | 68.7 | 68.7 | No | 2.45933 |
| 110010 | 0.4624 | 90.0 | 110000000 120000000 | 68.7 | 68.7 | No | 1.05400 |
| 110020 | 0.4624 | 0.0 | 110000000 170000000 | 68.7 | 68.7 | No | 1.05400 |
| 120010 | 0.4624 | 90.0 | 120010000 130000000 | 68.7 | 68.7 | No | 1.75667 |
| 120020 | 0.4624 | 0.0 | 120000000 180000000 | 68.7 | 68.7 | No | 1.05400 |
| 130010 | 0.4624 | 90.0 | 130010000 200000000 | 68.7 | 68.7 | No | 2.45933 |
| 130020 | 0.4624 | 0.0 | 130000000 190000000 | 68.7 | 68.7 | No | 1.75667 |
| 140010 | 0.2312 | 90.0 | 140000000 010010000 | 68.7 | 68.7 | No | -0.351333 |
| 140020 | 0.541983 | 0.0 | 140000000 150000000 | 0.0 | 0.0 | No | -0.351333 |
| 150010 | 0.4624 | 90.0 | 150000000 060010000 | 68.7 | 68.7 | No | -0.351333 |
| 160010 | 0.4624 | 90.0 | 160000000 110010000 | 68.7 | 68.7 | No | 0.351333 |
| 170010 | 1.10807 | 90.0 | 170000000 180000000 | 0.0 | 0.0 | No | 1.05400 |
| 180010 | 1.33394 | 90.0 | 180010000 190000000 | 0.0 | 0.0 | No | 1.75667 |
| 190010 | 1.03803 | 90.0 | 190010000 210000000 | 0.0 | 0.0 | No | 2.45933 |
| 200010 | 0.754086 | 90.0 | 200010000 240000000 | 20.0 | 20.0 | No | 3.16200 |
| 200020 | 1.79585 | 0.0 | 200000000 210000000 | 20.0 | 20.0 | No | 2.45933 |
| 210010 | 1.03803 | 90.0 | 210010000 240000000 | 20.0 | 20.0 | No | 3.16200 |
| 220010 | 0.203838 | 90.0 | 220010000 250000000 | 20.0 | 20.0 | No | 3.51044 |
| 220020 | 0.823478 | 0.0 | 220000000 230000000 | 20.0 | 20.0 | No | 3.16200 |
| 230010 | 0.4624 | 90.0 | 230010000 250000000 | 20.0 | 20.0 | No | 3.51044 |
| 230020 | 0.823478 | 0.0 | 230000000 | 20.0 | 20.0 | No | 3.16200 |

| Component ID[1] | Area ($ft^2$) | Orientation (referenced to horizontal) (deg) | Connecting Volume IDs From To | Forward Loss Coefficient | Reverse Loss Coefficient | Choke Flag | Face Position (ft) |
|---|---|---|---|---|---|---|---|
| | | | 240000000 | | | | |
| 240010 | 0.973291 | 90.0 | 240010000<br>250000000 | 20.0 | 20.0 | No | 3.51044 |
| 250010 | 0.107639 | 90.0 | 250010000<br>260000000 | 0.0 | 0.0 | Yes | 4.03537 |
| 3700101 | 1.0 | 0.0 | 360010000<br>250000000 | 0.0 | 0.0 | No | 3.51044 |

Notes: [1] Digits 1-4 correspond to the "J" IDs in Figure 5.4.1-1.

### 5.4.3 RELAP5 Heat Conductor Description

Energy sources in RELAP5 representations must be described with powered heat conductors connected to fluid volumes. In addition, non-powered heat conductors may be used to transport energy between disjoint fluid paths and/or into heat sinks. To properly describe the thermal characteristics of conductors, the geometry is normally representative of individual components such as fuel rods. The total fuel assembly energy balance is maintained by assigning the proper heat transfer area to the conductor. For the RELAP5 description of the WP, two sets of conductors describing the fuel pins and guide tubes were defined; one as a powered set representing the $UO_2$ fuel pellets (IDs 3301001 through 3301013) and one as a passive set representing the fuel rod cladding and guide tubes (IDs 3481001 through 3481013).

The conductor series 3301 and 3481 were connected respectively to control volumes 01001000 through 130010000, where the SNF assemblies are located. The fuel rods were represented with independent pellet and clad conductors to simulate breached conditions with no gas gap between the fuel pellets and cladding and with water in contact with the $UO_2$ pellets. In this description, the fuel rod cladding was disassociated from the fuel pellet-to-water heat conduction path placing the pellets directly in contact with the fluid volume water mass. The cladding and guide tubes were in turn heated from secondary contact with the fluid volume water mass.

The outer containment shell of the WP was described with a set of nine passive heat conductors (IDs 3121001 through 3121009) representing large carbon steel heat sinks connected to the peripheral water filled volumes (IDs 140010000 through 220010000).

Initial conditions for all heat conductors were 50.0 EC (122.0 EF).

Global energy sources in the RELAP5 program are defined by the time-dependent solution of point kinetics equations for the fission contribution to the energy generation coupled with (optionally) fission product and actinide radioactive decay energy. The global energy sources are distributed locally to powered heat conductors (IDs 3301001 through 3301013) through power factors, which consist of nodal weights within conductors and overall weight factors among the conductors. For the RELAP5 WP representation, the time-dependent power history represented one fuel assembly, and the power factors were specified accordingly: 0.2 for one-fifth length full area assemblies and 0.1 for one-fifth length half area assemblies. Nodal power factors within conductors were given equal weighing.

The heat conductor descriptions for the RELAP5 representation are listed in Table 5.4.3-1 (Attachment VIII).

Table 5.4.3-1. RELAP5 Heat Conductor Specifications

| Conductor ID | Geom Type | Composition[1] | Coordinate (ft)<br>Left<br>Right | Volume Connection ID<br>Left<br>Rright | Initial Temperature (EF) | Heat Transfer Area ($ft^2$) | Power Factor |
|---|---|---|---|---|---|---|---|
| 3301001 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>010010000 | 122.0 | 316.8 | 0.1 |
| 3301002 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>020010000 | 122.0 | 316.8 | 0.1 |
| 3301003 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>030010000 | 122.0 | 316.8 | 0.1 |
| 3301004 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>040010000 | 122.0 | 316.8 | 0.1 |
| 3301005 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>050010000 | 122.0 | 316.8 | 0.1 |
| 3301006 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>060010000 | 122.0 | 633.6 | 0.2 |
| 3301007 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>070010000 | 122.0 | 633.6 | 0.2 |
| 3301008 | Cylinder | $UO_2$ | 0.0<br>1.535833e-02 | 0<br>080010000 | 122.0 | 633.6 | 0.2 |
| 3301009 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>090010000 | 122.0 | 633.6 | 0.2 |
| 3301010 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>100010000 | 122.0 | 633.6 | 0.2 |
| 3301011 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>110010000 | 122.0 | 633.6 | 0.2 |
| 3301012 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>120010000 | 122.0 | 633.6 | 0.2 |
| 3301013 | Cylinder | $UO_2$ | 0.0<br>1.286667e-02 | 0<br>130010000 | 122.0 | 633.6 | 0.2 |
| 3481001 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 010010000<br>010010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481002 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 020010000<br>020010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481003 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 030010000<br>030010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481004 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 040010000<br>040010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481005 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 050010000<br>050010000 | 122.0 | 265.875<br>531.750 | 0.0 |

| Conductor ID | Geom Type | Compo-sition[1] | Coordinate (ft) Left Right | Volume Connection ID Left Rright | Initial Temperature (EF) | Heat Transfer Area ($ft^2$) | Power Factor |
|---|---|---|---|---|---|---|---|
| 3481006 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 060010000<br>060010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481007 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 070010000<br>070010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481008 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 080010000<br>080010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481009 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 090010000<br>090010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481010 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 100010000<br>100010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481011 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 110010000<br>110010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481012 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 120010000<br>120010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3481013 | Cylinder | Zr-4 | 1.3125e-02<br>1.4997e-02 | 130010000<br>130010000 | 122.0 | 265.875<br>531.750 | 0.0 |
| 3121001 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 140010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121002 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 150010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121003 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 160010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121004 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 170010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121005 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 180010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121006 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 190010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121007 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 200010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121008 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 210010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |
| 3121009 | Rectang ular | Carbon Steel | 0.0<br>190.0 | 220010000<br>0 | 122.0 | 1.73<br>0.0 | 0.0 |

Note: [1] MOX thermal properties assumed to be similar to $UO_2$ (Assumption 3.3)

# 6. RESULTS

The criterion for determining where the egress junction area becomes influential in criticality consequences is where the exit mass flow becomes sufficiently restricted to limit the contribution of the void reactivity in terminating the event due to moderator mass loss. The initial power rise in criticality events with large reactivity insertion rates is halted by the Doppler reactivity feedback with significant void or density reactivity feedback (ultimately from voiding the WP) required to completely terminate the criticality (Ref. 1, Section 7). As the exit junction area is decreased sufficiently, the exit mass flow rate becomes restricted, resulting in higher pressures and temperatures, which partially determine criticality consequences (Ref. 1, Section 7). For sufficiently slow events, where the Doppler and moderator density reactivity feedback effects can terminate the criticality event without the necessity of a large void generation due to boiling (with subsequent moderator mass loss from internal pressurization), varying the exit junction area has little effect on the criticality consequences since internal pressures and exit flow rates remain low.

Unqualified data were used in the development of the results presented in this section.

## 6.1 RAPID REACTIVITY INSERTION RATE

A series of cases having a rapid reactivity insertion rate were run with decreasing exit junction area as a variable parameter. These calculations were performed for hypothetical criticality events where a reactivity insertion rate of 0.158 $/s was used to approximate the maximum rate of change in the available reactivity due to absorber redistribution within the WP. This rate corresponds to a maximum reactivity addition of 14.18 $ in 90 seconds (Section 2.1). As expected, peak values of the system pressure and fuel temperature were insensitive to the junction area until the exit flow area was decreased to sufficiently small values. The results for these variables are summarized in Table 6.1-1 with the pressure variation shown in Figure 6.1-1 and the temperature variation shown in Figure 6.1-2.

Table 6.1-1. Maximum Temperature and Pressure Values for PWR MOX SNF for a Reactivity Insertion Rate of 0.158 $/s

| Exit Junction Area | Temperature | | Pressure | |
|---|---|---|---|---|
| ($cm^2$) | (K) | ($^oF$) | (Pa) | (psia) |
| 10.0 | 413.91 | 285.37 | 1.15E+05 | 1.67E+01 |
| 5.0 | 413.91 | 285.37 | 1.15E+05 | 1.67E+01 |
| 0.5 | 413.92 | 285.39 | 1.43E+05 | 2.08E+01 |
| 0.375 | 413.92 | 285.38 | 1.63E+05 | 2.37E+01 |
| 0.25 | 453.23 | 356.15 | 9.17E+05 | 1.33E+02 |
| 0.10 | 493.70 | 428.99 | 5.89E+06 | 8.55E+02 |

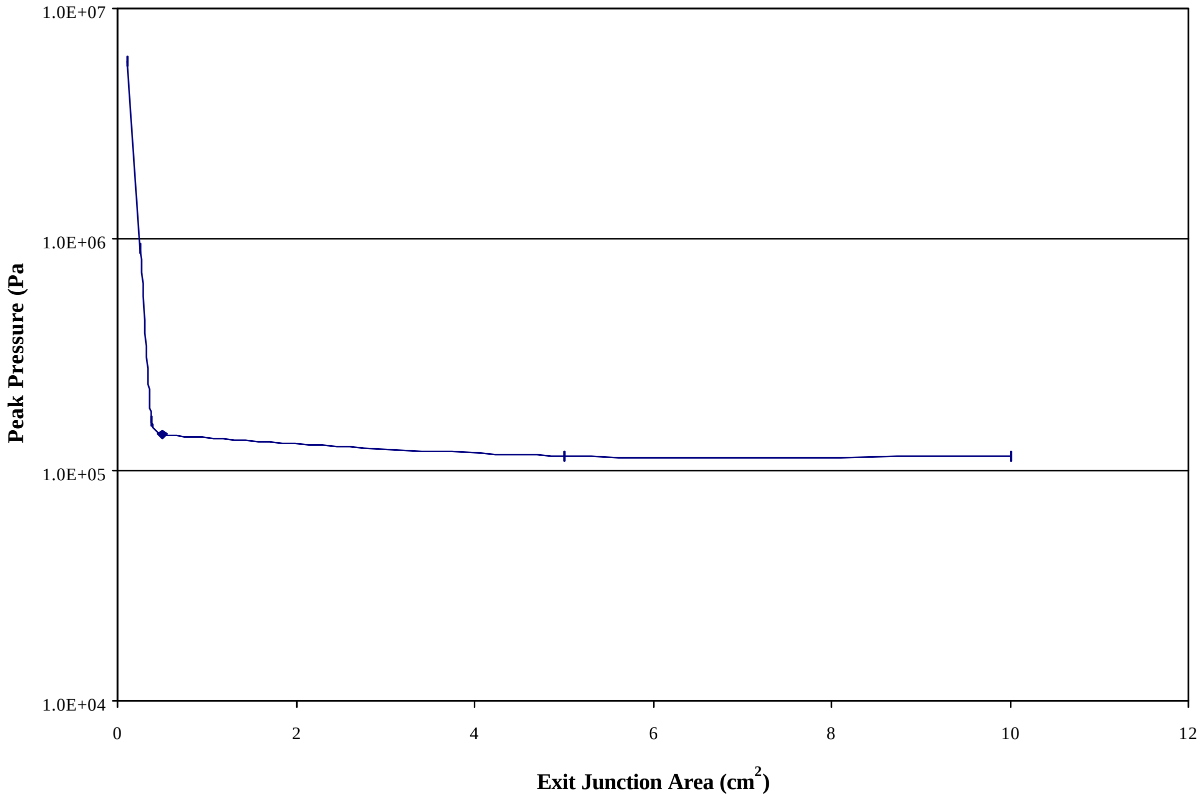


Figure 6.1-1. Peak WP Pressures vs WP Egress Junction Area for 0.158-$/s Reactivity Insertion Rate

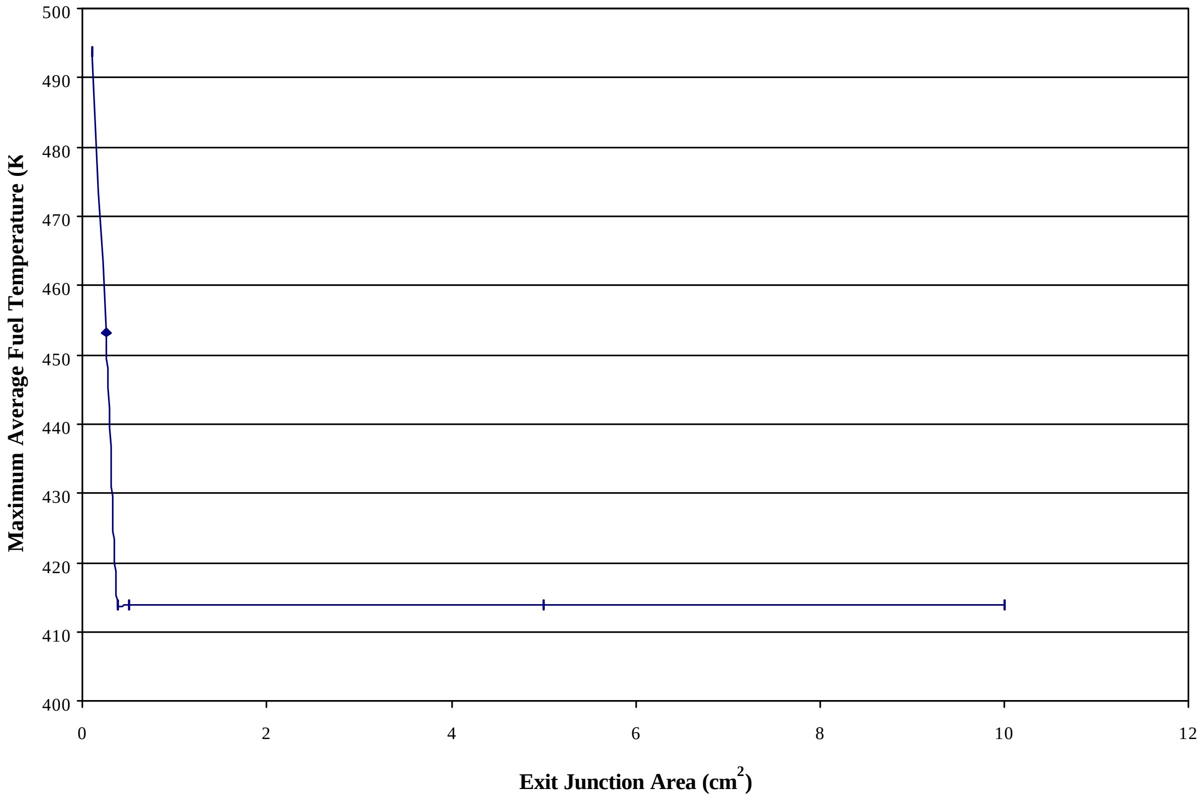


Figure 6.1-2. Peak Average Fuel Temperature for SNF Volume vs WP Egress Junction Area for 0.158-$/s Reactivity Insertion Rate

Detailed histories for a number of parameters affecting the criticality consequences are shown in Figures 6.1-3 through 6.1-9 with the egress junction area as a parameter (Cases: rlp5.MOX02cR1, rlp5.MOX03cR1, rlp5.MOX03dR1, rlp5.MOX03gR1, rlp5.MOX03fR1, and rlp5.MOX03eR1, respectively). In each case, the pressures and temperatures reached maximum values prior to ending the calculation. Figure 6.1-3 shows the pressure histories for a representative (since variation in parameter values among components was small) interior volume of the WP and Figure 6.1-4 shows the temperature histories for a representative SNF assembly. Figure 6.1-5 shows the fission power per assembly for the various cases. Additional assembly burnup for the most severe case (Case F) due to the transient criticality event is approximately 4.23e-6 GWd/MTHM (gigawattdays/metric ton heavy metal). Figure 6.1-6 shows the WP moderator inventory; and Figure 6.1-9 shows the exit junction mass flow rates. Figure 6.1-7 and Figure 6.1-8 show reactivity components for exit junction areas of 10.0 $cm^2$ and 0.375 $cm^2$, respectively. The increase in magnitude of the void reactivity components correlates with the decrease in the respective WP fluid inventories.

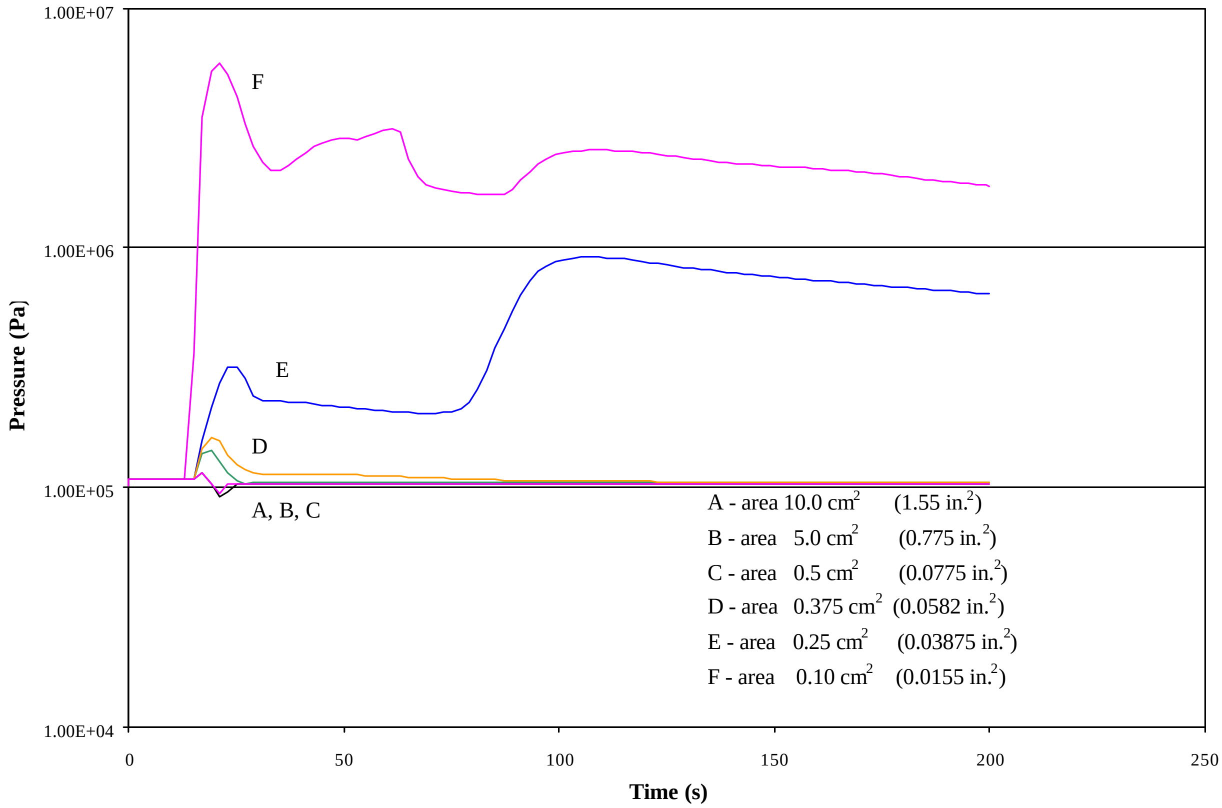


Figure 6.1-3. WP Pressure Histories for a Range of Egress Junction Areas for 0.158-$/s Reactivity Insertion Rate

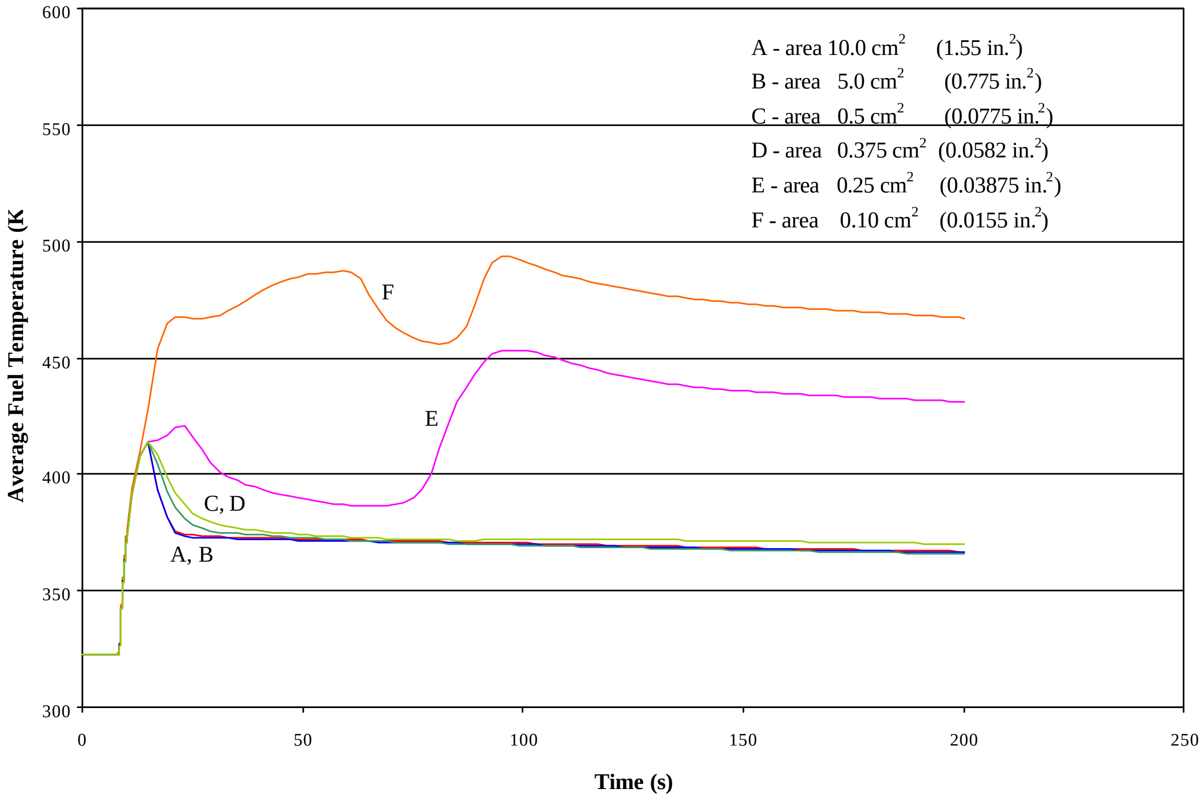


Figure 6.1-4. Fuel Temperature Histories for 0.158-$/s Reactivity Insertion Rate Parameterized by Egress Junction Area

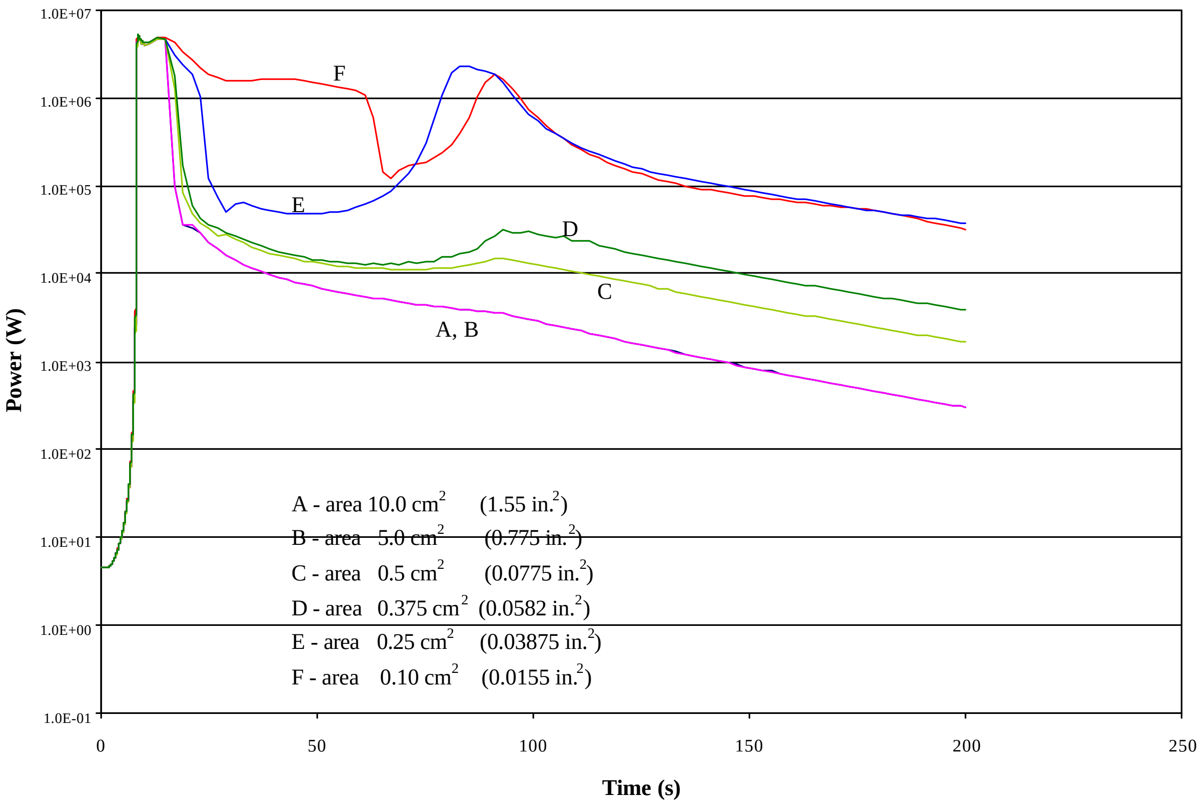


Figure 6.1-5. Fission Power Histories for 0.158-$/s Reactivity Insertion Rate Parameterized by Egress Junction Area

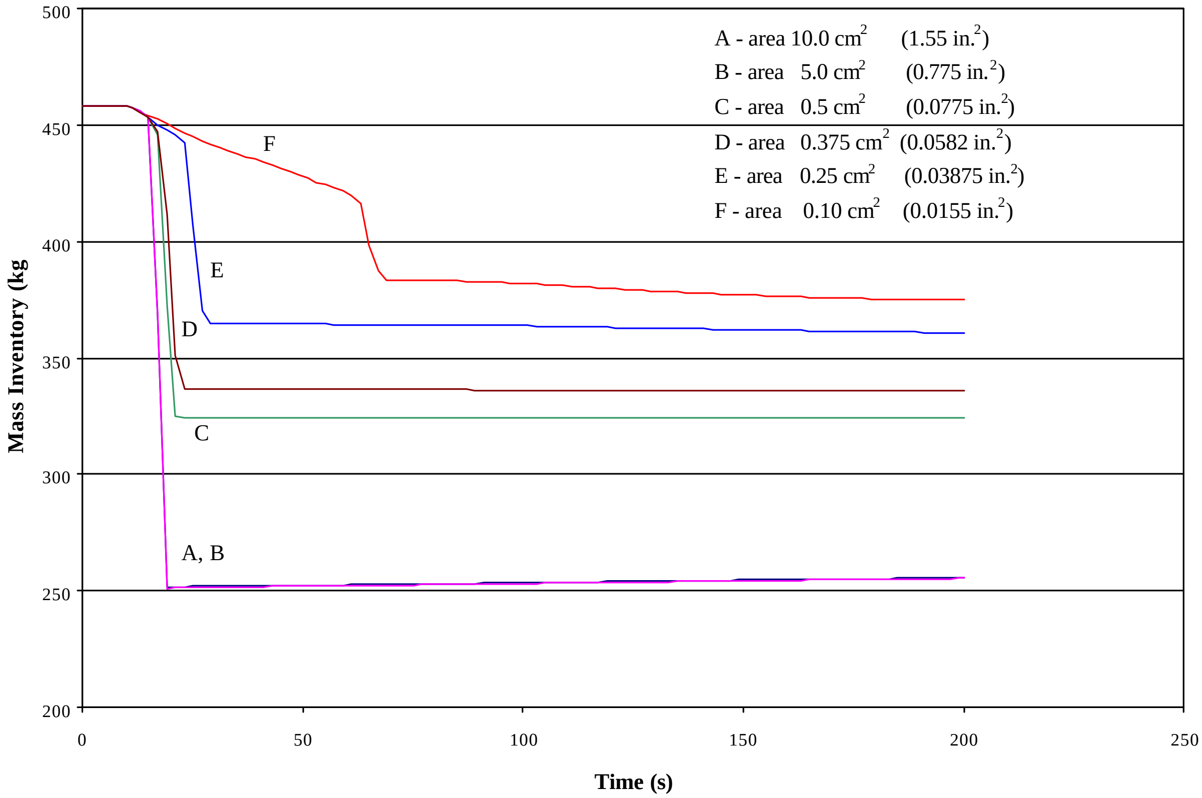


Figure 6.1-6. WP Moderator Inventory Histories for 0.158-$/s Reactivity Insertion Rate Parameterized by Egress Junction Area

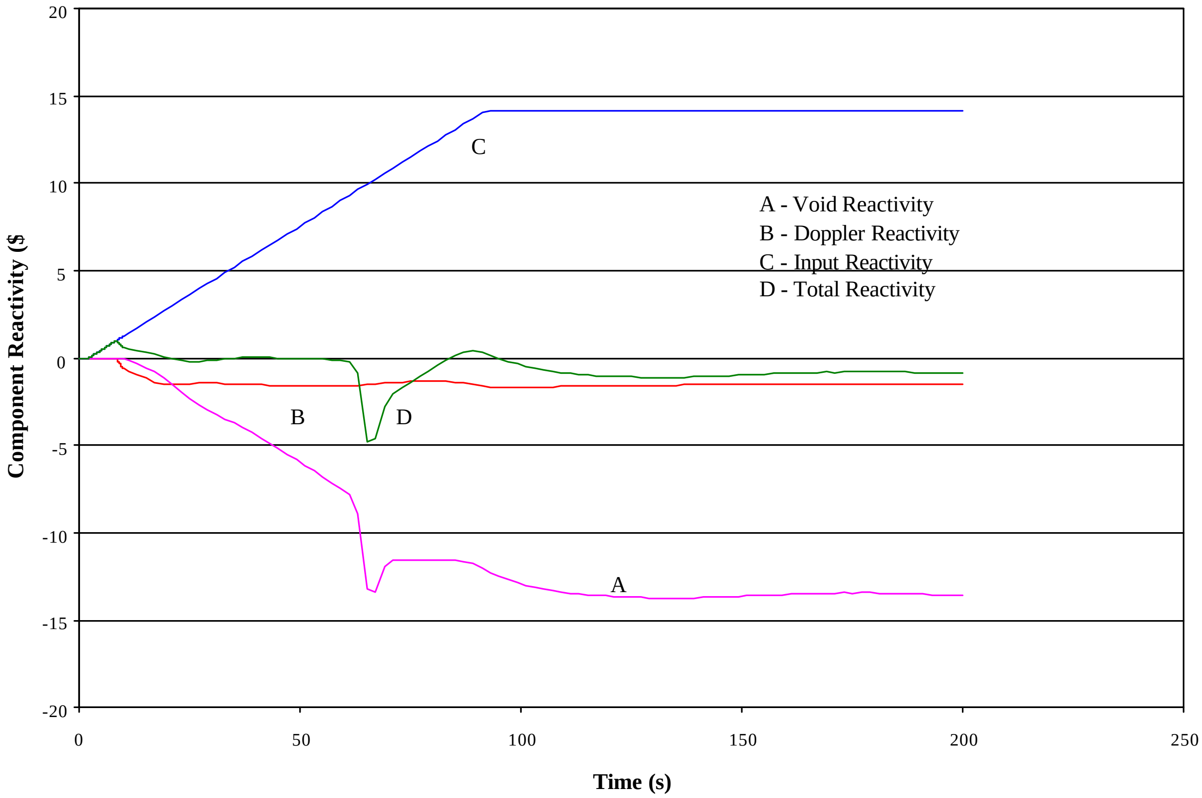


Figure 6.1-7. Reactivity Component Histories for 0.158-$/s Reactivity Insertion Rate with 0.1-cm$^2$ Egress Junction Area

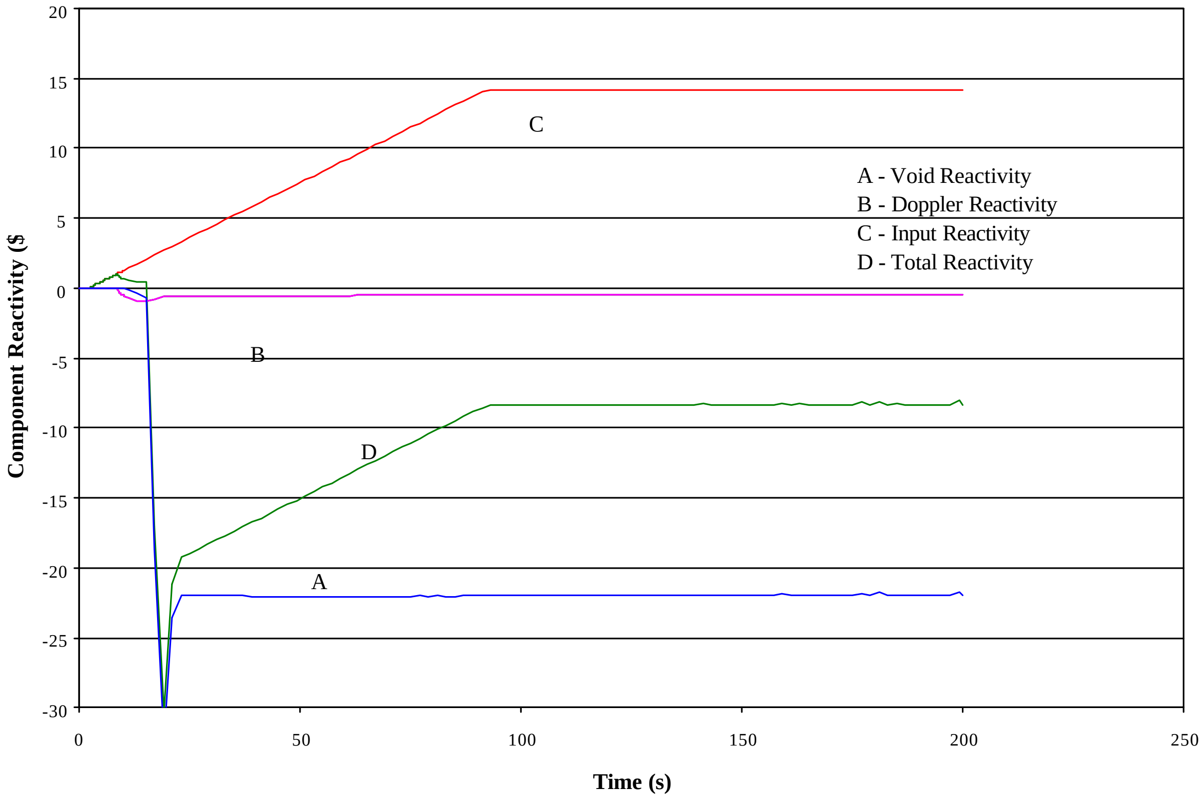


Figure 6.1-8. Reactivity Component Histories for 0.158-$/s Reactivity Insertion Rate with 10.0-cm$^2$ Egress Junction Area

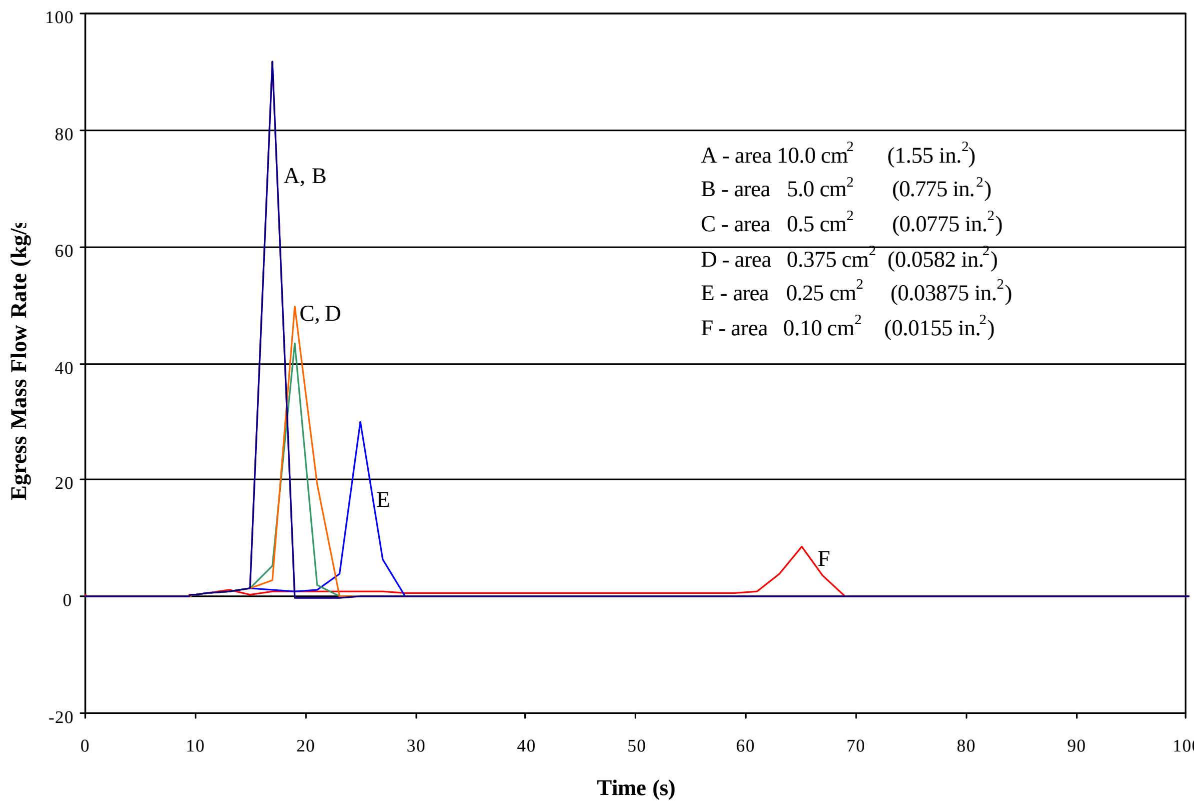


Figure 6.1-9. WP Egress Junction Mass Flow Rate Histories for 0.158-$/s Reactivity Insertion Rate Parameterized by Egress Junction Area

## 6.2 SLOW REACTIVITY INSERTION RATE

The consequences to a WP containing MOX PWR SNF of a criticality event with a low reactivity insertion were calculated for events having a reactivity addition rate of 0.0004 $/s and for steady-state events. The 0.0004 $/s rate is the same as the one used for the commercial PWR SNF reactivity consequence sensitivity calculation (Ref. 21, Section 2). This latter calculation showed that results had little sensitivity to the exit junction area. Consequently, only two exit junction areas were used for this calculation: a 10.0-cm$^2$ and a 0.1-cm$^2$ area (Cases: rlp5.MOX04cR1 and rlp5.MOX04eR1, respectively). These results are shown in Figures 6.2-1 through 6.2-5. No discernable differences are apparent in the results from these cases, which are similar to the results observed for the LEU low reactivity insertion rate cases (Ref. 21, Section 6). Thus, for this slow reactivity insertion rate, the exit area had no effect on the results. The negative reactivity from the change in fuel temperature and bulk density was sufficient to compensate for the slow reactivity rate without vapor generation as shown in Figure 6.2-2 where the maximum SNF assembly temperatures are below the vaporization level. Differential pressure histories associated with the corresponding temperature histories are shown in Figure 6.2-1. Differential pressure values are shown since the change in pressure is small with respect to the absolute pressure. The fission power/assembly history is given in Figure 6.2-3. The additional assembly burnup due to these transient criticality events is approximately 5.0e-7 GWd/MTHM. The WP moderator inventory history is given in Figure 6.2-4; and the exit junction mass flow rates in Figure 6.2-5.

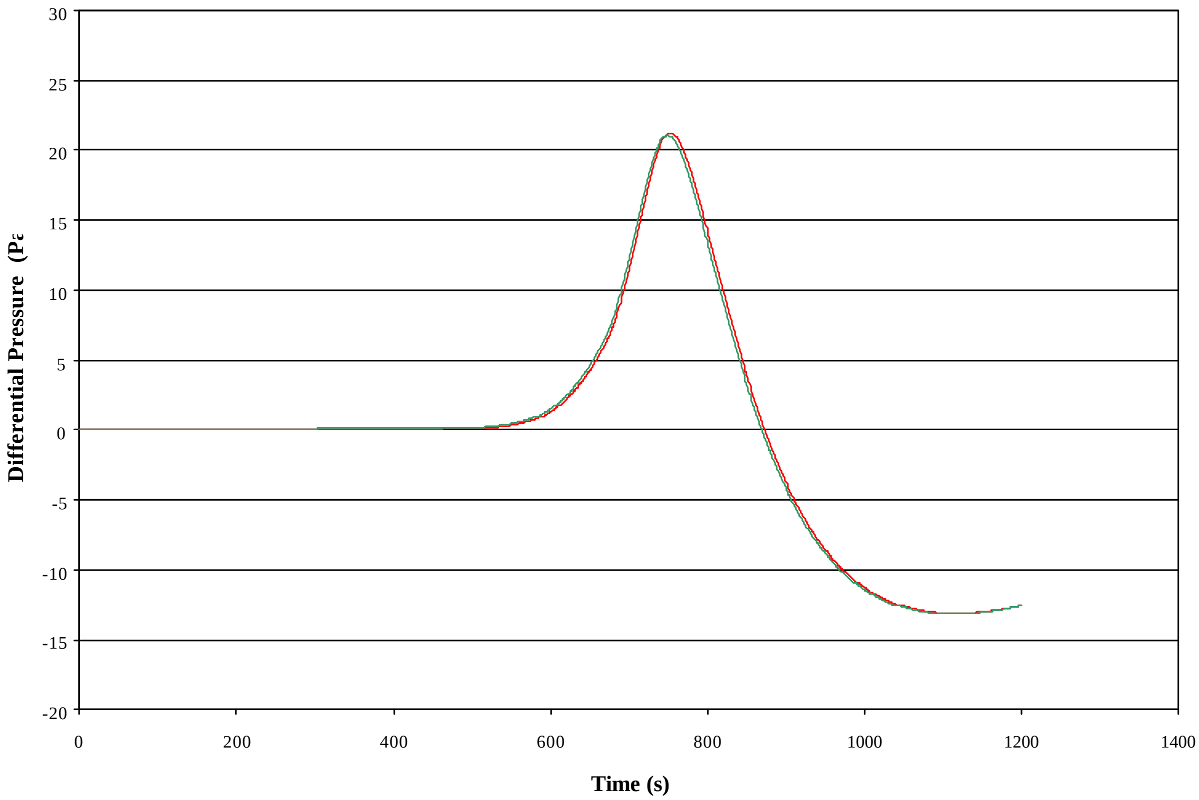


Figure 6.2-1. WP Pressure Histories for 10.0- and 0.1-cm$^2$ Egress Junction Areas and a 0.0004-$/s Reactivity Insertion Rate

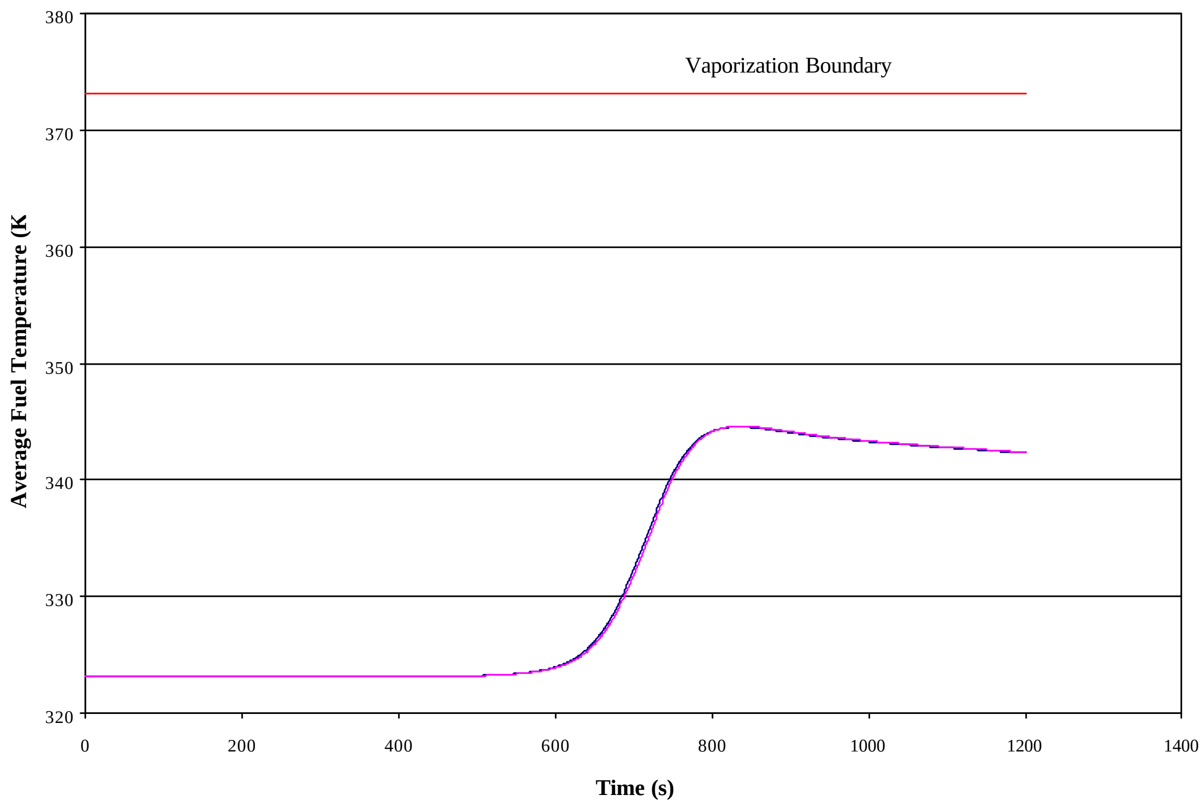


Figure 6.2-2. Fuel Temperature Histories for 10.0- and 0.1-cm$^2$ Egress Junction Areas and a 0.0004-$/s Reactivity Insertion Rate

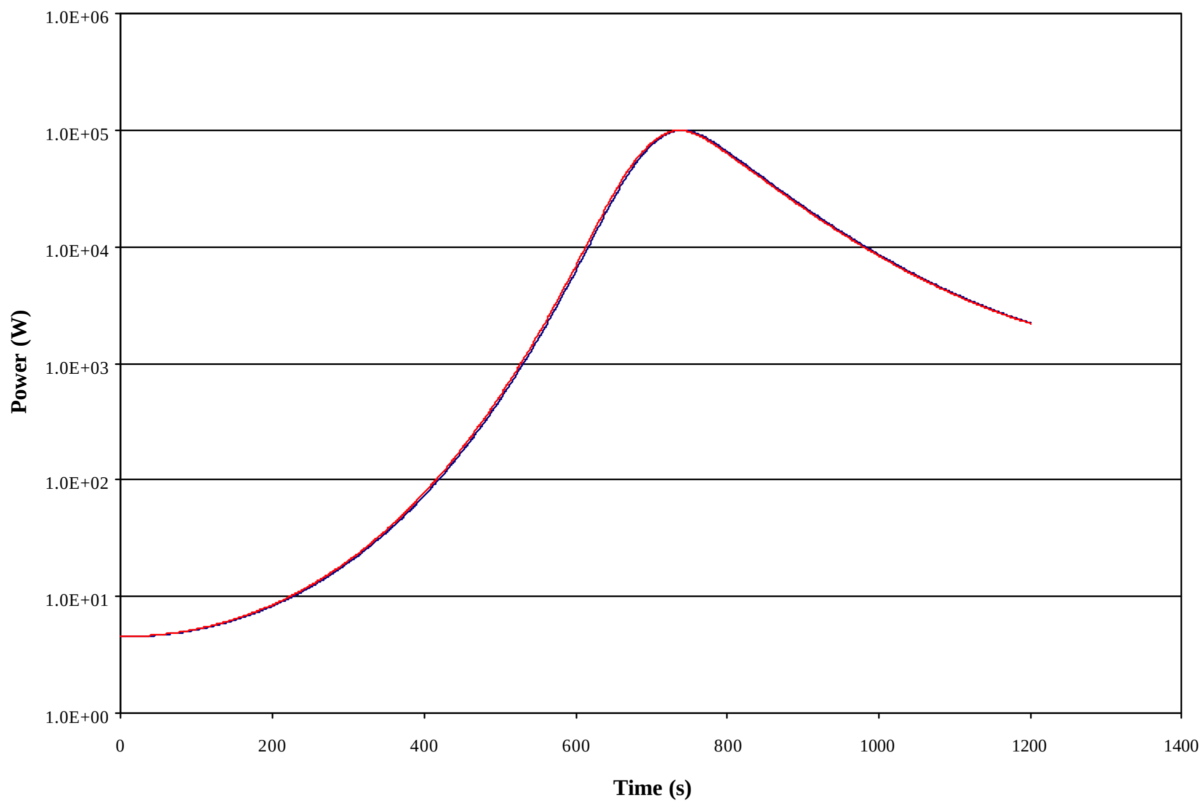


Figure 6.2-3. Fission Power Histories for 10.0- and 0.1-cm$^2$ Egress Junction Areas and a 0.0004-$/s Reactivity Insertion Rate

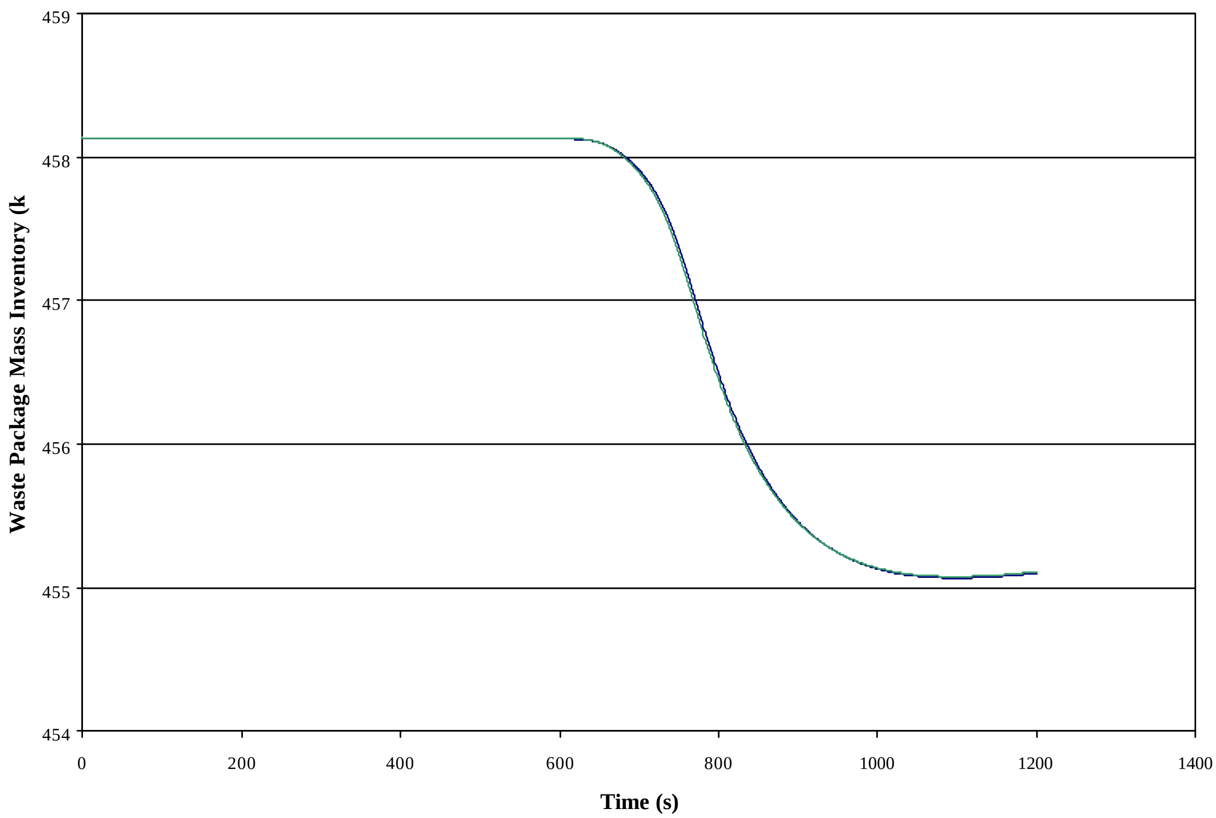


Figure 6.2-4. WP Moderator Inventory Histories for 10.0- and 0.1-$cm^2$ Egress Junction Areas and a 0.0004-$/s Reactivity Insertion Rate

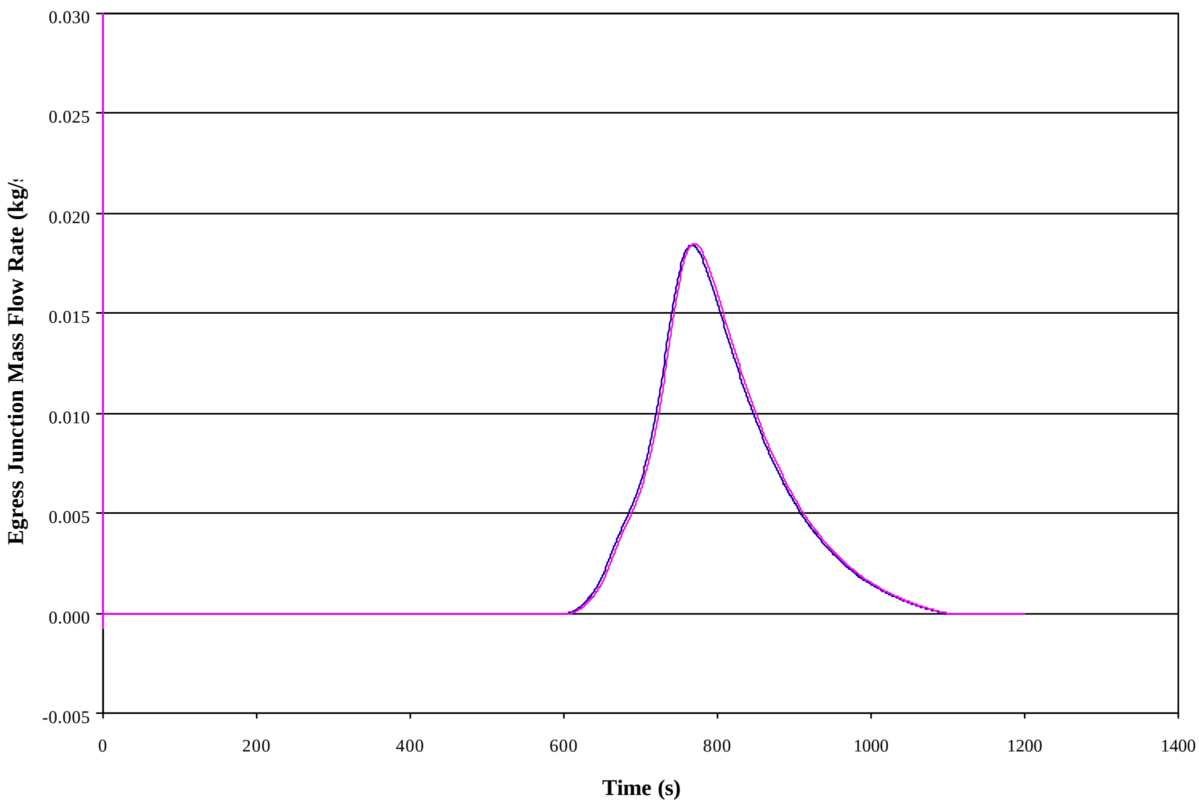


Figure 6.2-5. WP Egress Junction Mass Flow Rate Histories for 10.0- and 0.1-$cm^2$ Egress Junction Areas and a 0.0004-$/s Reactivity Insertion Rate

## 6.3 STEADY-STATE CRITICALITY

Results from the steady-state criticality calculation are given in terms of the excess radionuclide inventory in curies produced during the postulated criticality event. The excess inventory is referenced to the baseline levels from the MOX SNF in a decay-only mode. Table 6.3-1 lists the total radionuclide inventory levels based on 61 nuclides for the 21 PWR MOX WP at the end of the criticality event and extending 20,000 years past the end of the criticality. The radionuclide inventory level was nearly a factor of 2 over the baseline level immediately following the criticality event, but fell to less than 3% over the baseline level by 20,000 years after termination of the criticality event. The baseline activity level in this time period is predominately due to the Pu isotopes (> 90%) and is the principal activity contributor for the criticality case also ($ 70%) (Spreadsheet Curie.xls: Sheet "Summary"). Table 6.3-2 lists the changes in individual nuclide inventories relative to the baseline values for the same time periods.

Table 6.3-1. Total Activity (61 nuclides) for 21 PWR MOX SNF Waste Package for Steady-State Criticality Event

| Time Following Emplacement (y) | Time Following Criticality Termination (y) | Total Activity No-Criticality (Ci) | Total Activity 10,000 y Criticality (Ci) | Increase over Baseline Case (%) |
|---|---|---|---|---|
| 36000 | 1000 | 3.98004E+03 | 4.70748E+03 | 18.3 |
| 45000 | 10000 | 2.96840E+03 | 3.19413E+03 | 7.6 |
| 55000 | 20000 | 2.23317E+03 | 2.28937E+03 | 2.5 |

Table 6.3-2. Isotopic Activity for 21 PWR MOX SNF Waste Package for Steady-State Criticality Event

| Isotope | Activity (Ci) 25,000 y | Change at End of 10,000 y Criticality (Ci) | Change 1,000 y after 10,000 y Criticality (Ci) | Change 10,000 y after 10,000 y Criticality (Ci) | Change 20,000 y After 10,000 y Criticality (Ci) |
|---|---|---|---|---|---|
| H3 | 0.00000E+00 | 3.34950E-02 | 1.28660E-26 | 0.00000E+00 | 0.00000E+00 |
| C14 | 1.73000E-02 | 3.40423E-02 | 3.01221E-02 | 1.01607E-02 | 3.03121E-03 |
| Cl36 | 4.60000E-03 | -2.63100E-02 | -2.63100E-02 | 3.08000E-03 | 3.06000E-03 |
| Fe55 | 0.00000E+00 | 1.20000E-01 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| Co60 | 0.00000E+00 | 4.32000E-01 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| Ni59 | 9.49000E-01 | 1.75000E-01 | 1.83000E-01 | 1.64000E-01 | 1.49000E-01 |
| Ni63 | 0.00000E+00 | 2.40000E-02 | -3.80602E-01 | 3.60000E-02 | 3.60000E-02 |
| Se79 | 0.00000E+00 | -3.51500E-01 | -3.51600E-01 | 3.60000E-02 | 3.60000E-02 |
| Kr85 | 0.00000E+00 | 4.60978E-01 | -2.18000E-05 | 2.28000E-04 | 1.61600E-04 |
| Sr90 | 0.00000E+00 | 3.95000E+00 | -5.39000E+00 | 3.70000E-01 | 3.60000E-01 |
| Y90 | 0.00000E+00 | 9.40520E+00 | 1.89000E-10 | 0.00000E+00 | 0.00000E+00 |
| Zr93 | 5.59000E-02 | 3.08700E-01 | 3.08600E-01 | 9.60000E-03 | 1.06000E-02 |
| Nb93m | 5.60000E-02 | 4.29200E-01 | 4.23200E-01 | 5.70000E-03 | 5.60000E-03 |
| Nb94 | 2.49000E-01 | 4.73430E-02 | 4.63310E-02 | 3.30000E-02 | 2.36000E-02 |
| Tc99 | 4.99000E-04 | 5.42404E+00 | 5.40704E+00 | 1.23900E-03 | 1.23800E-03 |
| Ru106 | 0.00000E+00 | 6.49060E+00 | -1.93000E-02 | 0.00000E+00 | 0.00000E+00 |
| Pd107 | 1.54000E-18 | 1.19000E-01 | 1.19000E-01 | 5.30000E-02 | 5.30000E-02 |
| Cd113m | 0.00000E+00 | -3.30708E-01 | -3.35000E-01 | 0.00000E+00 | 0.00000E+00 |
| Sb125 | 0.00000E+00 | 2.11100E-01 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| Sn126 | 3.92000E-01 | 2.60000E-02 | 2.60000E-02 | 2.50000E-02 | 2.30000E-02 |
| I129 | 5.75000E-15 | 2.06000E-02 | 2.06000E-02 | 2.86000E-15 | 2.86000E-15 |
| Cs134 | 0.00000E+00 | 5.78000E+00 | 0.00000E+00 | 2.10000E-07 | 2.10000E-07 |
| Cs135 | 5.61000E-25 | 3.87997E-01 | 3.87997E-01 | -3.00000E-27 | -2.00000E-27 |
| Cs137 | 0.00000E+00 | 1.64000E+01 | 1.51000E-09 | 0.00000E+00 | 0.00000E+00 |
| Ba137m | 0.00000E+00 | 1.55000E+01 | 1.43000E-09 | 0.00000E+00 | 0.00000E+00 |
| Pm147 | 0.00000E+00 | 5.52000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| Sm147 | 0.00000E+00 | 2.82000E-06 | 2.82000E-06 | 0.00000E+00 | 0.00000E+00 |
| Sm151 | 0.00000E+00 | 3.54000E+00 | 1.60000E-03 | 0.00000E+00 | 0.00000E+00 |
| Eu154 | 0.00000E+00 | 4.17000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| Eu155 | 0.00000E+00 | 3.10000E-01 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| Pb210 | 7.32000E-02 | 1.80000E-02 | 2.30000E-02 | 8.70000E-02 | 1.56000E-01 |
| Po218 | 7.32000E-02 | 1.80000E-02 | 2.30000E-02 | 8.70000E-02 | 1.56000E-01 |
| Fr221 | 8.64000E-02 | -8.00000E-03 | -9.00000E-03 | -1.60000E-02 | -1.90000E-02 |
| Ra226 | 7.32000E-02 | 1.80000E-02 | 2.30000E-02 | 8.70000E-02 | 1.56000E-01 |
| Ra228 | 1.90000E-07 | 0.00000E+00 | 0.00000E+00 | 6.00000E-09 | 1.50000E-08 |
| Ac227 | 2.25000E-03 | 2.14600E-02 | 2.10200E-02 | 1.71300E-02 | 1.36500E-02 |
| Th229 | 8.64000E-02 | -8.00000E-03 | -9.00000E-03 | -1.60000E-02 | -1.90000E-02 |
| Th230 | 7.98000E-02 | 2.90000E-02 | 3.70000E-02 | 1.04000E-01 | 1.70000E-01 |
| Th232 | 1.90000E-07 | 0.00000E+00 | 0.00000E+00 | 6.00000E-09 | 1.50000E-08 |
| Pa231 | 2.25000E-03 | 2.14600E-02 | 2.10200E-02 | 1.71400E-02 | 1.36500E-02 |
| U232 | 1.08000E-07 | 1.05999E-02 | 2.68000E-06 | 2.06430E-06 | 1.94990E-06 |
| U233 | 1.45000E-01 | -2.30000E-02 | -2.30000E-02 | -2.20000E-02 | -2.10000E-02 |
| U234 | 3.82000E-01 | 8.85000E-01 | 8.96000E-01 | 8.72000E-01 | 8.48000E-01 |
| U235 | 8.53000E-03 | -1.18000E-03 | -1.13000E-03 | -1.30000E-03 | -1.30000E-03 |
| U236 | 2.19000E-01 | 9.00000E-03 | 1.00000E-02 | 1.60000E-02 | 1.90000E-02 |
| U238 | 1.32000E-01 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| Np237 | 1.43000E+00 | 0.00000E+00 | 0.00000E+00 | 1.00000E-02 | 0.00000E+00 |
| Pu238 | 0.00000E+00 | 3.60000E+01 | 1.42000E-02 | 2.44000E-23 | 0.00000E+00 |
| Pu239 | 2.15000E+02 | -9.00000E+00 | -9.00000E+00 | -6.00000E+00 | -4.60000E+00 |

| Isotope | Activity (Ci) 25,000 y | Change at End of 10,000 y Criticality (Ci) | Change 1,000 y after 10,000 y Criticality (Ci) | Change 10,000 y after 10,000 y Criticality (Ci) | Change 20,000 y After 10,000 y Criticality (Ci) |
|---|---|---|---|---|---|
| Pu240 | 5.84000E+01 | 3.80000E+01 | 3.41000E+01 | 1.32400E+01 | 4.59000E+00 |
| Pu241 | 4.05000E-02 | 2.12821E+01 | -6.20000E-03 | -2.97000E-03 | -1.32000E-03 |
| Pu242 | 1.85000E+00 | -1.30000E-01 | -1.40000E-01 | -1.40000E-01 | -1.40000E-01 |
| Am241 | 4.21000E-02 | 2.06814E+01 | 4.31280E+00 | -3.08000E-03 | -1.31000E-03 |
| Am242m | 0.00000E+00 | 5.81000E-02 | 4.25000E-04 | 2.60000E-23 | 0.00000E+00 |
| Am243 | 2.11000E+00 | 4.28800E+00 | 3.90100E+00 | 1.66900E+00 | 6.54000E-01 |
| Cm242 | 0.00000E+00 | 3.03000E-01 | 3.50000E-04 | 2.14000E-23 | 0.00000E+00 |
| Cm243 | 0.00000E+00 | 3.86000E-07 | 1.06000E-17 | 0.00000E+00 | 0.00000E+00 |
| Cm244 | 0.00000E+00 | 6.00000E-01 | 1.40000E-17 | 0.00000E+00 | 0.00000E+00 |
| Cm245 | 4.04000E-02 | -6.70000E-03 | -6.20000E-03 | -2.96000E-03 | -1.31000E-03 |
| Cm246 | 8.49000E-04 | 1.25400E-03 | 1.08100E-03 | 2.90700E-04 | 6.70000E-05 |
| Cm247 | 1.11000E-07 | -1.34000E-08 | -1.34000E-08 | -1.35000E-08 | -1.35000E-08 |
| | | | | | |
| **Total** | | 1.91678E+02 | 3.46400E+01 | 1.07493E+01 | 2.67642E+00 |
| **Decreased** | | -9.85940E+00 | -1.56714E+01 | -6.17931E+00 | -4.78124E+00 |
| **Increased** | | 2.01504E+02 | 5.03114E+01 | 1.69286E+01 | 7.45766E+00 |
| **Max Increase** | | 3.80000E+01 | 3.41000E+01 | 1.32400E+01 | 4.59000E+00 |
| **% Increase Due to Pu240** | | 18.9 | 67.8 | 78.2 | 61.5 |
| **Total/WP** | 2.88853E+02 | 4.02524E+03 | 7.27441E+02 | 2.25734E+02 | 5.62048E+01 |

# 7. ATTACHMENTS

Hardcopy attachments are listed in Table 7-1. Electronic data files are provided on a compact disk (CD) (Ref. 7).

Table 7-1. List of Attachments

| Attachment Number | Description | Number of Pages |
|---|---|---|
| I | SAS2H Data File for MOX Reactivity Calculation (out.mox1e.wp) | 4 |
| II | STRIP FORTRAN Source with Sample Input and Output Files | 8 |
| III | MOX SAS2H Depletion Data File W3_35-5gwd_2cy-6stps | 5 |
| IV | Base RELAP5/MOD3.2 Data File | 25 |
| V | Script Files to Collect Isotopic Values from ORIGEN-S Output Files | 2 |
| VI | Document Input Reference Sheet (DIRS) | 8 |
| VII | Directory of Files on CD (Ref. 7) | 5 |
| VIII | Calculational Worksheets for RELAP5 Geometry | 5 |

## 8. REFERENCES

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3. CRWMS M&O 1998. *Software Qualification Report for MCNP Version 4B2, A General Monte Carlo N-Particle Transport Code.* CSCI: 30033 V4B2LV. DI: 30033-2003 Rev. 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980622.0637.

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ATTACHMENT I

SAS2H input data file for the base MOX SNF WP reactivity feedback calculation. Additional cases use this file with variations in the fuel temperatures and water densities.

```
=sas2h    parm='skipcellwt,skipshipdata'
SAS2H: Fissile PU 4.0wt%, 35.6GWD/MTU, 25000yr, Inf-Assem Mixed H2O+Iron
'
' Iron (fe) rust in the water around the fuel pins 58 wt. %
'    Case out.mox.wp.inp - Compares with 25000 yr MCNP case 21MS1F
'
' Westinghouse 17x17 MOX fuel Assembly, high temp burnup 35.6 Gwd/MTHM
' Vantage 5 bundle - Fissile Pu 4 wt% HM
' Representation follows Commercial SNF analysis using B & W 15x15 fuel
assembly
' Case out.fe.mox.inp - Path B outer radius derived from 12.23 pin cells/G.T.
'                       Mix=0 in fuel pin gap
' Case out.fe.mox1a.inp - Path B radius used 10.56 p.c/G.T
'                       Mix=0 in fuel pin gap
' Case out.fe.mox1b.inp - Path B radius used 10.56 p.c/G.T
'                       Mix=3 in fuel pin gap
' Case out.fe.mox1c.inp - Path B radius used 10.56 p.c/G.T
'                       Mix=0 in fuel pin gap, GT radii modified
' Case out.fe.mox1d.inp - Path B radius used 10.56 p.c/G.T
'                       Mix=0 in fuel pin gap, GT radii modified,
'                       Correct MIX=2 for MOX dimensions, H2O densities
' Case out.fe.mox1f.inp - Path B radius used 10.56 p.c/G.T
'                       Mix=0 in fuel pin gap, GT radii modified,
'                       Correct MIX=2 for MOX dimensions, H2O densities
'                       Sas2h eigenvalue high - raise last radius
' Case out.mox1a.wpi.inp - Path B radius used 10.56 p.c/G.T
'                       Mix=0 in fuel pin gap, GT radii modified,
'                       Correct MIX=2 for MOX dimensions, H2O densities
'                       Mix Comp as (1-x)*Fe2O3 + x*H2O
' Case out.mox1a.wp.inp Path-B radius 11.04 p.c/G.T. Buckling search for WP
'                       Mix=0 in fuel pin gap, GT radii modified,
'                       Correct MIX=2 for MOX dimensions, H2O densities
'                       Mix Comp as (1-x)*Fe2O3 + x*H2O
' Case out.mox1b.wp.inp Buckling search for WP, set dy=55.0
' Case out.mox1c.wp.inp Buckling search for WP, set dy=40.0
' Case out.mox1e.wp.inp Buckling search for WP, set dy=44.0
'
44group     latticecell
'
'  MCNP input mixtures for fuel-pin-cell, assembly-cell, and waste package
'  mixtures from SAS2H-ORIGENS at 25000 yr
'
  u-233       1 0 8.308600E-07 300.00 end
  u-234       1 0 3.386430E-06 300.00 end
  u-235       1 0 2.169270E-04 300.00 end
  u-236       1 0 1.848360E-04 300.00 end
  u-238       1 0 2.136450E-02 300.00 end
  np-237      1 0 1.105420E-04 300.00 end
```

```
  pu-239      1 0 1.868310E-04 300.00 end
  pu-240      1 0 1.381940E-05 300.00 end
  pu-241      1 0 2.099100E-11 300.00 end
  pu-242      1 0 2.490360E-05 300.00 end
  am-241      1 0 6.586460E-10 300.00 end
  am-243      1 0 5.576220E-07 300.00 end
  o           1 0 5.003520E-02 300.00 end
  mo-95       1 0 3.876310E-05 300.00 end
  tc-99       1 0 4.254610E-05 300.00 end
  ru-101      1 0 4.720380E-05 300.00 end
  rh-103      1 0 4.214700E-05 300.00 end
  ag-109      1 0 1.040670E-05 300.00 end
  nd-143      1 0 3.224570E-05 300.00 end
  nd-145      1 0 2.342700E-05 300.00 end
  sm-147      1 0 1.001630E-05 300.00 end
  sm-149      1 0 1.898300E-07 300.00 end
  sm-150      1 0 1.291530E-05 300.00 end
  sm-152      1 0 6.372550E-06 300.00 end
  eu-151      1 0 1.197420E-06 300.00 end
  eu-153      1 0 5.824350E-06 300.00 end
  gd-155      1 0 2.891220E-07 300.00 end
sr-90      1 0 1-20        300.00 end
zr-93      1 0 1-20        300.00 end
zr-94      1 0 1-20        300.00 end
zr-95      1 0 1-20        300.00 end
nb-94      1 0 1-20        300.00 end
ru-106     1 0 1-20        300.00 end
rh-105     1 0 1-20        300.00 end
pd-105     1 0 1-20        300.00 end
pd-108     1 0 1-20        300.00 end
sb-124     1 0 1-20        300.00 end
xe-131     1 0 1-20        300.00 end
xe-132     1 0 1-20        300.00 end
xe-135     1 0 1-20        300.00 end
xe-136     1 0 1-20        300.00 end
cs-134     1 0 1-20        300.00 end
cs-135     1 0 1-20        300.00 end
cs-137     1 0 1-20        300.00 end
ba-136     1 0 1-20        300.00 end
la-139     1 0 1-20        300.00 end
pr-141     1 0 1-20        300.00 end
pr-143     1 0 1-20        300.00 end
nd-147     1 0 1-20        300.00 end
ce-144     1 0 1-20        300.00 end
pm-147     1 0 1-20        300.00 end
pm-148     1 0 1-20        300.00 end
eu-154     1 0 1-20        300.00 end
eu-155     1 0 1-20        300.00 end
'-----------------------------------------
'
'  Homogenized zirc-4 clad and water gap
'  Spreadsheet MOX_96_sas2h.xls; Parh-B geom
'
 h         2 0 7.553602-03  300.00 end
```

```
 o         2 0 3.776801-03  300.00 end
cr         2 0 6.740014-05  300.00 end
fe         2 0 1.255093-04  300.00 end
zr         2 0 3.771931-02  300.00 end
arbm-sn  5.819074 1  0  0  0  50000  100.0
           2 0.014   300.00 end
'
'  sn         2 0 4.13376-04  300.00 end
'--------------------------------------------
'
'  Moderator around fuel pins and guide tubes
'
'  Contains 58 wt% fe2o3
'
'  h          3  0  2.80888-02  300.00  end
'  o          3  0  4.84328-02  300.00  end
'  fe         3  0  2.29256-02  300.00  end
'
'  Mix Moderator Comp as (1-x)*Fe2O3 + x*H2O
'    x=0.73007 lambda = 0.996133
'    x=0.73    lambda = 0.996107
'
 h          3  0  5.64049-02  300.00  end
 o          3  0  3.74873-02  300.00  end
fe          3  0  6.18991-03  300.00  end
'
' 0 ppm boron
'--------------------------------------------
'
'  Zirc-4
'
 o         4 0 2.96400-04  300.00 end
cr         4 0 7.59820-05  300.00 end
fe         4 0 1.41490-04  300.00 end
zr         4 0 4.25220-02  300.00 end
arbm-sn    6.5600  1  0  0  0  50000  100.0
           4 0.014   300.00 end
'
'  sn         4 0 4.6601-04  300.00 end
'--------------------------------------------
'
'  Water region inside of the guide tubes
'
 o         5 0 3.34390-02  300.00 end
 h         5 0 6.68780-02  300.00 end
'
' 0 ppm boron
'--------------------------------------------
'
end comp
'---------------------------------------------
'
'  fuel - pin - cell geometry:
'  Water - Zirc-4  homogenized for water in gap
```

```
'
'  MCNP assembly pitch = 10.7086 + 10.7086 = 21.4172
'  21.4172/17(pin-cells) = 1.25984 pin-cell pitch
'  pellet OD  0.784352 cm
'  clad   ID  0.8001   cm
'  clad   OD  0.9144   cm
'  Clean water + hematite + Zirc4 homogenized into MIX=2
'
squarepitch  1.25984  0.784352 1  3  0.9144  2 0.8001 0 end
'
'  Standard pin-cell pitch = 1.25984
'  Standard gap with gas and standard clad
'
'----------------------------------------------------------------
'
'  Inf - pin-cell buckling
'
more data   bkl=0.8150   dy=43.870   dz=365.76   end
'----------------------------------------------------------------
'
'  assembly and cycle parameters
'
'  guide tube region is different
'  Path B radii determined by keeping pin cell area fractions
'  the same as in the Commercial SNF SAS2H cases
'  spreadsheet MOX_96_SAH2H.xls Sheet PATH-B Geom - 10.56 pin cells/G.T.
'
npin/assm=264 fuelngth=365.76 ncycles=1 nlib/cyc=1
printlevel=7 inplevel=3 numztotal=4   end
5  0.5715
4  0.61214  3 0.7107886  500 2.4665
'     4  0.61214  3 0.7107886  500 2.416681
'
'  Inf - assembly buckling
'
bon   end
nit   end
xsd
SAS2H: Fissile Pu 4.0 wt% HM, 35.6GWD/MTU, 25000yr, Inf-Assem
x5=  1.0-4  1.0-4  1.0  0.0  0.0  0.815
     43.870  365.76   0.0   1.0   1.0-3   0.75  end
power=7.25 burn=1.0-20 down=1.0-20  end
end
```

ATTACHMENT II

STRIP Program

The RELAP5/MOD3.2 program writes two files as output:

1) a formatted print file containing 'major edits' at specified times, a list periodically of the minor edit variables, and
2) a binary 'restart' file to enable a case to resume.

The major edits form periodic snapshots of the problem variables. Minor edits form histories of particular problem variables and can thus be displayed graphically. The RELAP5/MOD3.2 code also has an option to collect all the minor edit variables at each time point from the restart file and put them into a formatted "strip" file. The FORTRAN-90 program, "Strip", reads a RELAP5/MOD3.2 strip file, pairs the time variable with each minor edit variable and writes the information in a series of more compact files for use in later analysis. The output of the code can be readily checked against the strip files by visual inspection.

1. STRIP Source

```
C     Last change:  T    16 Aug 99    4:40 pm
      program strip
c
      implicit REAL*8  (a-h,o-z)
c
c     program to read RELAP strip files and align into columns for use
c     with Excel or Psiplot for plotting.
c
c
c     units
c     50     = data input
c     55     = spread sheet output
c     60     = print file
c
      dimension             plotdat(75)
      INTEGER*4             scrno, scrni, ital1, isprd
      LOGICAL*4             isfopn, isfdef, skipr
      CHARACTER*10          headr1, headr2, headr3
      CHARACTER*1           alf(27)
      CHARACTER*1           num(10), noyes, yes
      CHARACTER*120         iomsg
      CHARACTER*80          card
      CHARACTER*15          filenam, outfile, avar, tmpnam, dum1, dum2
      CHARACTER*10          alfvar(75), numvar(75)
      CHARACTER*13          cblnk
      CHARACTER*7           chdir(2)
c
      data cblnk /'             '/
      data headr1 /'plotinf   '/, headr2 /'plotalf   '/,
     *     headr3 /'plotrec   '/
      data yes   /'y'/
```

```
c
      data num /'0', '1', '2', '3', '4', '5', '6', '7', '8', '9'/
      data maxpts /1500/, maxvar /75/
      data delt20 /2.0d0/
      DATA zero   /0.0e0/
c
c     define files and open them
c
      scrni  = 5
      scrno  = 6
      ital1  = 50
      iout   = 60
      WRITE (UNIT=scrno, FMT=2041)
2041  FORMAT (' input data file name = ':)
      read (UNIT=scrni, FMT=3001) filenam
      WRITE (UNIT=scrno, FMT=2042)
2042  FORMAT (' input final time = ':)
      read (scrni, '(e12.5)') fintim
c
3001  FORMAT (a15)
3002  FORMAT (a4)
      inquire (file=filenam, exist=isfdef, err=1001, iostat=ierr)
      if (.not.isfdef) then
         write (scrno, 2005) filenam
         GO TO 2000
      end if
2005  format (' data file ',a15,' does not exist'/' exit called')
      open (unit=ital1, file=filenam, status='old', form='formatted',
     *      access='sequential', err=1005, iostat=ierr)
c
c     count records in filenam - mrec
      irec   = 1
      mrec   = 0
10    read  (UNIT=ital1, FMT=1107) card
      dum1   = ADJUSTL(card(1:10))
      if (dum1(1:7) .ne. headr3(1:7))go to 10
      mrec   = mrec + 1
      read (card(16:30), '(e15.6)') timdat
      if (timdat .lt. fintim) go to 10
      rewind (UNIT=ital1)
c
      skipr  = .false.
      write (UNIT=scrno, FMT=2044) mrec
2044  format (' Input file has ',i5, 'records'/
     *        ' set skip flag to reduce number y or n' :)
      read (scrni, '(a1)') noyes
      if (noyes .eq. yes) then
         skipr = .true.
         write (UNIT=scrno, FMT=2046)
         read (scrni, '(i6)') numskp
      END if
2046  format (' number of records to skip = ':)
c
25    write (UNIT=scrno, FMT=2045)
```

```
2045  format (' Continue data procesing - y or n ':)
      READ (scrni, '(a1)') noyes
      if (noyes .ne. yes) go to 2000
c
c     read two records, skip first record - title records
      read  (UNIT=ital1, FMT=1107) card
      read  (UNIT=ital1, FMT=1107) card
1107  format (a80)
c     look for plot information record
30    read  (UNIT=ital1, FMT=1107) card
      DO 40 i=1,80
      m = i
      IF (card(i:i) .ne. ' ') GO TO 45
40    continue
c     blank card - read next one
      go to 30
45    IF (card(m:m+6) .eq. headr1(1:7)) then
         read (card(11:20), '(i10)') numdat
      END if
      IF (numdat .GT. maxvar) then
         WRITE (UNIT=scrno, FMT=1023)
         GO TO 2000
      END if
1023  FORMAT (' number of minor edits exceeds max allowed'/
     *         ' exit called')
      numdat = numdat - 1
c     read minor edit variable headings
      read (UNIT=ital1, FMT=1020) avar, (alfvar(k), k=1,numdat)
      read (UNIT=ital1, FMT=1020) avar, (numvar(k), k=1,numdat)
1020  format (8a10)
c
c     select the record to plot
c
      ivarl = irec + 1
      IF (ivarl .GT. numdat) then
         WRITE (UNIT=scrno, FMT=1022)
         GO TO 2000
      END if
1022  FORMAT (' list of minor edits exceeded')
      do 75 n=ivarl,numdat
      write (UNIT=scrno, FMT=2022) alfvar(n), numvar(n)
      READ (scrni, '(a1)') noyes
      irec = n
      IF (noyes .EQ. yes) GO TO 80
75    continue
c     check for more files
      go to 25
c
c     read the data records - terminate with EOF
c
2022  format (1x,a10,2x,a10,' ':)
c
80    continue
c
```

```
      dum1    = ADJUSTL(alfvar(irec))
      dum2    = ADJUSTL(numvar(irec))
      DO 84 j=1,8
      IF (dum1(j:j) .EQ. ' ') GO TO 84
      jdx = j
84    continue
      DO 86 j=1,8
      IF (dum2(j:j) .EQ. ' ') GO TO 86
      kdx = j
86    continue
      jdx     = min0(jdx,5)
      kdx     = 8-jdx
      tmpnam = dum1(1:jdx)//dum2(1:kdx)
      outfile = tmpnam(1:(jdx+kdx))//'.dat'
c
c      CALL SYSTEM ('dir')
c      pause
      call SYSTEM ('cd temp')
c      CALL SYSTEM ('dir')
c      WRITE (UNIT=scrno, FMT=9031) outfile
9031  FORMAT (' file name = ',a12)
c      pause
      inquire (file=outfile, exist=isfdef, err=1001, iostat=ierr)
      if (isfdef) then
         open (unit=iout, file=outfile, status='old',
     *   form='formatted', access='sequential', err=1010,
     *   iostat=ierr)
         close (UNIT=iout,STATUS='delete')
      end if
c
      open (unit=iout, file=outfile, status='new',
     *      form='formatted', access='sequential', err=1010,
     *      iostat=ierr)
c
      WRITE (UNIT=iout, FMT=2020) filenam
2020  FORMAT (5x,'data from file - ',a15/)
      WRITE (UNIT=iout, FMT=2015) alfvar(1),
     * alfvar(irec), numvar(irec)
2015  format (5x,a10,5x,a10/5x,' (sec)   ',4x,a10/)
      lrecno = 0
      IF (skipr) then
         nrec   = numskp
      else
         nrec  = 1
      end if
c      WRITE (UNIT=scrno, FMT=9010) nrec
9010  FORMAT (' nrec to skip = ',i6)
      kcnt   = 0
      ctim   = zero
      call system ('cd ..')
c      CALL SYSTEM ('dir')
c      pause
      lrecno = kcnt
90    continue
```

```
      nxtrec = lrecno + nrec
c     read the first record of strip file
      read (UNIT=ital1, FMT=2001, END=2090, ERR=1001) avar,
     * (plotdat(k), k=1,numdat)
      IF (.not. skipr) GO TO 96
c     store the first record
      IF (kcnt .EQ. 0) GO TO 96
c     skip nrec-1 records
      kcnt = kcnt + 1
      if (kcnt .lt. nxtrec) then
      GO TO 90
      end if
c      WRITE (UNIT=scrno, FMT=9021) nxtrec
9021  FORMAT (' nxtrec = ', i6)
2001  format (a15, 4e15.6/(5e15.6))
2010  FORMAT (1p,2e15.6)
96    continue
      lrecno = kcnt
      call system ('cd temp')
      WRITE (UNIT=iout, FMT=2010) plotdat(1), plotdat(irec)
      if (kcnt .eq. 0) kcnt = 1
      call system ('cd ..')
c      call system ('cd juveni~1')
2090  continue
      IF (plotdat(1) .lt. fintim) GO TO 90
      rewind (UNIT=ital1)
      CALL SYSTEM ('cd temp')
      CLOSE (UNIT=iout, STATUS='keep')
      call system ('cd ..')
c      call system ('cd juveni~1')
      go to 25
c
c     error messages
c
1001  write (scrno, 1002) ierr, filenam
1002  format (' error = ',i8,' encountered attempting to access file ',
     * a20)
      go to 2000
c
1005  write (scrno, 1006) ierr, filenam
1006  format (' error = ',i8,' encountered attempting to open file ',
     * a20)
      go to 2000
c
1010  write (scrno, 1006) ierr, outfile
c
2000  continue
      end
```

2. Sample Input Strip File

```
  RELAP5/3.2           strip file                24-Jun-1999
  relap5/mod2  waste package c103x1hbv.test.strp
  plotinf         55         0
  plotalf   time      p         p         p         p         p         p
  p         p         hvmix     hvmix     sonicj    vapgen    vapgen
vapgen
  vapgen    vapgen    vapgen    tmass     tmassv    tmassv    tmassv
tmassv
  tmassv    tmassv    tmassv    tmassv    tmassv    tmassv    tmassv
mflowj
  mflowj    mflowj    mflowj    mflowj    mflowj    mflowj    mflowj
mflowj
  mflowj    mflowj    mflowj    htvat     rkfipow   rkgapow   rkreac
cntrlvar
  cntrlvar  cntrlvar  cntrlvar  cntrlvar  cntrlvar  cntrlvar  cntrlvar
  plotnum          0 150010000  60010000  70010000  80010000  90010000
100010000
 250010000 240010000  90010000 250010000 250010000 150010000  60010000
70010000
  80010000  90010000 100010000         0 260010000 150010000  60010000
70010000
  80010000  90010000 100010000 220010000 230010000 240010000 250010000
80010000
  80020000  70010000  70020000 240010000 230010000 230020000 250010000
220010000
 220020000  20010000  20020000   3301008         0         0         0
81
        14        56        60        65        70        75        80
  plotrec          .000000E+00   1.013254E+05   1.013254E+05   1.013254E+05
   1.013254E+05   1.013254E+05   1.013254E+05   1.013254E+05   1.013254E+05
    .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
    .000000E+00    .000000E+00    .000000E+00    .000000E+00   4.490972E+02
    .000000E+00   6.368977E+00   1.967957E+01   1.967957E+01   1.967957E+01
   1.967957E+01   1.967957E+01   2.415648E+01   2.415648E+01   1.376029E+01
   3.502303E+01    .000000E+00    .000000E+00    .000000E+00    .000000E+00
    .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
    .000000E+00    .000000E+00    .000000E+00   3.231511E+02   4.634700E+00
   3.653000E-01    .000000E+00    .000000E+00    .000000E+00    .000000E+00
    .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
  plotrec         1.000000E-02   1.075159E+05   1.060990E+05   1.038763E+05
   1.015874E+05   9.924545E+04   9.686730E+04   9.374152E+04   9.516440E+04
    .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
    .000000E+00    .000000E+00    .000000E+00    .000000E+00   4.490874E+02
    .000000E+00   6.368994E+00   1.967962E+01   1.967960E+01   1.967958E+01
   1.967956E+01   1.967954E+01   2.415642E+01   2.415642E+01   1.376026E+01
   3.501335E+01   3.410194E-02   2.372985E-03   2.627495E-02   3.793676E-03
   6.202511E-02   5.451060E-02  -2.357969E-02   2.478254E+00   4.129710E-02
  -1.562832E-02   1.348391E-02   1.050594E-03   3.231511E+02   4.651265E+00
   3.653010E-01   3.553265E-03    .000000E+00  -1.459565E-10  -1.171647E-03
   4.726666E-03   3.555020E-03   5.008634E-02    .000000E+00   7.100000E-01
  plotrec         2.000000E-02   1.046268E+05   1.032420E+05   1.011549E+05
```

```
 9.907315E+04   9.699584E+04   9.492212E+04   9.210218E+04   9.337293E+04
  .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
  .000000E+00    .000000E+00    .000000E+00    .000000E+00   4.490737E+02
  .000000E+00   6.368986E+00   1.967959E+01   1.967957E+01   1.967956E+01
 1.967954E+01   1.967952E+01   2.415640E+01   2.415640E+01   1.376025E+01
 3.500011E+01   1.121941E-03  -2.055325E-05   5.532075E-04  -2.973859E-05
 6.016500E-03   5.328805E-03  -1.381403E-03   2.883632E+00   3.447919E-03
-4.805961E-04   2.801862E-04  -1.327511E-05   3.231511E+02   4.665872E+00
 3.653039E-01   6.650467E-03    .000000E+00  -1.975029E-11  -2.797694E-03
 9.453333E-03   6.655639E-03   1.003265E-01    .000000E+00   7.100000E-01
plotrec         3.000000E-02   1.030670E+05   1.016796E+05   9.958141E+04
 9.748258E+04   9.538323E+04   9.328374E+04   9.043707E+04   9.172116E+04
  .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
  .000000E+00    .000000E+00    .000000E+00    .000000E+00   4.490573E+02
  .000000E+00   6.368982E+00   1.967958E+01   1.967956E+01   1.967954E+01
 1.967953E+01   1.967951E+01   2.415638E+01   2.415638E+01   1.376024E+01
 3.498396E+01   3.957219E-03   2.322828E-04   2.791887E-03   3.424082E-04
 1.097558E-02   9.389635E-03  -3.279840E-03   3.393939E+00   6.364134E-03
-1.647311E-03   1.425709E-03   9.158744E-05   3.231511E+02   4.679066E+00
 3.653085E-01   9.416994E-03    .000000E+00   2.848080E-10  -4.753726E-03
 1.418000E-02   9.426274E-03   1.507059E-01    .000000E+00   7.100000E-01
plotrec         4.000000E-02   1.015588E+05   1.001717E+05   9.807489E+04
 9.597816E+04   9.388151E+04   9.178519E+04   8.894152E+04   9.022409E+04
  .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
  .000000E+00    .000000E+00    .000000E+00    .000000E+00   4.490383E+02
  .000000E+00   6.368978E+00   1.967957E+01   1.967955E+01   1.967953E+01
 1.967951E+01   1.967949E+01   2.415637E+01   2.415637E+01   1.376023E+01
 3.496519E+01   3.526008E-03   2.458410E-04   2.495895E-03   3.359990E-04
 1.018977E-02   8.453297E-03  -2.934241E-03   3.850954E+00   5.489125E-03
-1.321726E-03   1.270948E-03   9.147199E-05   3.231511E+02   4.690910E+00
 3.653145E-01   1.187258E-02    .000000E+00   7.489204E-10  -7.020047E-03
 1.890667E-02   1.188662E-02   2.012105E-01    .000000E+00   7.100000E-01
plotrec         5.000000E-02   1.001984E+05   9.881131E+04   9.671442E+04
 9.461755E+04   9.252073E+04   9.042416E+04   8.758023E+04   8.886284E+04
  .000000E+00    .000000E+00    .000000E+00    .000000E+00    .000000E+00
  .000000E+00    .000000E+00    .000000E+00    .000000E+00   4.490168E+02
  .000000E+00   6.368974E+00   1.967955E+01   1.967954E+01   1.967952E+01
 1.967950E+01   1.967948E+01   2.415635E+01   2.415635E+01   1.376022E+01
 3.494398E+01   3.133709E-03   2.562385E-04   2.224622E-03   3.285738E-04
 9.479837E-03   7.613232E-03  -2.623204E-03   4.272640E+00   4.721612E-03
-1.038623E-03   1.129399E-03   9.080387E-05   3.231511E+02   4.701482E+00
 3.653218E-01   1.403956E-02    .000000E+00   1.356153E-09  -9.574360E-03
 2.363333E-02   1.405897E-02   2.518272E-01    .000000E+00   7.100000E-01
```

3. STRIP Sample Output File

```
    data from file - 103x1hbv.s02

      time            tmass
     (sec)              0

 0.000000E+00   4.490972E+02
```

```
1.000000E-02   4.490874E+02
2.000000E-02   4.490737E+02
3.000000E-02   4.490573E+02
```

ATTACHMENT III

Input data file for 4.0 wt% HM fissile Pu case for a 35.6 GWd/MTHM burn and decay to one million years.

```
=sas2h    parm=skipcellwt
 plut. burning in Westinghouse PWR (2 cycles) cy 1 with WABAs,
'                           cy 2 without WABAs!
'    run all cycles as on SAS2H case - change compositions in PATH B
'    follow boron letdown curve with 6 steps per cycle
44groupndf5   latticecell
'
'  this is a 35.6 MWd/MTM case
'     sas deck modified from from ORNL - B. Murphy
'
' --------------------------------------------------------
'       make sure we use the 44 group library!!!!
' --------------------------------------------------------
'       mixtures for fuel-pin unit cell
' fuel rods are mixed-oxide with uranium and plutonium.
'
'     use 4.0 w/o enriched Pu
'   density derived from fuel mass/volume
uo2   1 den=9.8426 1 901 92234 0.002 92235 0.2 92236 0.001
  92238 99.797 end
puo2  1 den=0.4372 1 901 94239 93.6 94240 5.9 94241 0.4
  94242 0.1 end
'  NO IFBA's used for MOX core
'  b-10  1 0 6.4584-5   901 end
'  zr    1 0 3.2292-5   901 end
'     the boron-10 coating is assumed mixed with the fuel
'
'      --------------------
'    some extra nuclides needed from library
zr-94  1 0 1-20     901 end
tc-99  1 0 1-20     901 end
ru-106 1 0 1-20     901 end
rh-103 1 0 1-20     901 end
rh-105 1 0 1-20     901 end
xe-131 1 0 1-20     901 end
cs-133 1 0 1-20     901 end
cs-134 1 0 1-20     901 end
ce-144 1 0 1-20     901 end
pr-143 1 0 1-20     901 end
nd-143 1 0 1-20     901 end
nd-145 1 0 1-20     901 end
nd-147 1 0 1-20     901 end
pm-147 1 0 1-20     901 end
sm-149 1 0 1-20     901 end
sm-151 1 0 1-20     901 end
sm-152 1 0 1-20     901 end
eu-153 1 0 1-20     901 end
eu-154 1 0 1-20     901 end
```

```
eu-155 1 0 1-20     901 end
u-232  1 0 1-20     901 end
u-233  1 0 1-20     901 end
u-237  1 0 1-20     901 end
np-238 1 0 1-20     901 end
pu-236 1 0 1-20     901 end
pu-237 1 0 1-20     901 end
pu-243 1 0 1-20     901 end
pu-244 1 0 1-20     901 end
am-242 1 0 1-20     901 end
cm-245 1 0 1-20     901 end
cm-246 1 0 1-20     901 end
cm-247 1 0 1-20     901 end
cm-248 1 0 1-20     901 end
bk-249 1 0 1-20     901 end
cf-249 1 0 1-20     901 end
cf-250 1 0 1-20     901 end
cf-251 1 0 1-20     901 end
cf-252 1 0 1-20     901 end
cf-253 1 0 1-20     901 end

' ------------------------------------------------------------
'  nearly Zirc-2 - not a great effect although Zirc-4 has Cr & Fe
arbmzirc 6.44 4 0 0 1 40000 97.91 26000 0.5 50116 0.86 50120
  0.73 2 1 607 end
'    above is zircalloy specified as an arbitrary material
'    because it may not be in the library
' -----------------------------------------------------
h2o    3 0.707      583 end
co-59  3 0 1-20     583 end
arbm-bormod 0.707 2 0 0 0 5010 39.99 5011 60.01 3 1301.0-6 583 end
'      above is 1301 ppm initial boron concentration in moderator
'      (40% isotopically enriched in B-10)
'      94 Design cases used 750 ppm av. Boron
' ------------------------------------------------------
'       mixtures for shipping cask (just one assembly here!)
'
n      4 0 1.0-20 end
n      5 0.00122 end
' ------------------------------------------------------
'       mixtures for larger unit cell
'     check WABA numbers  use ornl b4c value (redrived)
'   no wabas for cy 2 or cy 3
arbm-alox 3.72 2 0 1 0 13027 2 8016 3 9 0.95568 583 end
b4c   9 den=2.52  0.04432  583 end
'
'   arbm-alox 3.72 2 0 1 0 13027 2 8016 3 9 0.97952 end
'   b4c       9 0.041 end
end comp
' ------------------------------------------------------
'       fuel-pin-cell geometry
'
'     pitch=1.25984 cm
'     pellet OD=0.78435 cm
```

```
'      clad OD=0.9144 cm
'      clad ID=0.8001 cm
'
'      squarepitch 1.25984 0.8202 1 3 0.95 2 0.8357 0 end (LOPAR)
squarepitch 1.25984 0.78435 1 3 0.9144 2 0.8001 0 end
'
' ---------------------------------------------------------
'        assembly and cycle parameters
'
npin/assm=264 fuelngth=365.76 ncycles=12 nlib/cyc=1 lightel=22
printlevel=4 inplevel=2 numzones=12 mxrepeats=0 end
'
'    this assembly contains NO WABAs - cy 2, (Full MOX core Cy 1 only)
'
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 9 4.8896 2 4.9755
    500 8.1972 2 8.2999 9 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 9 4.8896 2 4.9755
    500 8.1972 2 8.2999 9 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 9 4.8896 2 4.9755
    500 8.1972 2 8.2999 9 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 9 4.8896 2 4.9755
    500 8.1972 2 8.2999 9 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 9 4.8896 2 4.9755
    500 8.1972 2 8.2999 9 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 9 4.8896 2 4.9755
    500 8.1972 2 8.2999 9 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 3 4.8896 2 4.9755
    500 8.1972 2 8.2999 3 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 3 4.8896 2 4.9755
    500 8.1972 2 8.2999 3 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 3 4.8896 2 4.9755
    500 8.1972 2 8.2999 3 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 3 4.8896 2 4.9755
    500 8.1972 2 8.2999 3 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 3 4.8896 2 4.9755
    500 8.1972 2 8.2999 3 8.414 3 8.6763 500 12.0834
'
3 0.5715 2 0.6121 3 0.7108 500 4.5513 3 4.7912 3 4.8896 2 4.9755
    500 8.1972 2 8.2999 3 8.414 3 8.6763 500 12.0834
'
'    discharge burnup is 27.01 GWd/MT  - cy 1
'    discharge burnup is 35.58 GWd/MT  - cy 2
'
```

```
'
 power=23.165 burn=91.2 down=0  bfrac=0.861 end
 power=23.165 burn=91.8 down=0  bfrac=0.623 end
 power=23.165 burn=91.1 down=0  bfrac=0.442 end
 power=23.165 burn=92.0 down=0  bfrac=0.329 end
 power=23.165 burn=91.0 down=0  bfrac=0.179 end
 power=23.165 burn=35.9 down=108  bfrac=0.034 end
'
 power=7.35 burn=91.2 down=0  bfrac=0.861 end
 power=7.35 burn=91.8 down=0  bfrac=0.623 end
 power=7.35 burn=91.1 down=0  bfrac=0.442 end
 power=7.35 burn=92.0 down=0  bfrac=0.329 end
 power=7.35 burn=91.0 down=0  bfrac=0.179 end
 power=7.35 burn=35.9 down=108  bfrac=0.034 end
'
' ----------------------------------------------------------
'       light elements
 c 0.06  n 0.034  o 62.14  al 0.0457  s 0.00397
 ti 0.0498  v 0.00227  cr 2.34  mn 0.109 fe 4.6 mo 0.1816
 co 0.033  ni 4.402   cu 0.011 zr 111.178 cd 0.00003
 sn 1.8168 hf 0.00886 w 0.00227 p 0.142 nb 0.328 si 0.0659
' ----------------------------------------------------------
'       shipping cask zone description
'
27n-18couple tempcask=325 numzones=2 detect=0 dryfuel=yes
4 12.0834 5 12.5
zone=1 fuelbnds=1
' ----------------------------------------------------------
szfcask=0.25 end
' ----------------------------------------------------------
end
=origens
0$$  a8 26 a11 71 e
1$$ 1  1t
 w 17x17 MOX
3$$ 21 0 1 e
2t
35$$ 0  t
'
56$$ 0 7 a13 -1 a15 3 0 4 e   5t
Part B W 17x17, 4.0wt%, 35.6 gwd/mtu decay
per W assembly
60**  0 1 90 365.25 730.5 1826.25  3652.5
' 65$$ a2 1 a4 1 a10 1 a23 1 0 1 a28 1 a31 1 a44 1 0 1 a49 1 a52 1 e
65$$ a4 1 2z 1 2z 1 a16 1 2z 1 a25 1 2z 1 2z 1 a37 1 2z 1
 a46 1 2z 1 2z 1 a58 1 2z 1 e
6t
'
56$$ 0 10 a10 7 a14 5 a17 4 e  57** 10  e  5t
60**  15 20 30 50 100 150 200 250 300 400
' 65$$ a2 1 a4 1 a10 1 a23 1 0 1 a28 1 a31 1 a44 1 0 1 a49 1 a52 1 e
65$$ a4 1 2z 1 2z 1 a16 1 2z 1 a25 1 2z 1 2z 1 a37 1 2z 1
 a46 1 2z 1 2z 1 a58 1 2z 1 e
6t
```

```
'
56$$ 0 10 a10 10 a14 5 a17 4 e  57** 400  e  5t
60**  500 1+3 2+3 4+3 6+3 8+3 1+4 1.2+4 1.4+4 1.5+4
' 65$$ a2 1 a4 1 a10 1 a23 1 0 1 a28 1 a31 1 a44 1 0 1 a49 1 a52 1 e
65$$ a4 1 2z 1 2z 1 a16 1 2z 1 a25 1 2z 1 2z 1 a37 1 2z 1
 a46 1 2z 1 2z 1 a58 1 2z 1 e
6t
'
56$$ 0 10 a10 10 a14 5 a17 4 e  57** 1.5+4  e  5t
60**  1.6+4 1.7+4 1.8+4 1.9+4 2.0+4 2.1+4 2.2+4 2.3+4 2.4+4 2.5+4
' 65$$ a2 1 a4 1 a10 1 a23 1 0 1 a28 1 a31 1 a44 1 0 1 a49 1 a52 1 e
65$$ a4 1 2z 1 2z 1 a16 1 2z 1 a25 1 2z 1 2z 1 a37 1 2z 1
 a46 1 2z 1 2z 1 a58 1 2z 1 e
6t
'
56$$ 0 10 a10 10 a14 5 a17 4 e  57** 2.5+4  e  5t
60**  3.5+4 4.5+4 5+4 5.5+4 6+4 6.5+4 7+4 1+5 2+5 2.5+5
' 65$$ a2 1 a4 1 a10 1 a23 1 0 1 a28 1 a31 1 a44 1 0 1 a49 1 a52 1 e
65$$ a4 1 2z 1 2z 1 a16 1 2z 1 a25 1 2z 1 2z 1 a37 1 2z 1
 a46 1 2z 1 2z 1 a58 1 2z 1 e
6t
'
56$$ 0 3 a10 10 a14 5 a17 4 e  57** 2.5+5  e  5t
60**  3+5 5+5 999999
' 65$$ a2 1 a4 1 a10 1 a23 1 0 1 a28 1 a31 1 a44 1 0 1 a49 1 a52 1 e
65$$ a4 1 2z 1 2z 1 a16 1 2z 1 a25 1 2z 1 2z 1 a37 1 2z 1
 a46 1 2z 1 2z 1 a58 1 2z 1 e
6t
'
56$$ f0  t
end
```

ATTACHMENT IV

Base input data file for PWR MOX SNF criticality consequence calculation for a rapid and slow rate of reactivity insertion. This file was modified for the Westinghouse Vantage 5 MOX assemblies from the LEU criticality consequence calculation (Ref. 21) RELAP5/MOD3.2 data file.

```
= relap5/mod2  waste package rlp5.MOX02cR1.inp
*-----------------------------------------------------------
*
*
* { this is /kappa/jrw/lv/relap/r5wp2d.in
*
* the input is a transition from tmi-1 power uprate lbloca
* to waste package (near field) criticality excursion consequences
* The input is a Waste Package for Westinghouse 17 by 17 Vantage 5
* 4.0 wt% HM fissile Pu in fresh pins, 35.6 GWD/MTHM burnup, 25000 yr
* decay period for isotopics
* The geometry reflects the 2-D representation
*
*
*------------------ base representation description ----------------------
*
*     fti  document 32-1244460-00
*     by: ks pacheco
*
* the base deck for the tmi-1 representation was taken from 2772base1.in
* contained in 32-1234886-00.  /kappa/ksp/tmipug/base/tmibase.in
*
*  21 fuel asemblies, 264-pins/fa, 24-guide tubes/fa, 1 instrument tube/fa
*        one-fifth length representation - Initial Power into Assembly is 5
Watts
*        for Full Length assemblies
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*   deck obtained from tuck w. (lynchburg) 07/31/97
*   07/31/97 modifiation - jam (lv)
*   Vantage 5 update JR Worsham, JA McClure 07/20/99
*     delete most of the $$$ cards from deck
*     convert to mod3 format
*     junction control flag - change from 3xxxx to 0xxxx
*                               no horizontal stratification
*     heat structure cards ...8xx and ...9xx - CHF Changes
*                               MOD2 - 5 wds, MOD3 - 9 wds
*     add Time-Dependent Vol and Time-Dependent Junction to input
*     InFlow Conditions
*     Add Minor Edits
*
*   Case 113a Reduce reactivity ramp rate to 14.18$ in 60.0 sec.
*   Case 123a Reduce reactivity ramp rate to 14.18$ in 3600.0 sec.
*   Case 123b rerun case c123a with revised MCNP void reactivity table
```

```
*              using Tuck's definition of delta rho
*   Case 220a case c123b with slow reactivity insertion (0.0004 $/hour)
*   Case 220b case c220a with slow reactivity insertion (0.0004 $/sec)
*   Case 220c case c220b with bulk void reactivity feedback in place of MCNP
curve
*   Case 221a case c220c with Jun 250 area = 5.0 sqcm (0.775 sqin)
*              Turn off Choking option for interior junctions
*              Use Homogeneous Representation, No momentum flux in exit Jun
*   Case 221b case c220c with Jun 250 area = 1.5 sqcm (0.2325 sqin)
*   Case 221c case c220c with Jun 250 area = 0.5 sqcm (0.0775 sqin)
*   Case 221d case c220c with Jun 250 area = 0.375 sqcm (0.0582 sqin)
*   Case 221e case c220c with Jun 250 area = 0.25 sqcm (0.03875 sqin)
*   Case 221f case c220c with Jun 250 area = 0.1 sqcm (0.0155 sqin)
*   Case 221g case c220c with Jun 250 area = 100.0 sqcm (15.5 sqin) as
*              check on c220c case
*
*   Case rlp5.MOX01a Initial case for MOX reactivity consequences
*              Exit area =100.0 sqcm (15.5 sqin)
*   Case rlp5.MOX01b Adjust Junction connections and bring loops to closure
*              Exit area =100.0 sqcm (15.5 sqin)
*   Case rlp5.MOX01c Adjust Junction connections and bring loops to closure
*              Exit area =100.0 sqcm (15.5 sqin), zero ramp $
*   Case rlp5.MOX01d Adjust Reactivity Contrl
*   Case rlp5.MOX02a Case for MOX reactivity consequences
*              Exit area =100.0 sqcm (15.5 sqin)
*   Case rlp5.MOX02b Case for MOX reactivity consequences
*              Exit area =100.0 sqcm (15.5 sqin), reduce ramp rate
*   Case rlp5.MOX02c Case for MOX reactivity consequences
*              Exit area =10.0 sqcm (15.5 sqin), use converged TS set
*   Case rlp5.MOX02c Case for MOX reactivity consequences
*              Add Pu-239 Delayed Neutron Data
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
100   new   transnt
101   run
* 101   inp-chk
102   british   british
105   150.  160.
*
*  noncondensible gas
110   "nitrogen"
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* time step control
*         end     min     max    time  minor  major  restart
*        time    delt    time    step  edit   edit    point
*        (sec)   (sec)   step    optn  freq   freq    freq
*
*
*    set end  MIN TS  MAX TS  Cntrl TS/Minor Ed TS/Major Ed  TS/Restrt
  201     0.1  1.0-8   1.0-4    07    100         1000        1000
  202     2.0  1.0-8   1.0-3    07     40           80          80
```

```
  203    10.0  1.0-8   1.0-5    07    500         5000       10000
  204   100.0  1.0-8   1.0-4    07    500        10000      100000
  204   300.0  1.0-8   5.0-4    07   2000        20000      100000
*
*
* trips name     code      op name   code    add  l/n
0000501 time     0         ge null      0     20.00 l *
0000501 time     0         ge null      0    200.00 l * prob end
*  0000502 time     0         ge null      0   1000.0  * jun 370
*
*   problem end trip
600  501
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
*        general tables
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*  reactivity insertion
*
20200100  reac-t
*   reactivity ramp rate 0.1576 $/s
20200101  0.0  0.0  2.0  0.0  92.0  14.18  1.0+10  14.18
*
*     zero ramp - check steady level
*  20200101  0.0  0.0  90.0  0.0  1.0+10  0.0
*  lower ramp insertion rate to 0.0004 $/hr
*  20200101  0.0  0.0  20.0  0.0  3600.0  1.44  7200.0  2.88  10800.0  4.32
*
*   average fuel temperature vs. reactivity (MOX)
*   Spreadsheet MOX_96_sas2h.xls Sheet Path-B geom
*
20200200  reac-t
*
*          fuel temp. K      reactivity, dollars     density lb/ft**3
*
20200201    273.15              +0.277946
20200202    300.01              +0.277946
20200203    323.15               0.0
20200204    373.15              -0.562172
20200205    433.15              -1.175436
20200206    543.15              -2.250746
20200207    813.15              -4.720711
*
*  moderator density reactivity feedback
*
20200500  reac-t
*
*          density  kg/m**3    reactivity, dollars     fuel temp. f
*
20200501      699.999853          -39.688829           *  1004
```

```
20200502      724.999847         -34.617905           *  1004
20200503      749.999915         -29.932688           *  1004
20200504      774.999838         -25.597751           *  1004
20200505      799.999832         -21.577987           *  1004
20200506      824.999827         -17.845935           *  1004
20200507      849.999821         -14.374743           *  1004
20200508      874.999816         -11.142801           *  1004
20200509      899.999810         -08.128449           *   518
20200510      919.999807         -05.912608           *   518
20200511      939.999803         -03.814156           *   518
20200512      958.099168         -02.047433           *   518
20200513      972.999796         -00.997818           *   212
20200514      988.183837          00.00               *   122
20200515      999.999790         +00.727593           *   122
20200516     1041.199900         +00.727593           *    80.33
*
*
*     MCNP mixture level reactivity table (beta = 0.002582)
*     Table for LEU Fuel
*     Row 5 of fueled assemblies
*
*        Mixture level (ft)    Reactivity ($)
*
20201000  reac-t
*
20201001    0.0                 -30.902
20201002    0.04399             -30.902
20201003    0.18933             -16.660
20201004    0.23657             -14.959
20201005    0.28415             -12.911
20201006    0.71                  0.0
*
*
*     minor edits
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*     pressure
*
301   "p"          150010000           * Vol Pressure
302   "p"          060010000           * Vol Pressure
303   "p"          070010000           * Vol Pressure
304   "p"          080010000           * Vol Pressure
305   "p"          090010000           * Vol Pressure
306   "p"          100010000           * Vol Pressure
307   "p"          250010000           * Vol Pressure
*
*     Fluid Inventory
*
310   "tmass"      0                   * Fluid Mass inventory
*
*     enthalpy
*
315   "hvmix"      090010000           * Vol Enthalpy
```

```
317   "hvmix"      250010000           * Vol Enthalpy
*
*
*     volume vapor generation/unit vol
*
321   "vapgen"     150010000           * Vol vapor gen rate
322   "vapgen"     060010000           * Vol vapor gen rate
323   "vapgen"     070010000           * Vol vapor gen rate
324   "vapgen"     080010000           * Vol vapor gen rate
325   "vapgen"     090010000           * Vol vapor gen rate
326   "vapgen"     100010000           * Vol vapor gen rate
*
*
*     Volume Mass
*
331   "tmassv"     150010000           * Vol Mass
332   "tmassv"     060010000           * Vol Mass
333   "tmassv"     070010000           * Vol Mass
334   "tmassv"     080010000           * Vol Mass
335   "tmassv"     090010000           * Vol Mass
336   "tmassv"     100010000           * Vol Mass
337   "tmassv"     220010000           * Vol Mass
338   "tmassv"     230010000           * Vol Mass
339   "tmassv"     240010000           * Vol Mass
340   "tmassv"     250010000           * Vol Mass
*
*     mass flow
*
341   "mflowj"     080010000           * Jun Flow
342   "mflowj"     080020000           * Jun Flow
343   "mflowj"     070010000           * Jun Flow
344   "mflowj"     030020000           * Jun Flow
345   "mflowj"     240010000           * Jun Flow
346   "mflowj"     230010000           * Jun Flow
347   "mflowj"     230020000           * Jun Flow
348   "mflowj"     250010000           * Jun Flow
349   "mflowj"     220010000           * Jun Flow
350   "mflowj"     220020000           * Jun Flow
*
*
*     average fuel temperature
*
351   "htvat"      3301008             * Avg Metal Temp
*
*   control variables
*
*   kinetics parameters
*
389   "rkfipow"    0           * "fission" "power"
390   "rkgapow"    0           * "decay heat" "power"
391   "rkreac"     0           * "total" "reactivi"
393   "cntrlvar"   014         * "doppler reac
394   "cntrlvar"   056         * "void reactivity
395   "cntrlvar"   060         * "ramp reactivity
```

```
396   "cntrlvar"   065         * "total calc reac
397   "cntrlvar"   070         * "assembly energy
398   "cntrlvar"   075         * "Sum (Heat slab vapor gen rate)
* 392   "cntrlvar"   081         * "MCNP void Reactivity
*
*     pressure
*
20800301   "p"         150010000            * Vol Pressure
20800302   "p"         060010000            * Vol Pressure
20800303   "p"         070010000            * Vol Pressure
20800304   "p"         080010000            * Vol Pressure
20800305   "p"         090010000            * Vol Pressure
20800306   "p"         100010000            * Vol Pressure
20800307   "p"         250010000            * Vol Pressure
*
*     Fluid Inventory
*
20800310   "tmass"     0                   * Fluid Mass inventory
*
*     enthalpy
*
20800315   "hvmix"     090010000           * Vol Enthalpy
20800317   "hvmix"     250010000           * Vol Enthalpy
*
*
*     volume vapor generation/unit vol
*
20800321   "vapgen"    150010000           * Vol vapor gen rate
20800322   "vapgen"    060010000           * Vol vapor gen rate
20800323   "vapgen"    070010000           * Vol vapor gen rate
20800324   "vapgen"    080010000           * Vol vapor gen rate
20800325   "vapgen"    090010000           * Vol vapor gen rate
20800326   "vapgen"    100010000           * Vol vapor gen rate
*
*
*     Volume Mass
*
20800331   "tmassv"    150010000           * Vol Mass
20800332   "tmassv"    060010000           * Vol Mass
20800333   "tmassv"    070010000           * Vol Mass
20800334   "tmassv"    080010000           * Vol Mass
20800335   "tmassv"    090010000           * Vol Mass
20800336   "tmassv"    100010000           * Vol Mass
20800337   "tmassv"    220010000           * Vol Mass
20800338   "tmassv"    230010000           * Vol Mass
20800339   "tmassv"    240010000           * Vol Mass
20800340   "tmassv"    250010000           * Vol Mass
*
*     mass flow
*
20800341   "mflowj"    080010000           * Jun Flow
20800342   "mflowj"    080020000           * Jun Flow
20800343   "mflowj"    070010000           * Jun Flow
20800344   "mflowj"    030020000           * Jun Flow
```

```
20800345   "mflowj"     240010000           * Jun Flow
20800346   "mflowj"     230010000           * Jun Flow
20800347   "mflowj"     230020000           * Jun Flow
20800348   "mflowj"     250010000           * Jun Flow
20800349   "mflowj"     220010000           * Jun Flow
20800350   "mflowj"     220020000           * Jun Flow
*
*
*     average fuel temperature
*
20800351   "htvat"      3301008             * Avg Metal Temp
*
*   control variables
*
*   kinetics parameters
*
20800389   "rkfipow"    0           * "fission" "power"
20800390   "rkgapow"    0           * "decay heat" "power"
20800391   "rkreac"     0           * "total" "reactivi"
20800393   "cntrlvar"   014         * "doppler reac
20800394   "cntrlvar"   056         * "void reactivity
20800395   "cntrlvar"   060         * "ramp reactivity
20800396   "cntrlvar"   065         * "total calc reac
20800397   "cntrlvar"   070         * "assembly energy
20800398   "cntrlvar"   075         * "Sum (Heat slab vapor gen rate)
* 20800392   "cntrlvar"   081         * "MCNP void Reactivity
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*   waste package
*
* representationing begins with central planar region
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* bottom of cylinder
*
1400000   "bot-watr"  "branch"
*       no. of jun  jun cntrl
1400001   2         0
*       aflow(norm)  len       vol    angle(az) inclin  elev change
1400101    0.00     .2293299  .2075716   0.0   -90.0   -.2293299
1400101    0.00     .25142236 .20454480  0.0   -90.0   -.25142236
*       wall rough  hyd dia   cntrl
1400102   4.1667-5   1.0+10    00
*       vol cntrl   press      temp
1400200   003        14.696    122.00
*       from vol    to vol     ajun      k(f)   k(r)   jun cntrl
1401101   140000000 010010000  .2038375  72.0   72.0   01000
1401101   140000000 010010000  .2312     68.7   68.7   01000
*       liq vel    vap vel    interface vel
1401201   0.0       0.0        0.0
*       from vol    to jun     ajun      k(f)   k(r)   jun cntrl
1402101   140000000 150000000  .5419829   0.0    0.0   01003
```

```
*       liq vel    vap vel    interface vel
1402201   0.0       0.0        0.0
*
* bottom side of cylinder
*
1500000   "bos-watr"  "branch"
1500001   1         0
1500101    0.00     .2293299  .2276341   0.0   -90.0   -.2293299
1500101    0.00     .22483924 .22424063  0.0   -90.0   -.22483924
*                          cntrl (therm-off, mix-off, pack-on,
*                                vert strat-on,  interphase fric-pipe,
*                                wall-xdir, non-eq)
1500102   4.1667-5   1.0+10    0000000
1500200   003        14.696    122.00
1501101   150000000 060010000  .4076750  72.0   72.0   01000
1501101   150000000 060010000  .4624     68.7   68.7   01000
1501201   0.0       0.0        0.0
*
* side of cylinder fuel level 1
*
1600000   "s1-watr"   "branch"
1600001   1         0
1600101    0.00     .71       .7989270   0.0   -90.0   -.71
1600101    0.00     .70266667 .7989270   0.0   -90.0   -.70266667
1600102   4.1667-5   1.0+10    00
1600200   003        14.696    122.00
1601101   160000000 110010000  .4076750  72.0   72.0   01000
1601101   160000000 110010000  .4624     68.7   68.7   01000
1601201   0.0       0.0        0.0
*
* side of cylinder fuel level 2
*
1700000   "s2-watr"   "branch"
1700001   1         0
1700101    0.00     .71          .5438773    0.0   -90.0   -.71
1700101    0.00     .70266667    .5438773    0.0   -90.0   -.70266667
1700102   4.1667-5   1.0602200    00
1700200   003        14.696       122.00
1701101   170000000 180000000     1.1080708  0.0    0.0   01000
1701201   0.0       0.0           0.0
*
* side of cylinder fuel level 3
*
1800000   "s3-watr"   "branch"
1800001   1         0
1800101    0.00     .71          .8980821    0.0    90.0    .71
1800101    0.00     .70266667    .8980821    0.0    90.0    .70266667
1800102   4.1667-5   2.1134025    00
1800200   003        14.696       122.00
1801101   180010000 190000000     1.3339422  0.0    0.0   01000
1801201   0.0       0.0           0.0
*
* side of cylinder fuel level 4
*
```

```
1900000   "s4-watr"   "branch"
1900001   1          0
1900101    0.00      .71           .8738187    0.0    90.0    .71
1900101    0.00      .70266667    .8738187    0.0    90.0    .70266667
1900102   4.1667-5   2.0432176    00
1900200   003         14.696       122.00
1901101   190010000 210000000     1.0380308  0.0    0.0   01000
1901201   0.0        0.0           0.0
*
* side of cylinder - fuel level 5
*
2100000   "s5-watr"   "branch"
2100001   1          0
2100101    0.00      .71           .7822260    0.0    90.0    .71
2100101    0.00      .70266667    .7822260    0.0    90.0    .70266667
2100102   4.1667-5   1.6252320    0000000
2100200   003         14.696       122.00
*  2101101   210010000 240000000     1.0380308  0.0    0.0   01000
   2101101   210010000 240000000     1.0380308  20.0    20.0   01000
2101201   0.0        0.0           0.0
*
* 21 fuel assemblies
*
* half symmetry gives 13 planar fuel areas
*
* representationing begins with central fuel length,
*
* center fuel column,  at the cylinder bottom
*
* hydraulic dia. based on flow around fuel-clad, guide tubes, inst. tube
*
*---**---**---**---**---**---**---**---**---**---**---**---*
*
* column  1
*
0100000   "fuel-010"  "branch"
0100001   2          0
0100101    0.00      .71           .3516846   0.0   -90.0   -.71
0100101    0.00      .70266667    .37035853  0.0   -90.0   -.70266667
0100102   3.133-6   .04168514     00
0100102   3.133-6   .03929956     00
0100200   003         14.696       122.00
0101101   010000000 020010000      .2038375  72.0   72.0   01000
0101101   010000000 020010000      .2312     68.7   68.7   01000
0101201   0.0        0.0           0.0
0102101   010000000 060000000      .4076750  72.0   72.0   01003
0102101   010000000 060000000      .4624     68.7   68.7   01003
0102201   0.0        0.0           0.0
*
0200000   "fuel-020"  "branch"
0200001   2          0
0200101    0.00      .71           .3516846   0.0   -90.0   -.71
0200101    0.00      .70266667    .37035853  0.0   -90.0   -.70266667
0200102   3.133-6   .04168514     00
```

```
0200102   3.133-6   .03929956     00
0200200   003        14.696       122.00
0201101   020000000 030000000     .2038375  72.0   72.0   01000
0201101   020000000 030000000     .2312     68.7   68.7   01000
0201201   0.0       0.0           0.0
0202101   020000000 070000000     .4076750  72.0   72.0   01003
0202101   020000000 070000000     .4624     68.7   68.7   01003
0202201   0.0       0.0           0.0
*
0300000   "fuel-030"  "branch"
0300001   2         0
0300101    0.00     .71          .3516846   0.0    90.0    .71
0300101    0.00     .70266667    .37035853  0.0    90.0    .70266667
0300102   3.133-6   .04168514     00
0300102   3.133-6   .03929956     00
0300200   003        14.696       122.00
0301101   030010000 040000000     .2038375  72.0   72.0   01000
0301101   030010000 040000000     .2312     68.7   68.7   01000
0301201   0.0       0.0           0.0
0302101   030000000 080000000     .4076750  72.0   72.0   01003
0302101   030000000 080000000     .4624     68.7   68.7   01003
0302201   0.0       0.0           0.0
*
0400000   "fuel-040"  "branch"
0400001   2         0
0400101    0.00     .71          .3516846   0.0    90.0    .71
0400101    0.00     .70266667    .37035853  0.0    90.0    .70266667
0400102   3.133-6   .04168514     00
0400102   3.133-6   .03929956     00
0400200   003        14.696       122.00
0401101   040010000 050000000     .2038375  72.0   72.0   01000
0401101   040010000 050000000     .2312     68.7   68.7   01000
0401201   0.0       0.0           0.0
0402101   040000000 090000000     .4076750  72.0   72.0   01003
0402101   040000000 090000000     .4624     68.7   68.7   01003
0402201   0.0       0.0           0.0
*
0500000   "fuel-050"  "branch"
0500001   2         0
0500101    0.00     .71          .3516846   0.0    90.0    .71
0500101    0.00     .70266667    .37035853  0.0    90.0    .70266667
*                         cntrl (therm-off, mix-off, pack-on,
*                               vert strat-on,  interphase fric-pipe,
*                               wall-xdir, non-eq)
0500102   3.133-6   .04168514     0000000
0500102   3.133-6   .03929956     00
0500200   003        14.696       122.00
0501101   050010000 220000000     .2038375  72.0   72.0   01000
0501101   050010000 220000000     .2312     68.7   68.7   01000
0501201   0.0       0.0           0.0
0502101   050000000 100000000     .4076750  72.0   72.0   01003
0502101   050000000 100000000     .4624     68.7   68.7   01003
0502201   0.0       0.0           0.0
*
```

```
*---**---**---**---**---**---**---**---**---**---**---**---*
*
* column  2
*
0600000   "fuel-060"  "branch"
0600001   2         0
0600101    0.00     .71           .7033692   0.0   -90.0   -.71
0600101    0.00     .70266667     .74071706  0.0   -90.0   -.70266667
0600102   3.133-6   .04168514      00
0600102   3.133-6   .03929956      00
0600200   003        14.696        122.00
0601101   060000000 070010000      .4076750  72.0   72.0   01000
0601101   060000000 070010000      .4624     68.7   68.7   01000
0601201   0.0       0.0            0.0
0602101   060000000 160000000      .4076750  72.0   72.0   01003
0602101   060000000 160000000      .4624     68.7   68.7   01003
0602201   0.0       0.0            0.0
*
0700000   "fuel-070"  "branch"
0700001   2         0
0700101    0.00     .71           .7033692   0.0   -90.0   -.71
0700101    0.00     .70266667     .74071706  0.0   -90.0   -.70266667
0700102   3.133-6   .04168514      00
0700102   3.133-6   .03929956      00
0700200   003        14.696        122.00
0701101   070000000 080000000      .4076750  72.0   72.0   01000
0701101   070000000 080000000      .4624     68.7   68.7   01000
0701201   0.0       0.0            0.0
0702101   070000000 110000000      .4076750  72.0   72.0   01003
0702101   070000000 110000000      .4624     68.7   68.7   01003
0702201   0.0       0.0            0.0
*
0800000   "fuel-080"  "branch"
0800001   2         0
0800101    0.00     .71           .7033692   0.0    90.0    .71
0800101    0.00     .70266667     .74071706  0.0    90.0    .70266667
0800102   3.133-6   .04168514      00
0800102   3.133-6   .03929956      00
0800200   003        14.696        122.00
0801101   080010000 090000000      .4076750  72.0   72.0   01000
0801101   080010000 090000000      .4624     68.7   68.7   01000
0801201   0.0       0.0            0.0
0802101   080000000 120000000      .4076750  72.0   72.0   01003
0802101   080000000 120000000      .4624     68.7   68.7   01003
0802201   0.0       0.0            0.0
*
0900000   "fuel-090"  "branch"
0900001   2         0
0900101    0.00     .71           .7033692   0.0    90.0    .71
0900101    0.00     .70266667     .74071706  0.0    90.0    .70266667
0900102   3.133-6   .04168514      00
0900102   3.133-6   .03929956      00
0900200   003        14.696        122.00
0901101   090010000 100000000      .4076750  72.0   72.0   01000
```

```
0901101   090010000 100000000     .4624     68.7   68.7   01000
0901201   0.0       0.0           0.0
0902101   090000000 130000000     .4076750  72.0   72.0   01003
0902101   090000000 130000000     .4624     68.7   68.7   01003
0902201   0.0       0.0           0.0
*
1000000   "fuel-100"  "branch"
1000001   2         0
1000101   0.00      .71          .7033692   0.0    90.0    .71
1000101    0.00     .70266667    .74071706  0.0    90.0    .70266667
1000102   3.133-6   .04168514     0000000
1000102   3.133-6   .03929956     00
1000200   003        14.696       122.00
1001101   100010000 230000000     .4076750  72.0   72.0   01000
1001101   100010000 230000000     .4624     68.7   68.7   01000
1001201   0.0       0.0           0.0
1002101   100000000 200000000     .4076750  72.0   72.0   01003
1002101   100000000 200000000     .4624     68.7   68.7   01003
1002201   0.0       0.0           0.0
*
*---**---**---**---**---**---**---**---**---**---**---**---*
*
* column  3
*
1100000   "fuel-110"  "branch"
1100001   2         0
1100101    0.00     .71          .7033692   0.0   -90.0   -.71
1100101    0.00     .70266667    .74071706  0.0   -90.0   -.70266667
1100102   3.133-6   .04168514     00
1100102   3.133-6   .03929956     00
1100200   003        14.696       122.00
1101101   110000000 120000000     .4076750  72.0   72.0   01000
1101101   110000000 120000000     .4624     68.7   68.7   01000
1101201   0.0       0.0           0.0
1102101   110000000 170000000     .4076750  72.0   72.0   01003
1102101   110000000 170000000     .4624     68.7   68.7   01003
1102201   0.0       0.0           0.0
*
1200000   "fuel-120"  "branch"
1200001   2         0
1200101    0.00     .71          .7033692   0.0    90.0    .71
1200101    0.00     .70266667    .74071706  0.0    90.0    .70266667
1200102   3.133-6   .04168514     00
1200102   3.133-6   .03929956     00
1200200   003        14.696       122.00
1201101   120010000 130000000     .4076750  72.0   72.0   01000
1201101   120010000 130000000     .4624     68.7   68.7   01000
1201201   0.0       0.0           0.0
1202101   120000000 180000000     .4076750  72.0   72.0   01003
1202101   120000000 180000000     .4624     68.7   68.7   01003
1202201   0.0       0.0           0.0
*
1300000   "fuel-130"  "branch"
1300001   2         0
```

```
1300101    0.00     .71           .7033692   0.0    90.0    .71
1300101    0.00     .70266667     .74071706  0.0    90.0    .70266667
1300102   3.133-6   .04168514      00
1300102   3.133-6   .03929956      00
1300200   003        14.696        122.00
1301101   130010000 200000000      .4076750  72.0   72.0   01000
1301101   130010000 200000000      .4624     68.7   68.7   01000
1301201   0.0       0.0            0.0
1302101   130000000 190000000      .4076750  72.0   72.0   01003
1302101   130000000 190000000      .4624     68.7   68.7   01003
1302201   0.0       0.0            0.0
*
* water - column  3
*
*---**---**---**---**---**---**---**---**---**---**---**---*
*
2000000   "ts-watr"   "branch"
2000001   2         0
2000101    0.00     .71           .8633786   0.0    90.0    .71
2000101    0.00     .70266667     .8633786   0.0    90.0    .70266667
2000102   4.1667-5   1.0+10       0000000
2000200   003        14.696       122.00
*  2001101   200010000 240000000    .7540857   0.0    0.0   01000
   2001101   200010000 240000000    .7540857   20.0    20.0   01000
2001201   0.0       0.0           0.0
*  2002101   200000000 210000000   1.7958536   0.0    0.0   01003
   2002101   200000000 210000000   1.7958536   20.0    20.0   01003
2002201   0.0       0.0           0.0
*
* top of cylinder
*
*
* three water columns
*
*
2200000   "c1-watr"   "branch"
2200001   2         0
2200101    0.00     .3484394      .8633786   0.0    90.0    .3484394
2200102   4.1667-5   1.0+10       00
2200200   003        14.696       122.00
*  2201101   220010000 250000000    .2038375   0.0    0.0   01000
   2201101   220010000 250000000    .2038375   20.0    20.0   01000
2201101   220010000 250000000    .2312     20.0   20.0   01000
2201201   0.0       0.0           0.0
*  2202101   220000000 230000000    .8234784   0.0    0.0   01003
   2202101   220000000 230000000    .8234784   20.0    20.0   01003
2202201   0.0       0.0           0.0
*
2300000   "c2-watr"   "branch"
2300001   2         0
2300101    0.00     .3484394      .8633786   0.0    90.0    .3484394
2300102   4.1667-5   1.0+10       00
2300200   003        14.696       122.00
*  2301101   230010000 250000000    .4076750   0.0    0.0   01000
```

```
   2301101   230010000 250000000    .4076750   20.0    20.0   01000
2301101   230010000 250000000    .4624      20.0    20.0   01000
2301201   0.0       0.0          0.0
*  2302101   230000000 240000000    .8234784   0.0    0.0   01003
   2302101   230000000 240000000    .8234784   20.0    20.0   01003
2302201   0.0       0.0          0.0
*
2400000   "c3-watr"   "branch"
2400001   1         0
2400101    0.00     .3484394     .4918077   0.0    90.0    .3484394
2400102   4.1667-5  1.6908844    00
2400200   003        14.696      122.00
*  2401101   240010000 250000000    .9732914   0.0    0.0   01000
   2401101   240010000 250000000    .9732914   20.0    20.0   01000
2401201   0.0       0.0          0.0
*
* top plenum
*
2500000   "tp-watr"   "branch"
2500001   1         0
2500101    0.00     .5249344    1.2517607   0.0    90.0    .5249344
2500102   4.1667-5  1.3256083    00
2500200   003        14.696      122.00
*      change to match conditions
2500200   002        14.764      1.28e-5
*                      Junction area = 100 sqcm = 15.5 sqin
* 2501101   250010000 260000000    .1076391   0.0    0.0   01000
* 2501101   250010000 260000000    .1076391   0.0    0.0   00000
*                      Junction area = 10.0 sqcm = 1.55 sqin
 2501101   250010000 260000000    .01076391   0.0    0.0   00023
*                      Junction area = 5.0 sqcm = 0.775 sqin
* 2501101   250010000 260000000    .0053820  0.0    0.0   00023
*                      Junction area = 1.5 sqcm = 0.2325 sqin
* 2501101   250010000 260000000    .0016146  0.0    0.0   00023
*                      Junction area = 0.5 sqcm = 0.0775 sqin
* 2501101   250010000 260000000    5.382e-4  0.0    0.0   00023
*                      Junction area = 0.375 sqcm = 0.0582 sqin
* 2501101   250010000 260000000    4.04167e-4  0.0    0.0   00023
*                       Junction area = 0.25 sqcm = 0.03875 sqin
* 2501101   250010000 260000000    2.691e-4  0.0    0.0   00023
*                       Junction area = 0.10 sqcm = 0.0155 sqin
* 2501101   250010000 260000000    1.0764e-4  0.0    0.0   00023
*
*                       Junction area = 100.0 sqcm = 15.5 sqin
* 2501101   250010000 260000000    1.076391e-1  0.0    0.0   00023
*
2501201   0.0       0.0          0.0
*
* outside of waste package,
*
* drift at 14.696 psia
*
2600000   "drift"     "tmdpvol"
2600101   238.46  1.0  0.0  0.0  90.0  1.0  1.0e-6  0.0  0010
```

```
2600200   003
2600201   0.0        14.696      220.00
*
* drift inflow volume
*
3600000    "gnd-watr"  "tmdpvol"
3600101    238.46  1.0  0.0  0.0  90.0  1.0  1.0e-6 0.0  0010
3600200    103
3600201    0.0    14.696     122.0
*
* Time-Dependent Junction for inflow
*
3700000    "in-flow"  "tmdpjun"
3700101    360010000   250000000    1.0
3700200    1           0
*  3700200    1           502
3700201    0.0         1.381e-3     0.0       0.0
3700201    0.0         0.0     0.0       0.0
*  3700201    0.0         2.762e-3     0.0       0.0
*
*---**---**---**---**---**---**---**---**---**---**---**---*
***
***
***                 heat structure input
***
***
***
*---**---**---**---**---**---**---**---**---**---**---**---*
*
*     waste package wall
*
13121000   9   20   1   1   0.0
13121100   0   2
13121101   10.0     19
13121201   6   19
13121301   0.0 19
13121400   0
13121401   122. 20
13121501   140010000   10000000   1     1   1.73  9
13121601   0           0          0     1   1.73  9
13121701   0   0.0   0.0   0.0   9
* 13121801   0   0.0   0.0   0.0   9
* 13121901   0   0.0   0.0   0.0   9
  13121801   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  9
  13121901   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  9
*
*---**---**---**---**---**---**---**---**---**---**---**---*
*
*     fuel assembly clad, guide tubes, & inst-tube in fuel region
*
13481000   13    3    2   1   0.01570833
13481000   13    3    2   1   0.013125
13481100   0     1
13481101   2     0.01791112
```

```
13481101   2     0.014997241
13481201   5     2
13481301   0.0   2
13481400   0
13481401   122.  3
*                              225  *2.3633333 = 531.75  ft
*                              112.5*2.3633333 = 265.875 ft
13481501   010010000  10000000      1     1     265.8750   5
13481501   010010000  10000000      1     1     346.8   5
13481502   060010000  10000000      1     1     531.7500   13
13481502   060010000  10000000      1     1     693.6   13
13481601   010010000  10000000      1     1     265.8750   5
13481601   010010000  10000000      1     1     346.8   5
13481602   060010000  10000000      1     1     531.7500   13
13481602   060010000  10000000      1     1     693.6   13
13481701   0   0.0   0.0   0.0   13
* 13481801   0   0.0   0.0   0.0   13
* 13481901   0   0.0   0.0   0.0   13
  13481801   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  13
  13481901   0.0   10.0   10.0   0.0   0.0  0.0   0.0  1.0  13
*  13481801   0   0.05360754   0.05360754   0.0   13
*  13481901   0   0.04701465   0.04701465   0.0   13
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*     fuel assembly pellets - water in gap region
*
13301000   13     10    2    1     0.0
13301100   0     1
*  13301101   6     0.01535833   1     0.01570833  2   0.01791667
13301101   9     0.01535833
13301101   9     0.012866667
*  13301201   3     6    -4     7     -5    9
13301201   3     9
*  13301301   1.0   6     0.0   7     0.0   9
13301301   1.0   9
13301400   -1
13301401   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301402   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301403   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301404   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301405   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301406   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301407   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301408   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301409   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301410   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301411   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301412   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301413   122.  122.  122.  122. 122. 122. 122. 122. 122. 122.
13301501   0   0    0     0     0.0   13
*
* length of fuel pin = #pins/ass'y * 141.8/(5 * 12)
*                    = 208 * 2.363 = 491.57333
```

```
* length of fuel pin = #pins/ass'y * 144.0/(5 * 12)
*                    =    264      *    2.400
*                    = 633.6
*
13301601   010010000  10000000      1     1     245.78667   5
13301601   010010000  10000000      1     1     316.8   5
13301602   060010000  10000000      1     1     491.57333   13
13301602   060010000  10000000      1     1     633.6   13
13301701   1000     0.1        0.0        0.0   5
13301702   1000     0.2        0.0        0.0   13
* 13301801   0        0.0        0.0        0.0   13
* 13301901   0        0.05492351 0.05492351 0.0   13
13301801    0.0   10.0     10.0    0.0    0.0    0.0    0.0    1.0    13
13301901    0.0   10.0     10.0    0.0    0.0    0.0    0.0    1.0    13
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
* heat structure composition type
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* fuel   ( uo2 )
*
20100300  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* gap    (hot channel)
*
20100400  "tbl/fctn"  3         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* clad   ( zr-4)
*
20100500  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* base metal  ( carbon steel )
*
20100600  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* cladding  ( stainless steel )
*
20100700  "tbl/fctn"  1         1
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*$$$ *$$$ *
*$$$ *$$$ * gap    (avg channel)
*$$$ *$$$ *
*$$$ *$$$ 20100900  "tbl/fctn"  3         1
*$$$ *
*---**---**---**---**---**---**---**---**---**---**---**---**---*
```

```
*
*
*     heat structure thermal conductivities
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*    fuel     ( uo2 )
*
20100301    70.0     1.237e-3      200.0     1.237e-3
20100302   400.0     1.022e-3      800.0     0.745e-3
20100303  1200.0     0.592e-3     1600.0     0.492e-3
20100304  2000.0     0.430e-3     2400.0     0.395e-3
20100305  2800.0     0.383e-3     3200.0     0.367e-3
20100306  3600.0     0.370e-3     4000.0     0.380e-3
20100307  4400.0     0.405e-3     5000.0     0.470e-3
*
*    gap      ( bol )
*
20100401  "helium"     0.989748
20100402  "nitrogen"   0.008098
20100403  "oxygen"     0.002153
20100404  "krypton"    0.000000
20100405  "xenon"      0.000002
*
*    clad      (zr-4)
*
20100501     70.0   2.333e-3    200.0   2.333e-3    400.0   2.458e-3
20100502    800.0   2.805e-3   1200.0   3.278e-3   1600.0   3.805e-3
20100503   1800.0   4.112e-3   2000.0   4.445e-3   2100.0   4.667e-3
20100504   2200.0   4.945e-3   2800.0   7.000e-3
*
*    thermal conductivity     base metal   ( carbon steel )
*
20100601  0.0       .00728    2000.0    .00728
*
*    thermal conducitvity     cladding   ( stainless steel )
*
20100701  0.0       .00311    2000.0    .00311
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
*     heat structure volumetric heat capacities
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* volumetric heat capacity  fuel     ( uo2 )
*
20100351    77.0   33.8    200.0   40.62    400.0   43.87
20100352   600.0   45.82   800.0   47.12   1000.0   48.10
20100353  1200.0   48.88  1600.0   49.92   2000.0   50.37
20100354  2400.0   51.35  2800.0   53.62   3200.0   58.17
```

```
20100355  3600.0   66.30  4000.0   78.97   4400.0   90.80
20100356  4800.0   99.12  5100.0  101.40
*
* volumetric  heat  capacity   gap   (hot channel)
*
20100451  32.0   0.000075    5400.0    0.000075
*
* volumetric  heat  capacity   clad
*
20100551    32.0   28.346  1062.0    33.232   1140.0   35.432
20100552  1480.0   35.432  1510.0    49.440   1530.0   56.440
20100553  1560.0   58.916  1590.0    61.800   1610.0   66.332
20100554  1620.0   76.220  1650.0    80.340   1680.0   78.28
20100555  1700.0   74.16   1780.0    35.432   3000.0   35.432
*
* volumetric  heat  capacity   base metal   (carbon steel)
*
20100651  0.0       64.4      2000.0    64.4
*
* volumemetric heat capacity   cladding   (stainless steel)
*
20100751  0.0       64.4      2000.0    64.4
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
*        general tables
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*  test power insertion
*
* 20200100  power
* 20200101  0.0  0.0  5.0  0.0  25.0  1.0-2
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*
*        control varialbes
*
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
* 20547400  "hcpwr"    "constant"  3.15e6
* 20547400  "hcpwr"    "function"  3.15e4  0.0  0
* 20547401  time  0  1
*
*---**---**---**---**---**---**---**---**---**---**---**---**---*
***
***
***                    reactor kinetics
***
***
```

```
*---**---**---**---**---**---**---**---**---**---**---**---*
*
*  power in watts per assembly
*
30000000  "point"   "separabl"
30000001 "gamma-ac"  5.00000  .00000 .28637e+03   1.0  1.0
30000001 "gamma"  5.00000  .00000 .387297e+03   1.0  1.0
30000002  "ans73"   0.0   1.0
30000301  0.3230  0.000491  0.2910  0.00000341
30000301      *  fissions in Pu
*
*---**---**---**---**---**---**---**---**---**---**---**---*
*
*   Delayed Neutron Information
*   Fast Fission in Pu-239
*
30000101  0.038   0.01290
30000102  0.280   0.03110
30000103  0.216   0.1336
30000104  0.328   0.33165
30000105  0.103   1.26256
30000106  0.035   3.2090
*
*---**---**---**---**---**---**---**---**---**---**---**---*
*
*  general table for waste package reactivity insertion  ttt = 1
*
30000011  1
*  30000012  10081
*
*---**---**---**---**---**---**---**---**---**---**---**---*
*
*  moderator density reactivity feedback
*
*  beff = 0.00371
*
*          density  lf/ft**3    reactivity, dollars     fuel temp. f
*
30000501      43.6995724         -39.6888294          *  1004
30000502      45.2602714         -34.6179058          *  1004
30000503      46.8209705         -29.9326885          *  1004
30000504      48.3816695         -25.5977517          *  1004
30000505      49.9423685         -21.5779876          *  1004
30000506      51.5030675         -17.8459359          *  1004
30000507      53.0637665         -14.3747439          *  1004
30000508      54.6244655         -11.1428012          *  1004
30000509      56.1851645         -08.1284495          *   518
30000510      57.4337238         -05.9126080          *   518
30000511      58.6822830         -03.8141560          *   518
30000512      59.8121897         -02.0474332          *   518
30000513      60.7424057         -00.9978186          *   212
30000514      61.6903146          00.00               *   122
30000515      62.4279606         +00.7275935          *   122
30000516      65.0000000         +00.7275935          *    80.33
```

```
*
*  control volume weighting  - modified from Original deck with uniform
weights (porportional to volume fractions)
*
30000701   010010000   0   .022531251   0.0
30000702   020010000   0   .022531251   0.0
30000703   030010000   0   .022531251   0.0
30000704   040010000   0   .022531251   0.0
30000705   050010000   0   .022531251   0.0
30000706   060010000   0   .045062502   0.0
30000707   070010000   0   .045062502   0.0
30000708   080010000   0   .045062502   0.0
30000709   090010000   0   .045062502   0.0
30000710   100010000   0   .045062502   0.0
30000711   110010000   0   .045062502   0.0
30000712   120010000   0   .045062502   0.0
30000713   130010000   0   .045062502   0.0
30000714   140010000   0   .012443753   0.0
30000715   150010000   0   .013678393   0.0
30000716   160010000   0   .048603781   0.0
30000717   170010000   0   .033087495   0.0
30000718   180010000   0   .054636012   0.0
30000719   190010000   0   .053159916   0.0
30000720   200010000   0   .052524779   0.0
30000721   210010000   0   .047587753   0.0
30000722   220010000   0   .052524779   0.0
30000723   230010000   0   .052524779   0.0
30000724   240010000   0   .029919722   0.0
30000725   250010000   0   .076152518   0.0
*
* 30000501
* 30000502
* 30000503
* 30000504
* 30000505
* 30000506
* 30000507
* 30000508
* 30000509
* 30000510
* 30000511
* 30000512
* 30000513
* 30000514
* 30000515
* 30000516
* 30000701
* 30000702
* 30000703
* 30000704
* 30000705
* 30000706
* 30000707
* 30000708
```

```
* 30000709
* 30000710
* 30000711
* 30000712
* 30000713
* 30000714
* 30000715
* 30000716
* 30000717
* 30000718
* 30000719
* 30000720
* 30000721
* 30000722
* 30000723
* 30000724
* 30000725
*---**---**---**---**---**---**---**---**---**---**---**---**---*
*
*   average fuel temperature vs. reactivity
*
*
*           fuel temp. f      reactivity, dollars     density lb/ft**3
*
30000601     32.0               +0.2779469          *  62.4279606
30000602     80.33              +0.2779469          *  62.4279606
30000603    122.0                0.0                *  61.6903146
30000604    212.0               -0.5621724          *  61.6903146
30000605    320.0               -1.1754369          *  60.7424057
30000606    518.0               -2.2507464          *  60.7424057
30000607   1004.0               -4.7207118          *  56.1851645
*
*
*
*  heat structure weighting - (added to deck - B&W code does weights
*                              internally)
*
30000801   3301001   0   .04762000   0.0
30000802   3301002   0   .04761900   0.0
30000803   3301003   0   .04761900   0.0
30000804   3301004   0   .04761900   0.0
30000805   3301005   0   .04761900   0.0
30000806   3301006   0   .09523800   0.0
30000807   3301007   0   .09523800   0.0
30000808   3301008   0   .09523800   0.0
30000809   3301009   0   .09523800   0.0
30000810   3301010   0   .09523800   0.0
30000811   3301011   0   .09523800   0.0
30000812   3301012   0   .09523800   0.0
30000813   3301013   0   .09523800   0.0
*
*   Control Blocks
*
20500000   999
```

```
20500100   cntrlvar   function  0.04762  0.0    0
20500101   htvat    3301001    002
20500200   cntrlvar   function  0.04761  0.0    0
20500201   htvat    3301002    002
20500300   cntrlvar   function  0.04761  0.0    0
20500301   htvat    3301003    002
20500400   cntrlvar   function  0.04761  0.0    0
20500401   htvat    3301004    002
20500500   cntrlvar   function  0.04761  0.0    0
20500501   htvat    3301005    002
20500600   cntrlvar   function  0.095238 0.0    0
20500601   htvat    3301006    002
20500700   cntrlvar   function  0.095238 0.0    0
20500701   htvat    3301007    002
20500800   cntrlvar   function  0.095238 0.0    0
20500801   htvat    3301008    002
20500900   cntrlvar   function  0.095238 0.0    0
20500901   htvat    3301009    002
20501000   cntrlvar  function  0.095238 0.0    0
20501001   htvat    3301010    002
20501100   cntrlvar  function  0.095238 0.0    0
20501101   htvat    3301011    002
20501200   cntrlvar  function  0.095238 0.0    0
20501201   htvat    3301012    002
20501300   cntrlvar  function  0.095238 0.0    0
20501301   htvat    3301013    002
*
*    Doppler Reactivity
*           name   component Scale F.  Initial  Initial Val Falg
20501400   cntrlvar  sum       1.0      0.0    0
20501401  -6.63322e-5  1.0  cntrlvar 1 1.0  cntrlvar 2  1.0    cntrlvar 3
20501401  1.0213e-5    1.0  cntrlvar 1 1.0  cntrlvar 2  1.0    cntrlvar 3
20501402         1.0  cntrlvar 4  1.0   cntrlvar 5   1.0    cntrlvar 6
20501403         1.0  cntrlvar 7  1.0   cntrlvar 8   1.0    cntrlvar 9
20501404         1.0  cntrlvar 10 1.0   cntrlvar 11  1.0    cntrlvar 12
20501405         1.0  cntrlvar 13
*
*    Viod Reactivity
*
*           name    component   Scale F.  Initial  Initial Val Falg
20502000   cntrlvar  function   0.022531251  0.0    0
20502001   "rho"     010010000  005
20502100   cntrlvar  function   0.022531251  0.0    0
20502101   "rho"     020010000  005
20502200   cntrlvar  function   0.022531251  0.0    0
20502201   rho      030010000  005
20502300   cntrlvar  function   0.022531251  0.0    0
20502301   rho      040010000  005
20502400   cntrlvar  function   0.022531251  0.0    0
20502401   rho      050010000  005
20502500   cntrlvar  function   0.045062502  0.0    0
20502501   rho      060010000  005
20502600   cntrlvar  function   0.045062502  0.0    0
20502601   rho      070010000  005
```

```
20502700   cntrlvar  function   0.045062502  0.0    0
20502701   rho      080010000  005
20502800   cntrlvar  function   0.045062502  0.0    0
20502801   rho      090010000  005
20502900   cntrlvar  function   0.045062502  0.0    0
20502901   rho      100010000  005
20503000   cntrlvar  function   0.045062502  0.0    0
20503001   rho      110010000  005
20503100   cntrlvar  function   0.045062502  0.0    0
20503101   rho      120010000  005
20503200   cntrlvar  function   0.045062502  0.0    0
20503201   rho      130010000  005
20503300   cntrlvar  function   0.012443753  0.0    0
20503301   rho      140010000  005
20503400   cntrlvar  function   0.013678393  0.0    0
20503401   rho      150010000  005
20503500   cntrlvar  function   0.048603781  0.0    0
20503501   rho      160010000  005
20503600   cntrlvar  function   0.033087495  0.0    0
20503601   rho      170010000  005
20503700   cntrlvar  function   0.054636012  0.0    0
20503701   rho      180010000  005
20503800   cntrlvar  function   0.053159916  0.0    0
20503801   rho      190010000  005
20503900   cntrlvar  function   0.052524779  0.0    0
20503901   rho      200010000  005
20504000   cntrlvar  function   0.047587753  0.0    0
20504001   rho      210010000  005
20504100   cntrlvar  function   0.052524779  0.0    0
20504101   rho      220010000  005
20504200   cntrlvar  function   0.052524779  0.0    0
20504201   rho      230010000  005
20504300   cntrlvar  function   0.029919772  0.0    0
20504301   rho      240010000  005
20504400   cntrlvar  function   0.076152518  0.0    0
20504401   rho      250010000  005
*
20505000   cntrlvar  sum       1.0      0.0   0
20505001   0.0  1.0  cntrlvar 20  1.0  cntrlvar 21  1.0   cntrlvar 22
20505002        1.0  cntrlvar 23  1.0  cntrlvar 24  1.0   cntrlvar 25
20505003        1.0  cntrlvar 26  1.0  cntrlvar 27  1.0   cntrlvar 28
20505004        1.0  cntrlvar 29  1.0  cntrlvar 30  1.0   cntrlvar 31
*
20505500   cntrlvar  sum       1.0      0.0   0
20505501   0.0  1.0  cntrlvar 32  1.0  cntrlvar 33  1.0   cntrlvar 34
20505502        1.0  cntrlvar 35  1.0  cntrlvar 36  1.0   cntrlvar 37
20505503        1.0  cntrlvar 38  1.0  cntrlvar 39  1.0   cntrlvar 40
20505504        1.0  cntrlvar 41  1.0  cntrlvar 42  1.0   cntrlvar 43
20505505        1.0  cntrlvar 44
*
20505600   cntrlvar   sum       1.0      0.0   0
20505601   0.306497   1.0   cntrlvar 50  1.0   cntrlvar 55
*
20506000   cntrlvar  function   1.0    0.0   0
```

```
20506001   time      0          001
20506500   cntrlvar   sum        1.0    0.0  0
20506501   0.0  1.0  cntrlvar 14  1.0   cntrlvar 56  1.0  cntrlvar  60
*
20507000   cntrlvar  integral   1.0    0.0   0
20507001   rktpow    0
*
20507500   cntrlvar  sum    6.22971e-2    0.0   0
20507501   0.0    1.0  htgamw  312100100  1.0  htgamw  312100200
20507502          1.0  htgamw  312100300  1.0  htgamw  312100400
20507503          1.0  htgamw  312100500  1.0  htgamw  312100600
20507504          1.0  htgamw  312100700  1.0  htgamw  312100700
20507505          1.0  htgamw  312100900
*
*              scale factor = 1/area sum
* 20508000   cntrlvar  sum   0.26289886    0.0     0
* 20508001   0.0    0.3516846 voidf  050010000  0.7033692  voidf 100010000
* 20508002          0.8633786 voidf  200010000  0.7822260  voidf 210010000
*
* 20508100   cntrlvar  function  1.0    0.0    0
* 20508101   cntrlvar  80        010
*
. * end of data
```

ATTACHMENT V

Unix script files to strip selected isotopic data from the ORIGEN-S output data files.

KS.run.script

Script calls KS.script to act on the output file and place results in the output file.

```
awk -f KS.script W335-5-6.joklo2.output > NOCcuries.out
```

KS.script

Script searches for records containing isotopic names after encountering appropriate trigger character strings.

```
BEGIN {intable=0 && insas=0 }
/grams/ {insas=1}
/nuclide radioactivity/{if (insas) print $0; intable=1}
/initial/ {if (insas && intable) print $0}
/charge/ {if (insas && intable) print $0}
/ac227/ {if (insas && intable) print $0}
/am241 / {if (insas && intable) print $0}
/am242m/ {if (insas && intable) print $0}
/am243 / {if (insas && intable) print $0}
/ba137m/ {if (insas && intable) print $0}
/ c 14 / {if (insas && intable) print $0}
/cd113m/ {if (insas && intable) print $0}
/cl 36 / {if (insas && intable) print $0}
/cm242 / {if (insas && intable) print $0}
/cm243 / {if (insas && intable) print $0}
/cm244 / {if (insas && intable) print $0}
/cm245 / {if (insas && intable) print $0}
/cm246 / {if (insas && intable) print $0}
/cm247 / {if (insas && intable) print $0}
/co 60 / {if (insas && intable) print $0}
/cs134 / {if (insas && intable) print $0}
/cs135 / {if (insas && intable) print $0}
/cs137 / {if (insas && intable) print $0}
/eu154 / {if (insas && intable) print $0}
/eu155 / {if (insas && intable) print $0}
/fe 55 / {if (insas && intable) print $0}
/fr221 / {if (insas && intable) print $0}
/ h  3 / {if (insas && intable) print $0}
/ I129 / {if (insas && intable) print $0}
/kr 85 / {if (insas && intable) print $0}
/nb 93m/ {if (insas && intable) print $0}
/nb 94 / {if (insas && intable) print $0}
/ni 59 / {if (insas && intable) print $0}
/ni 63 / {if (insas && intable) print $0}
/np237 / {if (insas && intable) print $0}
/pa231 / {if (insas && intable) print $0}
```

```
/pb210 / {if (insas && intable) print $0}
/pd107 / {if (insas && intable) print $0}
/pm147 / {if (insas && intable) print $0}
/po218 / {if (insas && intable) print $0}
/pu238 / {if (insas && intable) print $0}
/pu239 / {if (insas && intable) print $0}
/pu240 / {if (insas && intable) print $0}
/pu241 / {if (insas && intable) print $0}
/pu242 / {if (insas && intable) print $0}
/ra226 / {if (insas && intable) print $0}
/ra228 / {if (insas && intable) print $0}
/ru106 / {if (insas && intable) print $0}
/sb125 / {if (insas && intable) print $0}
/se 79 / {if (insas && intable) print $0}
/sm147 / {if (insas && intable) print $0}
/sm151 / {if (insas && intable) print $0}
/sn126 / {if (insas && intable) print $0}
/sr 90 / {if (insas && intable) print $0}
/tc 99 / {if (insas && intable) print $0}
/th229 / {if (insas && intable) print $0}
/th230 / {if (insas && intable) print $0}
/th232 / {if (insas && intable) print $0}
/ u232 / {if (insas && intable) print $0}
/ u233 / {if (insas && intable) print $0}
/ u234 / {if (insas && intable) print $0}
/ u235 / {if (insas && intable) print $0}
/ u236 / {if (insas && intable) print $0}
/ u238 / {if (insas && intable) print $0}
/ y 90 / {if (insas && intable) print $0}
/zr 93 / {if (insas && intable) print $0}
/total/ {intable=0}
```

# ATTACHMENT VI

## OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT DOCUMENT INPUT REFERENCE SHEET

| 1. Document Identifier No./Rev.: | Change: | Title: |
|---|---|---|
| CAL-EBS-NU-000008 REV 00 | N/A | Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package |

| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
|---|---|---|---|---|---|---|---|---|---|
| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 2a | | | | | | | | | |
| 1 | Civilian Radioactive Waste Management System (CRWMS) Management & Operating Contractor (M&O) 1997. *Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21 PWR Assembly Waste Package*. BBA000000-01717-0200-00057 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980106.0331. | Attach. IV<br>Attach. III<br>Sect. 7<br>p. 37<br>Table 4.1-2<br>p. 18 | TBV-3294<br>TBV-3295<br>TBV-3296<br>TBV-3297<br>TBV-3298<br>TBV-3299 | Sect. 2, 5, 6<br>Sect. 2, 5, 6<br>Sect. 2, 5, 6<br>Sect. 5, 6<br>Sect. 5, 6<br>Sect. 5 | Base **RELAP5** Data File<br>Particle fall time in water<br>Max WP excess reactivity<br>**Assembly dimensions**<br>**WP dimensions**<br>**Equation**<br>**Resolved through peer review** | 3<br>3<br>3<br>3<br>3<br>3 | √<br>√<br>√<br>√<br>√<br>√ | N/A<br>N/A<br>N/A<br>N/A<br>N/A<br>N/A | N/A<br>N/A<br>N/A<br>N/A<br>N/A<br>N/A |
| 2 | Nuclear Regulatory Commission (NRC) 1995. *RELAP5/MOD3 Code Manual, Vol. 1.* NUREG/CR-5535. Washington, D.C.: NRC. TIC: 238741. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

| 1. Document Identifier No./Rev.: CAL-EBS-NU-000008 REV 00 | | | Change: N/A | Title: Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 3 | CRWMS M&O 1998. *Software Qualification Report for MCNP Version 4B2 A General Monte Carlo N-Particle Transport Code* CSCI: 30033 V4B2LV. DI: 30033-2003 Rev. 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980622.0637. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |
| 4 | Not Used | N/A | N/A | N/A | N/A | | N/A | N/A | N/A |
| 5 | Westinghouse Electric Corporation 1996. *Plutonium Disposition Study, Implementation of Weapons Grade MOX Fuel in Existing Pressurized Water Reactors for the Department of Energy, Oakland, California*. DOE/SF/19683-7, Revision 1. Pittsburgh, Pennsylvania: Westinghouse Electric Corporation. TIC: 245436. | p. 18<br>p. 17<br>p. 25 | TBV-3301 | Sect. 3 | Fuel Composition Data<br>**U and Pu Isotopic Distribution**<br>**Kinetics parameters**<br>**Resolved through peer review** | 3 | N/A | √ | N/A |
| 6 | CRWMS M&O 1997. *Software Qualification Report for The SCALE Modular Code System Version 4.3*. CSCI: 30011 V4.3. DI: 30011-2002 Rev. 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970731.0884. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

| 1. Document Identifier No./Rev.: CAL-EBS-NU-000008 REV 00 | | | Change: N/A | Title: Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
| | 2. Technical Product Input Source Title and Identifier(s) with Version | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 7 | CRWMS M&O 1999. *Electronic Data for Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package*, *CAL-EBS-NU-000008 REV 00*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990923.0239. | N/A | TBV-3302 | Sect. 5, 6 | Output files as a result of CAL-EBS-NU-000008 REV 00 Calculation **Resolved through peer review** | 3 | √ | N/A | N/A |
| 8 | CRWMS M&O 1998. *Westinghouse MOX SNF Isotopic Source*. BBA000000-01717-0210-00007 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980818.0131. | Sect. 5.1, p. 14 | TBV-3303 | Sect. 5.1 | Westinghouse Vantage 5 Assembly data **Resolved through peer review** | 3 | N/A | √ | N/A |
| 9 | Department of Energy (DOE) 1987. *Characteristics of Spent Fuel, High Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation, Volume 3 of 6, Appendix 2A: Physical Descriptions of LWR Fuel Assemblies*. DOE/RW-0184. Washington, D.C.: DOE. TIC: 202243. | pp. 2A-355 through 2A-358. | TBV-3304 | Sect. 5.1 | Westinghouse Vantage 5 assembly data **Resolved through peer review** | 3 | N/A | √ | N/A |

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

| 1. Document Identifier No./Rev.: CAL-EBS-NU-000008 REV 00 | | | Change: N/A | Title: Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 10 | CRWMS M&O 1998, *Summary Report of Commercial Reactor Criticality Data for McGuire Unit 1.* B00000000-01717-5705-00063 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980622.0079. | p. 37 | TBV-3305 | Sect. 5.1 | Westinghouse Vantage 5 assembly data<br>**Resolved through peer review** | 3 | N/A | √ | N/A |
| 11 | CRWMS M&O 1998. *Two (2) Data Cartridges for Westinghouse MOX SNF Isotopic Source BBA000000-01717-0210-00007 REV 00*. Las Vegas, Nevada: CRWMS M&O. MOL.19980629.0795. | entire | TBV-3606 | Section 5.1 | Assembly isotopic data for 25000 yr. Decay<br>**Resolved through peer review** | 3 | √ | N/A | N/A |
| 12 | Oak Ridge National Laboratory (ORNL) 1995. *SCALE 4.3, RSIC Computer Code Collection, CCC-545.* Oak Ridge, Tennessee: ORNL. TIC: 235920. | entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |
| 13 | CRWMS M&O 1998. *Criticality Evaluation of Intact and Degraded PWR WPs Containing MOX SNF.* A00000000-01717-0210-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980701.0482. | Table 6.2-2 | TBV-3407 | Sect. 5.2, 5.4 | MCNP $k_{eff}$ calculation for 21 PWR MOX WP<br>**Resolved through peer review** | 3 | √ | N/A | N/A |

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

| 1. Document Identifier No./Rev.: CAL-EBS-NU-000008 REV 00 | | | Change: N/A | Title: Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 14 | Holman, J.P. 1990. *Heat Transfer - 7th Edition*. New York, New York: McGraw-Hill Publishing Company. TIC: 242477. | pp. 14, 31, 420, 601, 602, 606. Tables A-8, A-9 | TBV-3408 | Sect. 5.3 | Parameter values for Steady State power calculation **Resolved through peer review** | 3 | N/A | √ | N/A |
| 15 | Weast, R.C. 1979. *CRC Handbook of Chemistry and Physics, 60th Edition, 1979-1980.* Boca Raton, Florida: CRC Press, Inc. TIC: 239951. | p. F-13 | N/A | Sect. 5.3. | Molecular weight of air Handbook value. | N/A | N/A | N/A | N/A |
| 16 | Walker, F.W.; Parrington, J R.; and Feiner, F. 1989. *Nuclides and Isotopes, Fourteenth Edition: Chart of the Nuclides.* San Jose, California: General Electric Company. TIC: 201637. | p. 57 | N/A | Sect. 5.3 | Steady State Power Calculation, Gas Constant Handbook Value | | N/A | N/A | N/A |
| 17 | DOE 1998. *Viability Assessment of a Repository at Yucca Mountain – Total System Performance Assessment – Volume 3.* DOE/RW-0508/V3. North Las Vegas, Nevada: DOE. ACC: MOL.19981007.0030. | pp. 3-15, 3-17, 3-37 | TBV-3316 | Sect. 5.3 | Steady State Power Calculation for WP **Resolved through peer review** | 3 | √ | N/A | N/A |

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

| 1. Document Identifier No./Rev.: CAL-EBS-NU-000008 REV 00 | | | Change: N/A | Title: Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 18 | American Society of Mechanical Engineers (ASME) 1967. *STEAM TABLES Thermodynamic and Transport Properties of Steam, Sixth Edition*. New York, New York: ASME. TIC: 103243. | pp. 218-221 | N/A | Sect. 5.3 | Steady State Power Calculation - Water Properties - Handbook Values | N/A | N/A | N/A | N/A |
| 19 | CRWMS M&O 1995. *Emplacement Scale Thermal Evaluations of Large and Small WP Designs.* BB0000000-01717-0200-00009 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960624.0097. | pp. 9, 34 | TBV-3318 | Sect. 5.3 | Steady State Power Calculation<br>**Resolved through peer review** | 3 | √ | N/A | N/A |
| 20 | CRWMS M&O 1996. *Second Waste Package Probabilistic Criticality Analysis: Generation and Evaluation of Internal Criticality Configurations*. BBA000000-01717-0200-00005 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960923.0196. | p. VI-4<br><br>p. 17 | TBV-3319<br><br>TBV-3300 | Sect. 5.3<br><br>Sect. 3 | Steady State Power Calculation<br>**Basis for Assumption**<br>**Resolved through peer review** | 3<br><br>3 | √<br><br>√ | N/A<br><br>N/A | N/A<br><br>N/A |
| 21 | CRWMS M&O 1999. *Sensitivity Study of Reactivity Consequences to Waste Package Egress Area*. CAL-EBS-NU-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990928.0239. | Sect. 5<br>Sect. 2 | TBV-3320 | Sect. 5.4<br>Sect. 6 | Relap5 Representation<br>Results Comparison<br>**Resolved through peer review** | 3 | √ | N/A | N/A |

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.: CAL-EBS-NU-000008 REV 00
Change: N/A
Title: Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package

| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
|---|---|---|---|---|---|---|---|---|---|
| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 22 | NRC 1995. *RELAP5/MOD3 Code Manual, Vol. 2, Users's Guide and Input Requirements*. NUREG/CR-5535. Washington, D.C.: NRC.TIC: 243017. | pp. 2-14 -2-16 | N/A | Sect. 5.4 | Relap5 Representation | | | N/A | N/A |
| 23 | Duderstadt, J.J. and Hamilton, L.J. 1976. *Nuclear Reactor Analysis*. New York, New York: John Wiley & Sons, Inc. TIC: 245454. | p. 64 | TBV-3321 | Sect. 5, 6 | Delayed Neutron Data for Pu<br>**Resolved through peer review** | 3 | N/A | √ | N/A |
| 24 | CRWMS M&O 1997. *Waste Package Design Basis Events*. BBA000000-01717-0200-00037 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971006.0075. | p. I-17 | TBV-3322 | Sect. 5.1 | WP Design Parameter<br>**Resolved through peer review** | 3 | √ | N/A | N/A |
| 25 | CRWMS M&O 1999. *Installation Test Plan (ITP) for RELAP5/MOD3.2 V1.0.* Las Vegas, Nevada: CRWMS M&O. SDN: 10091-ITP-1.0-00. ACC: ACC: MOL.19990929.0035. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |
| 26 | CRWMS M&O 1999. *Validation Test Plan (VTP) for RELAP5/MOD3.2 V1.0.* Las Vegas, Nevada: CRWMS M&O. SDN: 10091-VTP-1.0-00. ACC: ACC: MOL.19990929.0034. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

| 1. Document Identifier No./Rev.: CAL-EBS-NU-000008 REV 00 | | | Change: N/A | Title: Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 27 | CRWMS M&O 1999. *Software Activity Plan (SAP) for RELAP5/MOD3.2 V1.0.* Las Vegas, Nevada: CRWMS M&O. SDN: 10091-SAP-1.0-00. ACC: ACC: MOL.19990929.0031. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |
| 28 | CRWMS M&O 1999. *Software Requirements Document (RD) for RELAP5/MOD3.2 V1.0.* Las Vegas, Nevada: CRWMS M&O. SDN: 10091-RD-1.0-00. ACC: ACC: MOL.19990929.0032. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |
| 29 | CRWMS M&O 1999. *Software Design Document (DD) for RELAP5/MOD3.2 V1.0.* Las Vegas, Nevada: CRWMS M&O. SDN: 10091-DD-1.0-00. ACC: ACC: MOL.19990929.0033. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |
| 30 | CRWMS M&O 1999. *Validation Test Report (VTR) for RELAP5/MOD3.2 V1.0.* Las Vegas, Nevada: CRWMS M&O. SDN: 10091-VTR-1.0-00. ACC: MOL.19990929.0036. | Entire | N/A | Sect. 5, 6 | Software Documentation | | N/A | N/A | N/A |

# ATTACHMENT VII

The directory of files on the electronic media (CD) (Ref. 7) for this calculation is given in Tables VII-1 and VII-2. Files from the HP-9000 workstation directory were copied first to a PC, then to the CD. File names and sizes in bytes are listed as given on the originating hardware. The RELAP5/MOD3.2 program uses and creates a number of data files. Many of these files are intermediate in nature and thus are important but may not be directly referenced either as initial input data files or as resource files for tabular and/or graphical display of results from the calculation.

Table VII-1. Directory of HP Files on Compact Disk

| HP File Directory for CAL-EBS-NU-000008 REV 00 | | | | |
|---|---|---|---|---|
| Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | |
| Read (r), Write (w), Execute (x) Permissions | File Size (bytes) | Creation Date | Creation Time | File Name |
| -rw-r----- | 14871 | Sept 9, 1999 | 14:25 | 21MS1F |
| -rw-r--r-- | 289048 | Sept 9, 1999 | 14:25 | 21MS1F.O |
| -rw-r--r-- | 12009335 | Sept 9, 1999 | 14:33 | Case02cR1.lst |
| -rw-r--r-- | 12009549 | Sept 9, 1999 | 14:34 | Case03cR1.lst |
| -rw-r--r-- | 12009763 | Sept 9, 1999 | 14:34 | Case03dR1.lst |
| -rw-r--r-- | 12010084 | Sept 9, 1999 | 14:35 | Case03eR1.lst |
| -rw-r--r-- | 12010191 | Sept 9, 1999 | 14:35 | Case03fR1.lst |
| -rw-r--r-- | 12010512 | Sept 9, 1999 | 14:36 | Case03gR1.lst |
| -rw-r--r-- | 2289316 | Sept 9, 1999 | 14:36 | Case04cR1.lst |
| -rw-r--r-- | 2288888 | Sept 9, 1999 | 14:36 | Case04eR1.lst |
| -rw-r--r-- | 3563781 | Sept 9, 1999 | 14:36 | Case04eR1.r01.lst |
| -rw-r--r-- | 29809368 | Sept 9, 1999 | 14:37 | MOX02cR1.rst |
| -rw-r--r-- | 1351659 | Sept 9, 1999 | 14:37 | MOX02cR1.strp.set01 |
| -rw-r--r-- | 29809368 | Sept 9, 1999 | 14:37 | MOX03cR1.rst |
| -rw-r--r-- | 1351659 | Sept 9, 1999 | 14:37 | MOX03cR1.strp.set01 |
| -rw-r--r-- | 29809368 | Sept 9, 1999 | 14:38 | MOX03dR1.rst |
| -rw-r--r-- | 1351659 | Sept 9, 1999 | 14:38 | MOX03dR1.strp.set01 |
| -rw-r--r-- | 29809368 | Sept 9, 1999 | 14:39 | MOX03eR1.rst |
| -rw-r--r-- | 1351659 | Sept 9, 1999 | 14:39 | MOX03eR1.strp.set01 |
| -rw-r--r-- | 29809368 | Sept 9, 1999 | 14:39 | MOX03fR1.rst |
| -rw-r--r-- | 1351659 | Sept 9, 1999 | 14:39 | MOX03fR1.strp.set01 |
| -rw-r--r-- | 29809368 | Sept 9, 1999 | 14:40 | MOX03gR1.rst |
| -rw-r--r-- | 1351659 | Sept 9, 1999 | 14:40 | MOX03gR1.strp.set01 |
| -rw-r--r-- | 10440328 | Sept 9, 1999 | 14:40 | MOX04cR1.rst |
| -rw-r--r-- | 898329 | Sept 9, 1999 | 14:40 | MOX04cR1.strp.set01 |
| -rw-r--r-- | 29138008 | Sept 9, 1999 | 14:41 | MOX04eR1.rst |
| -rw-r--r-- | 898329 | Sept 9, 1999 | 14:41 | MOX04eR1.strp.set01 |
| -rw-r--r-- | 2358329 | Sept 9, 1999 | 14:41 | MOX04eR1.strp.set02 |
| -rw-r----- | 9072 | Sept 9, 1999 | 14:07 | h2oh13f.mox.inp |
| -rw-r--r-- | 2697120 | Sept 9, 1999 | 14:07 | h2oh13f.mox.lst |
| -rw-r--r-- | 6154 | Sept 9, 1999 | 14:04 | infh2oa.mox.inp |
| -rw-r--r-- | 668233 | Sept 9, 1999 | 14:05 | infh2oa.mox.lst |
| -rw-r--r-- | 6474 | Sept 9, 1999 | 14:06 | out.fin.mox.inp |
| -rw-r--r-- | 5063082 | Sept 9, 1999 | 14:06 | out.fin.mox.lst |

| HP File Directory for CAL-EBS-NU-000008 REV 00 | | | | |
|---|---|---|---|---|
| Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | |
| Read (r), Write (w), Execute (x) Permissions | File Size (bytes) | Creation Date | Creation Time | File Name |
| -rw-r--r-- | 6717 | Sept 9, 1999 | 14:08 | out.wpn.mox.inp |
| -rw-r--r-- | 5063605 | Sept 9, 1999 | 14:09 | out.wpn.mox.lst |
| -rw-r--r-- | 52163 | Sept 9, 1999 | 14:41 | rlp5.MOX01aR1.inp |
| -rw-r--r-- | 53406 | Sept 9, 1999 | 14:41 | rlp5.MOX02cR1.inp |
| -rw-r--r-- | 53533 | Sept 9, 1999 | 14:41 | rlp5.MOX03cR1.inp |
| -rw-r--r-- | 53664 | Sept 9, 1999 | 14:41 | rlp5.MOX03dR1.inp |
| -rw-r--r-- | 53862 | Sept 9, 1999 | 14:41 | rlp5.MOX03eR1.inp |
| -rw-r--r-- | 53923 | Sept 9, 1999 | 14:41 | rlp5.MOX03fR1.inp |
| -rw-r--r-- | 54148 | Sept 9, 1999 | 14:41 | rlp5.MOX03gR1.inp |
| -rw-r--r-- | 54514 | Sept 9, 1999 | 14:41 | rlp5.MOX04cR1.inp |
| -rw-r--r-- | 54238 | Sept 9, 1999 | 14:41 | rlp5.MOX04eR1.inp |
| -rw-r--r-- | 3086 | Sept 9, 1999 | 14:41 | rlp5.MOX04eR1.r01.inp |
| -rwxr--r-- | 1216 | Sept 9, 1999 | 13:23 | runmcnp |
| -rwxr--r-- | 2829 | Sept 9, 1999 | 14:48 | runxrlp5 |
| -rwxr--r-- | 708 | Sept 9, 1999 | 14:48 | runxstrp |
| -rw-r--r-- | 9174 | Sept 9, 1999 | 13:23 | w3_35-5gwd_2cy-6stps.inp |
| -rw-r--r-- | 15158077 | Sept 9, 1999 | 13:22 | w3_35-5gwd_2cy-6stps.output |
| -rw-r--r-- | 6788 | Sept 9, 1999 | 14:02 | wpi.mox1a.inp |
| -rw-r--r-- | 5142388 | Sept 9, 1999 | 14:01 | wpi.mox1a.lst |
| -rw-r--r-- | 17096525 | Sept 24, 1999 | 09:20 | W335-5-6-joklo1.output |
| -rw-r--r-- | 9005 | Sept 24, 1999 | 10:41 | W335-5-6.joklo1.inp |
| -rw-r--r-- | 9018 | Sept 24, 1999 | 07:31 | W335-5-6.joklo2.inp |
| -rw-r--r-- | 17580491 | Sept 24, 1999 | 07:57 | W335-5-6.joklo2.output |
| -rw-r--r-- | 9078 | Sept 24, 1999 | 10:27 | h2oh13f.mox1a.inp |
| -rw-r--r-- | 2696600 | Sept 24, 1999 | 13:17 | h2oh13f.mox1a.lst |
| -rw-r--r-- | 6033 | Sept 24, 1999 | 10:55 | infh2o.mox.inp |
| -rw-r--r-- | 668359 | Sept 24, 1999 | 17:36 | infh2o.mox.lst |
| -rw-r--r-- | 668233 | Sept 10, 1999 | 19:18 | infh2oa.mox.lst |
| -rw-r--r-- | 6878 | Sept 24, 1999 | 13:54 | influx2.MOX1a.inp |
| -rw-r--r-- | 2535338 | Sept 24, 1999 | 17:35 | influx2.MOX1a.lst |
| -rw-r--r-- | 6024 | Sept 24, 1999 | 08:05 | infox.mox.inp |
| -rw-r--r-- | 667715 | Sept 24, 1999 | 19:27 | infox.mox.lst |
| -rw-r--r-- | 6087 | Sept 24, 1999 | 08:15 | infox.mox1a.inp |
| -rw-r--r-- | 670093 | Sept 24, 1999 | 11:48 | infox.mox1a.lst |
| -rw-r--r-- | 6167 | Sept 24, 1999 | 13:32 | infox.mox1b.inp |
| -rw-r--r-- | 670183 | Sept 24, 1999 | 17:02 | infox.mox1b.lst |
| -rw-r--r-- | 5131789 | Sept 26, 1999 | 10:35 | out..fe.mox1f1.lst |
| -rw-r--r-- | 5577 | Sept 26, 1999 | 08:57 | out.e49.mox1a.inp |
| -rw-r--r-- | 5244657 | Sept 26, 1999 | 09:03 | out.e49.mox1a.lst |
| -rw-r--r-- | 5733 | Sept 26, 1999 | 19:23 | out.e49.mox1b.inp |
| -rw-r--r-- | 5060224 | Sept 26, 1999 | 19:30 | out.e49.mox1b.lst |
| -rw-r--r-- | 6003 | Sept 26, 1999 | 11:20 | out.e49.mox1c.inp |
| -rw-r--r-- | 5060987 | Sept 26, 1999 | 11:13 | out.e49.mox1c.lst |
| -rw-r--r-- | 6396 | Sept 26, 1999 | 07:09 | out.e49.mox1d.inp |
| -rw-r--r-- | 5062580 | Sept 26, 1999 | 07:13 | out.e49.mox1d.lst |
| -rw-r--r-- | 5256 | Sept 26, 1999 | 16:29 | out.fe.mox.inp |
| -rw-r--r-- | 5314692 | Sept 26, 1999 | 16:33 | out.fe.mox.lst |
| -rw-r--r-- | 5507 | Sept 26, 1999 | 10:19 | out.fe.mox1a.inp |

| HP File Directory for CAL-EBS-NU-000008 REV 00 | | | | |
|---|---|---|---|---|
| Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | |
| Read (r), Write (w), Execute (x) Permissions | File Size (bytes) | Creation Date | Creation Time | File Name |
| -rw-r--r-- | 5314118 | Sept 26, 1999 | 10:24 | out.fe.mox1a.lst |
| -rw-r--r-- | 6788 | Sept 26, 1999 | 14:30 | out.fe.mox1a.wpi.inp |
| -rw-r--r-- | 5612 | Sept 26, 1999 | 11:04 | out.fe.mox1b.inp |
| -rw-r--r-- | 5315001 | Sept 26, 1999 | 11:10 | out.fe.mox1b.lst |
| -rw-r--r-- | 5708 | Sept 26, 1999 | 11:17 | out.fe.mox1c.inp |
| -rw-r--r-- | 5130148 | Sept 26, 1999 | 11:23 | out.fe.mox1c.lst |
| -rw-r--r-- | 5960 | Sept 26, 1999 | 10:25 | out.fe.mox1d.inp |
| -rw-r--r-- | 5130585 | Sept 26, 1999 | 10:30 | out.fe.mox1d.lst |
| -rw-r--r-- | 6249 | Sept 26, 1999 | 13:43 | out.fe.mox1e.inp |
| -rw-r--r-- | 5317135 | Sept 26, 1999 | 13:25 | out.fe.mox1e.lst |
| -rw-r--r-- | 6265 | Sept 26, 1999 | 22:13 | out.fe.mox1f.inp |
| -rw-r--r-- | 5131758 | Sept 26, 1999 | 22:17 | out.fe.mox1f.lst |
| -rw-r--r-- | 6266 | Sept 26, 1999 | 10:32 | out.fe.mox1f1.inp |
| -rw-r--r-- | 6656 | Sept 26, 1999 | 21:50 | out.fe.mox1g.inp |
| -rw-r--r-- | 5494153 | Sept 26, 1999 | 21:56 | out.fe.mox1g.lst |
| -rw-r--r-- | 5316 | Sept 26, 1999 | 16:55 | out.fegp.mox.inp |
| -rw-r--r-- | 71565 | Sept 26, 1999 | 16:49 | out.fegp.mox.lst |
| -rw-r--r-- | 4997 | Sept 26, 1999 | 10:51 | out.fin.inp |
| -rw-r--r-- | 5390793 | Sept 26, 1999 | 10:53 | out.fin.lst |
| -rw-r--r-- | 6513 | Sept 26, 1999 | 12:57 | out.fin.mox1c.inp |
| -rw-r--r-- | 5063246 | Sept 26, 1999 | 12:59 | out.fin.mox1c.lst |
| -rw-r--r-- | 9624 | Sept 26, 1999 | 20:17 | out.mox1.100.inp |
| -rw-r--r-- | 5149796 | Sept 26, 1999 | 20:48 | out.mox1.100.lst |
| -rw-r--r-- | 7574 | Sept 26, 1999 | 09:20 | out.mox1.122.inp |
| -rw-r--r-- | 5148317 | Sept 26, 1999 | 09:27 | out.mox1.122.lst |
| -rw-r--r-- | 7898 | Sept 26, 1999 | 15:36 | out.mox1.212.inp |
| -rw-r--r-- | 5150101 | Sept 26, 1999 | 14:59 | out.mox1.212.lst |
| -rw-r--r-- | 8012 | Sept 26, 1999 | 15:37 | out.mox1.320.inp |
| -rw-r--r-- | 5150827 | Sept 26, 1999 | 15:50 | out.mox1.320.lst |
| -rw-r--r-- | 8587 | Sept 26, 1999 | 16:02 | out.mox1.518.inp |
| -rw-r--r-- | 5150649 | Sept 26, 1999 | 16:14 | out.mox1.518.lst |
| -rw-r--r-- | 7145 | Sept 26, 1999 | 15:46 | out.mox1a.wp.inp |
| -rw-r--r-- | 5144163 | Sept 26, 1999 | 16:01 | out.mox1a.wp.lst |
| -rw-r--r-- | 7199 | Sept 26, 1999 | 16:06 | out.mox1b.wp.inp |
| -rw-r--r-- | 5144414 | Sept 26, 1999 | 16:10 | out.mox1b.wp.lst |
| -rw-r--r-- | 7259 | Sept 26, 1999 | 16:23 | out.mox1c.wp.inp |
| -rw-r--r-- | 5144769 | Sept 26, 1999 | 16:25 | out.mox1c.wp.lst |
| -rw-r--r-- | 7259 | Sept 26, 1999 | 16:40 | out.mox1d.wp.inp |
| -rw-r--r-- | 5144665 | Sept 26, 1999 | 16:44 | out.mox1d.wp.lst |
| -rw-r--r-- | 7323 | Sept 26, 1999 | 12:28 | out.mox1e.wp.inp |
| -rw-r--r-- | 5145633 | Sept 26, 1999 | 12:32 | out.mox1e.wp.lst |
| -rw-r--r-- | 9509 | Sept 26, 1999 | 20:14 | out.mox2.100.inp |
| -rw-r--r-- | 5148880 | Sept 26, 1999 | 20:23 | out.mox2.100.lst |
| -rw-r--r-- | 7670 | Sept 26, 1999 | 13:11 | out.mox2.122.inp |
| -rw-r--r-- | 5148777 | Sept 26, 1999 | 13:14 | out.mox2.122.lst |
| -rw-r--r-- | 7787 | Sept 26, 1999 | 14:11 | out.mox2.212.inp |
| -rw-r--r-- | 5149537 | Sept 26, 1999 | 14:17 | out.mox2.212.lst |
| -rw-r--r-- | 8473 | Sept 26, 1999 | 15:51 | out.mox2.518.inp |

| HP File Directory for CAL-EBS-NU-000008 REV 00 | | | | |
|---|---|---|---|---|
| Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | |
| Read (r), Write (w), Execute (x) Permissions | File Size (bytes) | Creation Date | Creation Time | File Name |
| -rw-r--r-- | 5150147 | Sept 26, 1999 | 16:13 | out.mox2.518.lst |
| -rw-r--r-- | 9394 | Sept 26, 1999 | 20:10 | out.mox3.100.inp |
| -rw-r--r-- | Sept 26, 1999 | Sept 26, 1999 | 20:26 | out.mox3.100.lst |
| -rw-r--r-- | 8359 | Sept 26, 1999 | 15:44 | out.mox3.518.inp |
| -rw-r--r-- | 5149583 | Sept 26, 1999 | 16:03 | out.mox3.518.lst |
| -rw-r--r-- | 9279 | Sept 26, 1999 | 16:56 | out.mox4.100.inp |
| -rw-r--r-- | 5151426 | Sept 26, 1999 | 17:06 | out.mox4.100.lst |
| -rw-r--r-- | 8246 | Sept 26, 1999 | 15:35 | out.mox4.518.inp |
| -rw-r--r-- | 5149039 | Sept 26, 1999 | 16:02 | out.mox4.518.lst |
| -rw-r--r-- | 9164 | Sept 26, 1999 | 16:52 | out.mox5.100.inp |
| -rw-r--r-- | 5150924 | Sept 26, 1999 | 17:07 | out.mox5.100.lst |
| -rw-r--r-- | 8126 | Sept 26, 1999 | 15:37 | out.mox5.518.inp |
| -rw-r--r-- | 5151777 | Sept 26, 1999 | 15:51 | out.mox5.518.lst |
| -rw-r--r-- | 9049 | Sept 26, 1999 | 16:48 | out.mox6.100.inp |
| -rw-r--r-- | 5150568 | Sept 26, 1999 | 16:57 | out.mox6.100.lst |
| -rw-r--r-- | 8934 | Sept 26, 1999 | 16:36 | out.mox7.100.inp |
| -rw-r--r-- | 5149959 | Sept 26, 1999 | 16:57 | out.mox7.100.lst |
| -rw-r--r-- | 8819 | Sept 26, 1999 | 16:30 | out.mox8.100.inp |
| -rw-r--r-- | 5152632 | Sept 26, 1999 | 16:36 | out.mox8.100.lst |
| -rw-r--r-- | 8702 | Sept 26, 1999 | 16:09 | out.mox9.100.inp |
| -rw-r--r-- | 5152005 | Sept 26, 1999 | 16:36 | out.mox9.100.lst |
| -rw-r--r-- | 6717 | Sept 26, 1999 | 09:22 | out.wpn.mox.inp |
| -rw-r--r-- | 5063605 | Sept 26, 1999 | 09:25 | out.wpn.mox.lst |
| -rw-r--r-- | 5142388 | Sept 26, 1999 | 14:21 | wpi.mox1a.lst |
| -rw-r--r-- | 54514 | Sept 26, 1999 | 07:22 | rlp5.MOX04cR1.inp |
| -rw-r--r-- | 43913 | Sept 08, 1999 | 8:49 | r5wp2d.c103c |

Table VII-2. Directory of PC Files on Compact Disk

| PC File Directory for CAL-EBS-NU-000008 REV 00 | | | | |
|---|---|---|---|---|
| Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package | | | | |
| DOS File Name | File Size (bytes) | Creation Date | Creation Time | File Name |
| CASE2CR1.S01 | 1,370,174 | 08-31-99 | 3:49p | Case2cR1.s01 |
| CASE3CR1.S01 | 1,370,174 | 08-31-99 | 3:50p | Case3cR1.s01 |
| CASE3DR1.S01 | 1,370,174 | 08-31-99 | 3:56p | Case3dR1.s01 |
| CASE3ER1.S01 | 1,370,174 | 09-24-99 | 9:38a | Case3eR1.s01 |
| CASE3FR1.S01 | 1,370,174 | 09-01-99 | 7:55a | Case3fR1.s01 |
| CASE3GR1.S01 | 1,370,174 | 08-30-99 | 3:20p | Case3gR1.s01 |
| CASE4CR1.S01 | 910,634 | 09-01-99 | 10:44a | Case4cR1.s01 |
| CASE4ER1.S01 | 910,634 | 08-31-99 | 3:53p | Case4eR1.s01 |
| CASE4ER1.S02 | 2,390,634 | 09-02-99 | 5:06p | Case4eR1.s02 |
| CURIE.XLS | 78,848 | 09-08-99 | 9:22p | curie.xls |
| KSRUN~1.SCR | 57 | 09-08-99 | 8:29p | KS.run.script |
| KS~1.SCR | 2,839 | 09-08-99 | 8:29p | KS.script |
| MOX03C.XLS | 3,804,160 | 09-01-99 | 10:23p | MOX03c.xls |
| MOX04A.XLS | 1,829,888 | 09-02-99 | 8:24a | MOX04a.xls |

| PC File Directory for CAL-EBS-NU-000008 REV 00 | | | | |
|---|---|---|---|---|
| **Criticality Consequence Calculation Involving Intact PWR MOX SNF in a Degraded 21 PWR Assembly Waste Package** | | | | |
| **DOS File Name** | **File Size (bytes)** | **Creation Date** | **Creation Time** | **File Name** |
| MOX_96~1.XLS | 166,400 | 09-01-99 | 9:57p | MOX_96_sas2h.xls |
| NOCCUR~1.OUT | 133,450 | 09-08-99 | 8:53a | NOCcuries.out |
| R5WP2D~1.C10 | 45,042 | 09-08-99 | 8:51p | r5wp2d.c103c |
| SSCCUR~1.OUT | 115,430 | 09-09-99 | 9:46a | SSCcuries.out |
| STRIP.EXE | 301,237 | 08-16-99 | 4:40p | strip.exe |
| STRIP.FOR | 7,310 | 08-16-99 | 4:40p | strip.for |

# ATTACHMENT VIII

Worksheets for calculating the RELAP5/MOD3.2 geometry and loss coefficient data are listed in this attachment. These data are summarized in Section 5.4.

## Westinghouse 17x17 MOX Fuel

Pin Pitch = .496 in.

Fuel Pellet OR = .1544 in.

Clad IR = .1575 in.

Clad OR = .180 in.

Guide Tube IR = .225 in.

Guide Tube OR = .241 in.

*Assume Inst. Tube = Guide Tube

Pellet Volume = 19.7718993760 $in^2 * height$

Clad Volume = 6.29810787228 $in^2 * height$

GT & IT Volume = .585592870630 $in^2 * height$

Fuel Water Volume $= (17 * .496)^2 * height$
$- 19.7718993760\ in^2 * height$
$- 6.29810787228\ in^2 * height$
$- .585592870630\ in^2 * height$

Fuel Region Water Volume $= (8.432\ in)^2 * height$
$- 19.7718993760\ in^2 * height$
$- 6.88370074291\ in^2 * height$

Fuel Region Water Volume = $44.4430238811\ in^2 * height$

= $44.4430238811\ in^2 * 144\ in/5$

Fuel Region Water Volume = $1279.95908778\ in^3$

Fuel Region Water Volume = $.74071706\ ft^3$

(1/2) = $.37035853\ ft^3$

Fuel Region Cross Flow Height = 8.432 in/12

= .70266667 ft

Hydraulic Diameter for Fluid Friction {$d_h$ (friction)}

Flow Region is Around Clad & Guide Tubes

Volume = $[(8.432)^2 - 264\,\pi\,(.18)^2 - 25\,\pi\,(.241)^2] * length$

= $39.6650260055\ in^2 * length$

Surface Area = $[264 * 2\,\pi\,(.18) + 25\,\pi\,(.241)] * length$

= $336.433157273\ in * length$

$$d_h\left(\text{friction}\right) = \frac{4 * 39.6650260055\,in^2 * length}{336.433157273\,in * length}$$

= .471594730163 in

$d_h$ (friction) = .03929956 ft.

Channel length = 144/5 = 28.8 in

Cross flow height = 8.432 in

Ratio for $d_h$ (friction) = 28.8/8.432 = 3.41555977230

Junction Area = [17 (.496 in) - 17 (.36 in)] 144/5 in

= [8.432 in - 6.12 in] 28.8 in

= 66.5856 $in^2$

Junction Area = .4624 $ft^2$

(1/2) = .2312 $ft^2$

Fuel Assembly Pellet - Heat Structure

13301101 9 .012866667

Pellet OR = .1544 in = .012866667 ft

Length of fuel (pins) in fluid volume to determine heat transfer surface area.

Surface Area = 2 π OR ∗ length

Length = 264 pins ∗ 144 in/[(5) ∗ 12 in/ft]

= 264 ∗ 28.8 in/12 (in/ft)

= 633.6 ft

Fluid volumes 010 through 050

= 1/2 (264) 2.4 ft

= 316.8 ft

| | | | | | | |
|---|---|---|---|---|---|---|
| 13301601 | 010010000 | 10000000 | 1 | 1 | 316.8 | 5 |
| 13301602 | 060010000 | 10000000 | 1 | 1 | 633.6 | 13 |
| 13301901 | 0 | .057843059 | .057843059 | 0.0 | 13 | |

Hydraulic Diameter for heat transfer $d_h$ (heat)

$$d_h \text{ (heat)} = \frac{4 * \text{ cross-sectional area of fluid volume to be heated} * \text{length}}{264 * 2 p \text{ OR (pellet)} * \text{length}}$$

$$= \frac{4 * 44.4430238811 \text{ in}^2}{264 * 2 \mathbf{p} * .1544 \text{ in}}$$

$d_h$ (heat) = .694116711476 in

= .057843059 ft

Fuel Pin Clad, Guide Tubes & Inst. Tube

Heat Structures

This is a combined structure -

IR (fuel rod) = .1575 in = .013125 ft

Area = $\pi\,(.180^2 - .1575^2)\,264$

$+\ \pi\,(.241^2 - .225^2)\,25$

Area (289 tubes) $= \pi\,(OR^2 \text{ effective} - IR^2)\,289$

$$OR_{\text{effective}} = \sqrt{\frac{\text{Area (289 tubes)}}{289\,p} + IR^2}$$

$OR_{\text{effective}}$= .179966896706 in

= .014997241 ft

13481000 13 3 2 1 .0131250

13481101 2 .014997241

Length of clad, GT & IT in fluid volume to determine heat transfer surface area

Surface Area = $2\,\pi\,OR_{\text{effective}} * \text{Length}$

Length = 289 tubes ∗ 144 in / (5 ∗ 12 in/ft)

= 289 ∗ 28.8 in / 12 in/ft

= 693.6 ft

Fluid Volumes 010 through 050

= 1/2 693.6 ft = 346.8 ft

| | | | | | | |
|---|---|---|---|---|---|---|
| 13481501 | 010010000 | 10000000 | 1 | 1 | 346.8 | 5 |
| 13481502 | 060010000 | 10000000 | 1 | 1 | 693.6 | 13 |

Hydraulic Diameter for heat transfer $d_h$ (heat)

$$d_h\ (\text{heat} - \text{outside}) = \frac{4 * \text{cross-sectional area of fluid volume to be heated} * \text{length}}{\text{outer} - \text{surface}}$$

$$= \frac{4 * 44.4430238811 * \text{length}}{289 * 2\pi .179966896706 * \text{length}}$$

= .543992926686 in

$d_h$ (heat-outside) = .045332744 ft

$$d_h\ (\text{heat} - \text{inside}) = \frac{4 * 44.4430238811 * \text{length}}{289 * 2\pi * .1575 * \text{length}}$$

= .621591865687 in

$d_h$ (heat-inside) = .051799322 ft

| | | | | | |
|---|---|---|---|---|---|
| 13481801 | 0 | .051799322 | .051799322 | 0.0 | 13 |
| 13481901 | 0 | .045332744 | .045332744 | 0.0 | 13 |