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CRITICALITY ANALYSES OF DISRUPTED CORE MODELS OF THREE MILE ISLAND UNIT 2

R. M. Westfall
J. T. West
G. E. Whitesides
J. T. Thomas

Sponsor: G. E. Whitesides, Originator: R. M. Westfall

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CRITICALITY ANALYSES OF DISRUPTED CORE MODELS OF THREE MILE ISLAND UNIT 2

R. M. Westfall, J. T. West, G. E. Whitesides, and J. T. Thomas

ABSTRACT

Three hypothetical disrupted core models were analyzed for the President's Commission on the Accident at Three Mile Island. Soluble boron in the present configuration was assumed to be 3180 weight parts per million (wppm). Positive reactivity effects due to fuel swelling, fuel slumping, and coolant displacement by ZrO_2 increase the cold, shutdown system multiplication factor from approximately 0.74 to 0.86. The increase in reactivity for the three models can be roughly correlated with a decrease in the borated water-to-fuel volume ratio. Each of the 39,825 pin-lattice locations was modeled explicitly in the Monte Carlo analyses of the reactor core. Parametric studies were performed with one-dimensional discrete-ordinates analyses. The report includes a benchmark critical analysis of the system at hot, zero-power startup, a description of the analytical methods used, and a comprehensive compilation of the data upon which the analytical models were based.

I. INTRODUCTION

At the request of W. R. Stratton, staff member of the President's Commission on the Accident at Three Mile Island, a series of analyses were performed to determine the reactivity effects of various hypothetical modes in which the reactor core of Three Mile Island Unit 2 may have been disrupted. The results of these analyses were forwarded to Dr. Stratton for use in preparing his portion of the commission report. The purpose of this memorandum is to provide formal documentation of this effort in terms of the hypothetical models studied and the analytical methods applied. The scope of this study was restricted to the disrupted core analyses. No quantitative judgment was made as to the likelihood of

the occurrence of the particular accident modes. Also, no recommendations are made as to specific actions to be taken to avoid a criticality incident during plant recovery operations.

The sources of information used in constructing the disrupted core models are described in Section II. This information includes data on the reactor design, a benchmark critical configuration, possible core disruptive mechanisms, and the soluble boron content of the reactor coolant. The disrupted-core models are described in Section III. The analytical methods are described in Section IV. This section includes a brief description of the 27-group neutron cross-section library and the geometry modeling features of the Monte Carlo transport programs MORSE-SGC/S¹ and KENO-IV.² The capability of these programs to represent the disrupted core with a high level of geometric detail was the primary reason for performing this study at Oak Ridge.

The results of the study are presented in Section V. The results pertain to three categories:

1. Parametric studies of the effects of fuel pin geometry changes determined through infinite-lattice pin-cell calculations.
2. A benchmark analysis of the as-measured critical configuration at hot, zero-power reactor-startup conditions.
3. Analyses of the disrupted core models including variations to determine the reactivity worths of the soluble boron, the control rods and the burnable poison rods.

Conclusions drawn from these results are summarized in Section VI.

II. MODEL DESIGN DATA

Reactor Design--The primary source of data on the design of Three Mile Island Unit 2 was the Final Safety Analysis Report (FSAR).³ Information was taken from this report on the following design features:

1. Fuel assembly design, compositions and dimensions including
 - a. fuel pins,
 - b. control rods,
 - c. axial power shaping rods,
 - d. lumped burnable poison rods,
 - e. orifice rods, and
 - f. instrumentation guide tubes.
2. Cycle one fuel-loading scheme.
3. Rod locations, 0-200 full power days.
4. Reactor vessel and internals.

Copies of the tables and figures from which this information was taken are included here as Appendix A. This information was supplemented with particular details supplied by the Babcock and Wilcox Company. These pertain to the various fuel enrichments, given in Table 1, the B₄C loadings of the lumped burnable poison rods, given in Table 2, and the density of the Ag-In-Cd control rods (10.17 g/cc). All analyses in this study include fuel and fixed-absorber compositions based upon the beginning-of-life value. That is, no variation due to the brief operating history of the reactor was taken into account.

Table 1. Cycle One Fuel Enrichments

Fuel Element ^a Designation	Fuel Enrichment, Weight % U-235
Fuel Type "A"	1.98
Fuel Type "B"	2.64
Fuel Type "C"	2.96

^aUO₂ at 10.138 g/cc (0.925 of theoretical).

Table 2. Lumped Burnable Poison
Rod^a B₄C Loadings

Rod Designation	^b B ₄ C Loading, Weight % B ₄ C
LBP-1	1.395
LPB-2	1.260
LPB-3	1.060

^a Al₂O₃-B₄C mixture at 3.7 g/cc.

^b Natural boron.

Benchmark Critical--Additional information supplied by the Babcock and Wilcox Company included a set of conditions under which Three Mile Island Unit 2 was critical.

1. Hot, zero-power startup (fuel and moderator at 551°K).
2. Coolant at 2200 psi (0.77 g/cc).
3. Soluble boron at 1490 wppm.
4. Control rods out.
5. Axial power shaping rods out.

Core Disruptive Mechanisms--Information concerning the possible modes in which the reactor core may have been disrupted was provided by staff members of the Babcock and Wilcox Company and by cognizant individuals at Oak Ridge National Laboratory. Three major phenomena have been postulated.

1. Zirconium Oxidation

- a. function of temperature and steam distributions.
- b. hydrogen release indicated approximately 35% of Zircaloy oxidized.
- c. ZrO₂ probably flaked off and crumbled.
- d. damage concentrated in upper axial center of core.
- e. damage likely on fuel rod clad, possible on LBP rod clad and control rod guide tubes.

2. Fuel Swelling

- a. rapid depressurization of core may have caused clad to "balloon out" and rupture.

- b. thermal stresses may have caused UO_2 to crack and crumble.
- c. UO_2 may convert to U_3O_8 at a lower density (10.96 vs 8.3 g/cc theoretical).

3. Fuel Slumping

- a. may occur with loss of clad integrity and physical displacement of UO_2 .
- b. heat transfer analyses indicate that the melting point of UO_2 may have been exceeded in the top central portion of the core.
- c. severe downward displacement of the fuel believed to be restricted to the area above the third axial spacer grid at the center of the core extending radially and upward to the first axial spacer grid at the third fuel assembly from the edge of the core.

Soluble Boron Content--Coolant samples dated June 7, 1979, and analyzed at Oak Ridge National Laboratory contained a boron content equivalent to 2400 wppm. Trace amounts of silver, indium, and cadmium were detected. The boron content was scheduled to be increased to 3180 wppm by July 1, 1979.

III. DISRUPTED CORE MODELS

Three disrupted core models were analyzed. For the intact portions of the reactor core, each of the three models included an explicit representation of the contents of the 39,825 pin lattice locations. That is, the fuel rods, control rods, axial power shaping rods, lumped burnable poison rods and the orifice rods were each treated with all available detail as to composition and geometry. No distinction was made between the 40 instrumentation tubes containing in-core detectors and the 137 remaining water-filled locations. Staff members of the Babcock and Wilcox Company have indicated that the in-core detectors are worth about 0.2% $\Delta k/k$ in negative reactivity. The major difference between the three disrupted core models was in the number of axial layers used to represent the disrupted portion of the core. The MORSE-SGC/S model includes seven

axial levels in the core while the KENO-IV models have a maximum of two axial core zones.

MORSE-SGC/S "Three Jump Slump" Model--This disrupted core model is shown in Fig. 1. The intent in designing this model was to incorporate all of the core disruptive mechanisms in an internally consistent manner. Thus, all of the fuel pins in the core are swollen by 30 percent with the fuel consisting of a UO_2 - U_3O_8 mixture with effective densities calculated to fill the increased volume and conserve the original mass of uranium. The densities for the two components in this mixture were 6.521 g/cc for U_3O_8 and 1.534 g/cc for UO_2 . Complete conversion from UO_2 to U_3O_8 (at a constant percentage of theoretical density) would result in a volume increase of 37 percent.

A second major feature of this model concerns the disposition of the ZrO_2 formed in the upper central portion of the core. Here it is assumed to be uniformly distributed in the coolant channels immediately below the slumped fuel. The ZrO_2 occupies 32.9 percent of the flow channel areas for an axial distance equal to the length of the slumped fuel. The fuel element spacer grids would be the primary mechanism for preventing the ZrO_2 from exiting the core.

The third major feature of this model concerns the nature of the slumped fuel. With the loss of the zircaloy clad, it is assumed that the UO_2 converts to U_3O_8 and is physically displaced downward to rest upon the spacer grids and non-disrupted fuel. The fuel is assumed to be a mixture of the types A and B fuel assemblies located in the disrupted region yielding an average enrichment of 2.3 wt % U-235. The slumped fuel has a 0.687 volume factor which is near the theoretical maximum

Fig. 1. MORSE-SGC/S Three Jump Slump Core Model*

*Control and Lumped Burnable Poison Rods from Disrupted Portion of Core Missing. Boron in Coolant in All Zones at 3180 wppm. Core Barrel, Radial, and Axial Reflector Regions in Model.

packing factor for spheres. The U_3O_8 and borated water are the only materials remaining in the disrupted region of the core. That is, portions of the control rods, lumped burnable poison rods and orifice rods that originally extended through this region have been removed from the model. This is a conservative assumption from the criticality safety point of view.

There are four radial zones in this model. A detailed layout of the contents of each radial zone is given in Appendix B. This appendix includes a description of how this model was mocked-up using the array of arrays feature of the MORSE-SGC/S geometry package. Of particular interest is the manner in which the overall pin lattice array was truncated axially and indented radially to accommodate the representation of the disrupted portion of the core.

KENO-IV "Displaced-Fuel Slump" Model--This disrupted core model is shown in Fig. 2. Here it is assumed that the complete upper half of the core has been disrupted. The fuel has converted to U_3O_8 and been displaced downward to form the same $U_3O_8-H_2O + B$ mixture assumed in the MORSE-SGC/S model. However, the fuel enrichment used here was 2.57 wt % U-235, which corresponds to the core average. This model assumes that the fuel clad and the other non-fuel materials in the disrupted region have been removed from the core. The lower half of the core is the normal pin lattice configuration (39,825 lattice locations). Details of the geometry mock-up in KENO-IV are given in Appendix C.

KENO-IV "In-Place Fuel Slump" Model--This disrupted core model is shown in Fig. 3. Here it is assumed that the fuel pin expands radially at constant clad density and volume and that the UO_2 slumps axially at

Fig. 2. KENO-IV Displaced Fuel Slump Model*

*Includes Radial and Axial Reflectors of $H_2O + B$

Fig. 3. KENO-IV In-Place Fuel Slump Model^b

^a h_f values: 144", 114.2", 94.6", 80.8", 70.4"

^bIncludes Radial and Axial Reflectors of $H_2O + B$

constant density and volume. Including the as-built core, five fuel heights were analyzed. The minimum fuel height corresponds to the case in which the outer diameter of the fuel pins is equal to the lattice pitch (1.443 cm) and thus the fuel pins are touching. The three intermediate fuel heights correspond to 25, 50, and 75 percent of the total possible increase in the cross sectional area of the fuel. The fuel pin clad and the other nonfuel material above the active portion of the core are present in this model. Details of the geometry mock-up in KENO-IV are given in Appendix C.

IV. ANALYTICAL METHODS

Neutron Cross Sections--The neutron cross sections used in these analyses were taken from a 27 energy-group library developed from ENDF/B-IV data for the U. S. Nuclear Regulatory Commission. The 27 energy-group structure was determined through an extensive series of model calculations.⁴ The group structure includes the boundaries of the 16-group Hansen-Roach⁵ cross-section library with two additional boundaries in the high-energy "fission-spectrum" range and nine additional boundaries in the low-energy "thermal-upscatter" range. The group structure is given in Table 3.

Resonance processing was performed using the NITAWL-S module of the SCALE system. This module applies the Nordheim⁶ method to calculate resonance self-shielding for the absorber materials located in a pin-lattice cell. Resonance processing was performed for nine nuclides: U-238, U-235, Zircaloy, Ag-107, Ag-109, In-113, In-115, Cd, and Mn. Several parameters determined the number of lattice-cell resonance analyses.

Table 3. 27-Broad-Energy Group Structure

Group No.	Upper Boundary	Group No.	Upper Boundary
1	20 MeV	15	3.05 eV
2	6.434	16	1.77
3	3	17	1.3
4	1.85	18	1.13
5	1.4	19	1
6	900KeV	20	0.8
7	400	21	0.4
8	100	22	0.325
9	1	23	0.225
10	3	24	0.1
11	550 eV	25	0.05
12	100	26	0.03
13	30	27	0.01
14	10		0.00001

This group structure was found to be adequate through the broad-group-determination procedure for the nuclides: U-238, U-235, Pu-239, Pu-240, Pu-241, Pu-242, B-10, SS-304, (Ni, Fe, Cr), Cd, Al, Cu, H₂O, zircaloy-2.

1. Fuel enrichment
2. Fuel diameter and density
3. Fuel temperature
4. Temperature and density of the coolant
5. Boron content of coolant
6. Presence of ZrO_2 in coolant

Appropriate Dancoff factors for the various combinations of cell parameters were applied. The $U_3O_8-H_2O + B$ mixtures were treated as infinite homogeneous media in the resonance processing for U-235 and U-238. Fuel enrichment was the only variable in these analyses.

Of particular interest to this study is the expected performance of this cross-section library in the analysis of systems similar to Three Mile Island Unit 2. The results of previous analyses⁷ of pin-lattice critical experiments with ENDF/B-IV data are given in Table 4. The 27-group library is a subset of the 218-group library in the table. Also, the 19-group library is a subset of the 27-group library. Thus, the 27-group library would yield system multiplication factors consistent with the results from 218- and 19-group libraries. The results using point cross sections are in good agreement with the multigroup results. For comparison purposes, the lattice pitch for the Three Mile Island Unit 2 fuel assemblies is 0.57 inches and the effective water/fuel volume ratio is 1.27 for the hot, zero-power startup configuration. Thus, Cases 1, 2, and 5 correspond fairly well to the critical benchmark configuration for Three Mile Island Unit 2. From these results, the expected multiplication factor calculated with the 27-group library for the critical benchmark would be between 0.980 and 0.990.

MORSE-SGC/S--This is a new version of the MORSE¹⁰ Monte Carlo transport codes. It combines the supergroup capabilities of MORSE-SGC¹

Table 4. Calculated Results for Critical Uranium Oxide
Lattices with Clean and Borated Water Moderators

Critical Experiment	Case	Water/Fuel Volume Ratio	Pitch (inches)	ENDF/B-IV Data					
				Point XSECS		218 Group		19 Group	
WCAP ^a A water moderated 23x23 array of 2.72% enriched UO ₂ rods	1	1.49	0.6	0.9869	0.0063	0.9848	0.0068	0.9867	0.0044
EPRI ³ Clean water moderated lattice of 2.35% enriched UO ₂ rods	2	1.20	0.615	0.9900	0.0060	0.9864	0.0042	0.9849	0.0039
	3	2.41	0.750	---	---	0.9922	0.0050	0.9934	0.0039
	4	3.68	0.87	0.9984	0.0061	0.9932	0.0047	0.9934	0.0039
EPRI ³ Borated water moderated lattice of 2.35% enriched UO ₂ rods	5 ^a	1.20	0.615	---	---	---	---	0.9837	0.0035
	6	2.41	0.75	---	---	---	---	0.9983	0.0036
	7	3.68	0.87	---	---	---	---	1.0007	0.0034

^a 468 wppm soluble boron

with a new array of arrays nesting feature developed for the U. S. Nuclear Regulatory Commission. The array of arrays feature provides for a single description of each type of fuel pin, lumped burnable poison rod, etc., followed by array specifications to define the fuel assemblies and a subsequent array specification of the fuel assemblies in the reactor core. The power of this procedure is demonstrated by the minimal computer storage requirement for the geometry description of the MORSE-SGC/S "Three Jump Slump" disrupted core model. Less than 9,000 decimal words of computer storage were required to describe the three-dimensional array containing 241,200 pin locations--plus the various uniform media bodies corresponding to the $U_3O_8-H_2O + B$ mixture and the water and steel reflector regions.

The MORSE-SGC/S analyses were performed on the Idaho National Engineering Laboratory CDC-7600 computer. Several initial neutron source distributions were specified for differing fuel regions. There was no discernable trend with source specification in the results. Standard variance reduction techniques such as Russian Roulette and splitting were applied. The analyses required about 1.2 minutes of CPU time per thousand histories calculated. Standard deviations of 0.003 were obtained with 60,000 histories, 0.006 with 30,000 histories, and 0.01 with 8,000 histories.

KENO-IV--This is the current production version of the KENO¹¹ series of multigroup Monte Carlo criticality programs. These programs feature an easily-specified geometry scheme which permits an extremely efficient particle tracking algorithm. The accuracy, efficiency, and ease-of-use of these programs has led to their being the most popular codes for

multidimensional criticality analyses. A high level of experience in this use has been accumulated in the last decade. Automated procedures in KENO-IV include source specifications, particle biasing, reflector weighting, and output edits.

The primary limitation in applying KENO-IV to this study stems from the very large number of pin-lattice locations that must be described. In KENO-IV, the entire mixed-box orientation array is stored in the computer memory. Thus, the primary application of KENO-IV has been to corroborate the MORSE-SGC/S results for those models requiring only one axial layer in the pin-lattice specifications.

Applying one-quarter core symmetry, the entire Three Mile Island Unit 2 reactor lattice was mocked-up in a 120 x 120 mixed box orientation array. A computer program, MAKARAY, was written to simplify the specification of this array. First the fuel assemblies were specified, then the combination of fuel assemblies corresponding to the first core loading was specified. From this information MAKARAY constructed the KENO-IV mixed-box orientation array for the one-quarter core. Note that the one-quarter core symmetry was achieved through the specification of hemicylinders for the pins lying on the X and Y core midplanes.

The KENO-IV analyses were performed on the Oak Ridge National Laboratory IBM-360/91 computer. The analyses required about 0.4 minutes of CPU time per thousand histories calculated. Standard deviations of 0.006 were obtained with 6,000 histories.

XSDRNP-S--This is the SCALE¹² system version of the XSDRN¹³ one-dimensional discrete-ordinates neutral particle transport programs. Its primary application in this study was in pin-lattice cell calculations

to determine the effects of various changes in fuel composition and geometry. The analyses were performed with the S_8 angular quadrature approximation and a P_3 scattering expansion order. ISDRNPM-S was executed in a SCALE system analytical sequence (CSAS1) which performs the problem-dependent cross-section processing and sets up the input for the transport analysis. NITAWL¹² input parameters and nuclide atom densities from these analyses were also used in the three-dimensional Monte Carlo analyses.

V. ANALYTICAL RESULTS

Infinite Pin Lattice Analyses--These analyses were performed to provide qualitative estimates of the reactivity effects due to possible core disruptive mechanisms. Since they are one-dimensional analyses, the combined effects of fuel and neutron absorbing rods are not calculated. Also, the neutron leakage is not taken into account. However, the leakage for this core is only worth about 4 percent in reactivity.

Generally, the reactivity effects are due to postulated changes in the fuel pin geometry and associated variations in the water-to-fuel volume ratio in the reactor core. One limit to this variation is the case of an infinite medium of $U(2.96)O_2$. The multiplication factor for this dry fuel case is 0.663. Note that the fuel enrichment corresponds to the highest of the three values for the Three Mile Island Unit 2 reactor core. Thus, some content of water and its associated neutron moderation must be present for this system to become critical.

The effects of water content on reactivity are complicated by the high soluble boron content of the reactor coolant. Pressurized water reactor fuel is normally considered to be undermoderated, that is, at

less than an optimum water-to-fuel volume ratio for maximum reactivity. Such is the case for the "cold clean" (unborated water) results listed in Table 5 and shown in Fig. 4. Reducing the lattice pitch lowers the multiplication factor still further. However, for the "cold borated" situation, the opposite effect is observed. The most reactive lattice pitch is significantly less than the design value. Eventually, the negative reactivity due to the loss of water overtakes the positive reactivity due to the loss of boron and the system multiplication factor comes back down.

The results of fuel swelling listed in Table 6 and shown in Fig. 5 reflect a similar variation. Fuel swelling removes water and boron from the system and the multiplication factor rises. Here the water-to-fuel volume ratio ranges from 1.65 to 1.07 while the lattice pitch variation discussed above resulted in a much wider range in this ratio (2.97 to 0.57). This limited range accounts for the monotonic behavior of the curves in Fig. 5.

The effect of boron concentration upon the system multiplication factor is given in Table 7. From 0 to 2400 wppm the reactivity worth of the boron is 1.13% $\Delta k/k_1 k_2$ per 100 wppm while from 2400 to 3180 wppm the worth is 1.08% $\Delta k/k_1 k_2$ per 100 ppm. Thus the incremental worth of the boron decreases as saturation is approached. These values are slightly higher than the 1% $\Delta k/k$ per 100 ppm soluble boron worth determined by the Babcock and Wilcox Company. This value, given in Table 4.3-11 of Appendix A, pertains to the hot reactor core at rated power. Thus the soluble boron worth should be somewhat reduced due to the lower water density and the presence of fixed absorbers.

Table 5. TMI^a Infinite Lattice Pitch Variation

Case	Lattice Pitch (cm)	Cold ^b Clean k_{∞}	Cold Borated ^c k_{∞}
1	1.154 (-20%)	1.142	1.025
2	1.227 (-15%)	1.229	1.047
3	1.299 (-10%)	1.284	1.040
4	1.371 (-5%)	1.319	1.016
5	1.443 (Design)	1.340	0.982
6	1.515 (+5%)	1.351	0.943
7	1.587 (+10%)	1.355	0.902
8	1.659 (+15%)	1.352	0.860
9	1.732 (+20%)	1.345	0.817

^a2.57 wt % enriched UO₂ (92.5% theoretical density),
0.94 cm OD, Zircaloy clad 1.092 cm OD, 0.958 cm ID.

^bAll materials at 293°K, H₂O at full density.

^c2400 wppm natural boron, June 7, 1979, ORNL analysis.

Table 6. TMI Infinite Lattice^a Fuel Swelling

Case	Swelling Factor	(UO ₂) (g/cc)	Fuel OD (cm)	Clad ^b OD (cm)	Cold Clean k_{∞}	Cold Borated k_{∞}
1	1.00(design)	10.14	0.940	1.092	1.340	0.982
2	1.05	9.66	0.963	1.097	1.338	0.984
3	1.10	9.22	0.985	1.116	1.335	0.989(3) ^c
4	1.15	9.10	1.008	1.137	1.329	1.001(7)
5	1.20	8.45	1.030	1.157	1.326	1.002(3)
6	1.30	7.80	1.071	1.193	1.316	1.012(5)

^aConstant lattice pitch of 1.443 cm, 2400 wppm boron in H₂O.

^bClad expanded at constant volume.

^cNext significant figure.

Fig. 4. TMI Infinite Lattice Pitch Variation

Fig. 5. TMI Infinite Lattice Fuel Swelling

Table 7. Multiplication Factor vs Boron Content and Enrichment

Fuel Enrichment	Boron Concentration, wppm		
	0	2400	3180
2.57 wt % (Core Average)	1.34	0.982	0.907
2.96 wt % (Type C)	-	1.032	0.957
2.64 wt % (Type B)	-	0.992	0.918
1.98 wt % (Type A)	-	-	0.811

Table 8. Combined Fuel Swelling, Interstitial ZrO_2

Case	2.96 Wt % Enriched Fuel, Cell Description	Multiplication Factor
A	Normal fuel, boron at 3180 ppm	0.959
B	30% swollen fuel,* boron at 3180 ppm	0.992
C	Case B, 33 vol % ZrO_2 in H_2O	1.012

*Fuel composed of U_3O_8 and UO_2 inside zircaloy clad.

The combined effect of fuel swelling and coolant displacement by ZrO_2 is given by the data in Table 8. The overall effect is worth 5.5% $\Delta k/k_1k_2$ while the swelling alone is worth 3.5% $\Delta k/k_1k_2$.

The results in Table 9 demonstrate the relative worths of the Ag-In-Cd control rods and the $B_4C-Al_2O_3$ lumped burnable poison rods. In these analyses, the cell lattice pitch was taken as the average spacing between control rod centers, and the intervening fuel rods were treated as a homogeneous fuel-clad-coolant medium. The primary purpose of the analyses was to determine the input parameters for treating resonance absorption in the control rods. The results indicate that the control rods are worth substantially more than the lumped burnable poison rods.

The results of infinite medium calculations for the $U_3O_8-H_2O + B$ mixtures appearing in the MORSE-SGC/S "Three Jump Slump" model and the KENO-IV "Displaced-Fuel Slump" model are given in Table 10. Of particular interest is a comparison between the multiplication factor for the 2.57 wt % enriched fuel case with the corresponding pin cell result in Table 7. In going from the pin cell to the displaced fuel, the water-to-fuel volume ratio has gone from 1.65 to 0.46. The corresponding reactivity increase was 8.2% $\Delta k/k_1k_2$.

Benchmark Critical Analyses--The results of these analyses are given in Table 11. Good agreement is shown between the system multiplication factors calculated with MORSE-SGC/S and KENO-IV. Furthermore, these values are consistent with the 27 group results from the analyses of critical experiments having the same level of neutron moderation. Since the water density is 0.77 g/cc for this system, the effective water-to-fuel volume ratio drops from 1.65 to 1.27. Good agreement is shown between the results of Table 11 and the appropriate values in Table 4.

Table 9. Relative Rod Worth*--
Control Rod vs LBP1

Absorber Type	Multiplication Factor
Ag-In-Cd rod, SS304 clad	0.466
LBP1-B ₄ C-Al ₂ O ₃ rod, Zr clad	0.680

*Pin-cell models include ZrO₂ and B(3180) in coolant, smeared ²³⁵U(2.57)O₂ fuel-clad-coolant.

Table 10. U₃O₈-H₂O^a Worth vs Enrichment

Fuel Enrichment	Multiplication Factor
2.3 wt %, inner core	0.948
2.57 wt %, core average	0.980 ^b

^aU₃O₈ at 68.7 vol % (0.635 theoretical density), H₂O and B (3180 wppm) at 31.3 vol %.

^bcf, U(2.57)O₂ K_∞ = 0.907 @ 3180 ppm boron, see Table 7.

Comparison of Cases A and B of Table 11 yields the lumped burnable poison rod worth in this configuration to be approximately 5% $\Delta k/k_1 k_2$. This value is consistent with the 4.4% $\Delta k/k$ burnable poison rod assembly (BPRA) control worth listed in the (FSAR)³ and reproduced in Table 4.3-9 of Appendix A.

Comparison of Cases A and C yields the control rod worth in this configuration to be approximately 12% $\Delta k/k$. This value is consistent with the 10.5% $\Delta k/k$ control rod worth at hot zero power listed in the FSAR³ and given in Table 4.3-12 of Appendix A. The FSAR value does not include the worth of the axial power shaping rods shown in Bank 8 of Fig. 4.3-25 in Appendix A. Thus the FSAR value should be somewhat less than the value given by the present analysis.

Disrupted Core Analyses--The base case for these analyses is the normal core (nondisrupted) with the soluble boron level set at the 3180 wppm value corresponding to the current status. The results from analyses of this configuration are given in Table 12. Again, good agreement is seen between the MORSE-SGC/S and KENO-IV results. The control rods are worth approximately 9% $\Delta k/k_1 k_2$ and the lumped burnable poison rods are worth approximately 4% $\Delta k/k_1 k_2$. The high soluble boron level in the coolant tends to reduce the worth of the fixed absorbers.

The results from the analyses of the MORSE-SGC/S "Three Jump Slump" model are given in Table 13. Comparison of Case A with the as-built, cold shutdown case in Table 12 indicates that the overall positive reactivity worth of the disruptive core mechanisms is approximately 17% $\Delta k/k_1 k_2$. The water-to-fuel volume ratio in this core varies from 0.47 in

Table 11. Hot,^a Zero-Power Startup Configuration^b

Case Description	Monte Carlo Code	Multiplication Factor
A. As measured critical ^c	MORSE-SGC/S	0.987 ± 0.003
	KENO-IV	0.983 ± 0.006
B. Case A with LBP rods removed	MORSE-SGC/S	1.042 ± 0.011
C. Case A with control rods inserted ^d	MORSE-SGC/S	0.864 ± 0.008
	KENO-IV	0.863 ± 0.009

^aCoolant at 532°F, 2200 psi, $\rho = 0.77$, fuel at 532°F.

^bControl rods out, soluble boron at 1490 wppm.

^cH₂O/fuel-volume ratio = 1.27; multi-group ENDF/B-IV cross sections calculated $K = 0.984$ for other low-enriched uranium pin-lattice criticals at this H₂O/fuel-volume ratio.

^dB&W calculates control rods to be worth 10.5% at hot, zero power.

Table 12. Normal Core Shutdown With Boron at 3180 wppm^a

Case Description	Monte Carlo Code	Multiplication Factor
A. As-built, cold shutdown ^b	KENO-IV	0.737 ± 0.006
	MORSE-SGC/S	0.752 ± 0.007
B. Case A with control rods out	MORSE-SGC/S	0.805 ± 0.006
C. Case A with LBP rods removed	MORSE-SGC/S	0.778 ± 0.008
D. Case A with control rods out and LBP rods removed	MORSE-SGC/S	0.819 ± 0.007

^aValue as of July 1, 1979.

^bCoolant at 293°K, $\rho = 1.0$, fuel at 293°K.

the $U_3O_8-H_2O + B$ mixture to 0.72 in the regions with ZrO_2 in the coolant to 1.07 in the remainder of the pin-lattice core. The average water-to-fuel volume ratio is 0.95.

The control rod worth for the borated core (Cases A and B) is less than $2\% \Delta k/k_1k_2$. However, the control rod worth for the unborated core (Cases D and F) is approximately $9\% \Delta k/k_1k_2$. Similarly, the lumped burnable poison rod worth for the borated core (Cases A and C) is less than $1\% \Delta k/k_1k_2$, while the unborated core worth (Cases E and F) is approximately $5\% \Delta k/k_1k_2$. Note that portions of the control and lumped burnable poison rods originally positioned in the disrupted region of the core are missing from this model.

The results from the analysis of the KENO-IV "Displaced-Fuel Slump" model are given in Table 14. Comparison of Case A with the as-built, cold shutdown case in Table 12 indicates that the positive reactivity worth of the fuel displacement is approximately $17\% \Delta k/k_1k_2$. The average water-to-fuel volume ratio is 1.06 for this configuration. Since this value is close to that of the "Three Jump Slump" model and the positive reactivity worths are the same, it appears that the reactivity can be grossly correlated with the water-to-fuel volume ratio.

However, the differential reactivity worths of the disruptive core mechanisms are highly dependent upon the particular features of the disrupted core models. For example, removal of the soluble boron from the pin-lattice portion of the core is worth $15\% \Delta k/k_1k_2$ for the "Three Jump Slump" model while it is worth more than $25\% \Delta k/k_1k_2$ for the "Displaced-Fuel Model." In the latter case, the coolant channels are at normal size and the boron is worth much more. Also, the control rods are worth more

Table 13. MORSE-SGC/S "Three Jump Slump"
Disrupted Core

Case Description	Multiplication Factor
A. Base configuration ^a	0.862 ± 0.006
B. Case A with control rods out	0.875 ± 0.006
C. Case A with LBP rods removed	0.868 ± 0.006
D. Case A with controls rods and boron ^b out	1.079 ± 0.012
E. Case A with LBP rods and boron ^b out	1.043 ± 0.010
F. Case A with control rods inserted, boron out	0.988 ± 0.011

^a13.5% of upper middle core collapsed as U₃O₈-H₂O mixture; ZrO₂ distributed in coolant channels of lower core; intact portion of fuel pin swollen by 30%; boron in coolant at 3180 wppm.

^bBoron remaining in U₃O₈-H₂O mixture.

Table 14. KENO-IV "Displaced-Fuel Slump"
Disrupted Core^a

Case Description	Multiplication Factor
A. Base configuration	0.845 ± 0.006
B. Case A with control rods out	0.870 ± 0.006
C. Case A with boron out ^b	1.080 ± 0.006

^aUpper 50% of core collapsed as U₃O₈-H₂O mixture; corresponding portions of control and LBP rods missing; lower half of core in normal configuration; boron in coolant at 3180 wppm.

^bBoron remaining in U₃O₈-H₂O mixture.

than $3\% \Delta k/k_1 k_2$ which, although small, is substantially more than the corresponding value for the "Three Jump Slump" model ($<2\% \Delta k/k_1 k_2$). This difference is all the more remarkable because the "Three Jump Slump" model has 73 percent more intact control rod volume than does the "Displaced-Fuel Slump" model. Evidently, the neutron moderation level has a very strong effect upon the control rod worth.

The results from the analysis of the KENO-IV "In-Place Fuel Slump" model are given in Table 15. Here we have the variation of the system multiplication factor as the fuel is displaced downward in the pins and the clad expands to accommodate the increase in cross-sectional area. The water-to-fuel volume ratio varies from 1.65 for the as-built core to 0.31 for the case with the fuel pins touching. A new reactivity search technique¹⁴ was used with these results to predict an optimum water-to-fuel volume ratio of 0.62. The maximum multiplication factor calculated in the study was 0.845 for the case in which the water-to-fuel volume ratio is 0.77. Both the system multiplication factor and the water-to-fuel volume ratio are in the range of the values calculated with the "Three Jump Slump" and the "Displaced-Fuel Models". The slightly lower water-to-fuel volume ratio corresponding to an equivalent multiplication factor with the "In-Place Fuel Slump" model is probably due to the presence of control and lumped burnable poison rods throughout this system. The fixed absorbers enhance the positive reactivity effect of spectral hardening. Indeed, the XSDRNPM lattice cell calculations do not include fixed absorbers and their results indicate a maximum system multiplication factor at a higher water-to-fuel volume ratio.

Table 15. KENO-IV "In-Place Fuel Slump" Disrupted Core^a

Assumptions: Fuel stays at constant density
(0.925 of theoretical);
Zr clad expands at constant volume;^b
fuel height drops to conserve volume.

Swelling (% of Max)	Height (cm)	Fuel OD (cm)	Clad OD (cm)	Min. Gap between pins (cm)	KENO-IV k-eff ^c	XSDRNPM ^d Lattice k _∞
None	365.8	0.94	1.092	0.176	0.737±0.006	0.907
25%	290.0	1.056	1.179	0.132	0.807±0.006	0.980
50%	240.2	1.160	1.273	0.085	0.845±0.005	1.014
75%	205.2	1.255	1.360	0.042	0.840±0.006	1.005
100%	178.8	1.344	1.443	0.0	0.812±0.0073	0.950

^aBoron at 3180 wppm, constant lattice pitch = 1.443 cm.

^bConstant clad volume, interior radius increases.

^cClad, control rods & LBP rods above,
core as normal.

^d2.57 wt % enriched UO₂ (core average).

VI. CONCLUSIONS

The significant results of the parametric studies, the benchmark critical analyses and the disrupted core analyses are summarized.

Parametric Studies--Infinite fuel-pin lattice and infinite fuel-coolant media analyses indicate that, while the fuel assemblies in unborated water are undermoderated, the high soluble boron content causes the shutdown configuration to be overmoderated. Therefore, core disruptive mechanisms which remove the coolant from the core introduce positive reactivity insertions. Core disruptive mechanisms introducing positive reactivity are:

1. Fuel pin lattice-pitch reduction,
2. Fuel pin swelling,
3. ZrO_2 in coolant channels, and
4. Fuel displacement into $U_3O_8-H_2O + B$ mixtures.

At very low water-to-fuel volume ratios (<0.6 for 2400 wppm boron, <0.4 for 3180 wppm boron), the borated systems become undermoderated and any further ejection of the coolant reduces the system multiplication factor. As a limiting case, an infinite medium of dry $U(2.97)O_2$ has a multiplication factor of 0.66.

Benchmark Critical Analyses--The Three Mile Island Unit 2 reactor in a critical configuration at hot, zero-power startup was analyzed as a benchmark experiment. The results of this analysis validate the analytical methods used in this study for the following reasons:

1. The multiplication factor for the benchmark configuration agreed well with the expected value drawn from the analyses of similar critical experiments using the same transport programs and the multigroup, ENDF/B-IV based, neutron cross sections.
2. Good agreement was obtained between independent analyses of the benchmark configuration using the Monte Carlo transport programs MORSE-SGC/S and KENO-IV.
3. Good agreement was obtained between calculated control rod worths and those predicted by the Babcock and Wilcox Company.
4. Good agreement was obtained between calculated lumped burnable poison rod worths and those predicted by the Babcock and Wilcox Company.

Disrupted Core Analyses--The analysis of three disrupted core models and a cold shutdown, normal-core base case yielded several important considerations.

1. Positive reactivity insertions due to the various core disruptive mechanisms increased the system multiplication factor from approximately 0.74 to 0.86.
2. To a first order approximation, the increase in reactivity for the three models can be correlated with a decrease in the borated water-to-fuel volume ratio.
3. The reactivity worths of the control rods and the lumped burnable poison rods are significantly reduced by the high soluble boron content in the reactor.
4. The presence of fixed absorbers in the disrupted portions of the core significantly reduces the reactivity worth of the soluble boron.
5. The water-to-fuel volume ratio corresponding to the maximum system multiplication factor is influenced by neutron absorption due to either fixed absorbers or the soluble boron.

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APPENDIX A

Core Design Data

In order to provide a complete set of the information upon which this study was based, certain tables and figures were excerpted from the Final Safety Analysis Report for inclusion in this appendix.

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Fig. 4.2-3. Reactor Vessel and Internals - General Arrangement
Three Mile Island Nuclear Station Unit 2

Fig. 4.2-4 Reactor Vessel and Internals Cross Section
Three Mile Island Nuclear Station Unit 2

Bank	No. Rods	Purpose
1	4	Safety
2	8	Safety
3	8	Safety
4	8	Safety
5	12	Regulating
6	12	Regulating
7	9	Regulating
8	8	APSR

Fig. 4.3-25. Rod Locations, 0-200 FPD
Three Mile Island Nuclear Station Unit 2

Radial Core Zones "Three Jump Stamp" Model, cf Figure 1-Text

Batch Designation	Number of Assemblies
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A	} Fuel Enrichments, 56 cf Table 1-Text	61
B		60
C		

* Batch A is discharged at the end of the first cycle

Fig. 4.3-1. Cycle One Fuel Loading Scheme
Three Mile Island Nuclear Station Unit 2

Table 4.3-1. Core Design Data

A. Reactor

1. Design heat output, MWt	2772
2. Vessel coolant inlet temperature, F	557
3. Vessel coolant outlet temperature, F	607.7
4. Core coolant outlet temperature, F	610.6
5. Core operating pressure, psig	2185

B. Core and Fuel Assemblies

1. Total No. of fuel assemblies in core	177
2. No. of fuel rods per fuel assembly	208
3. No. of control rod guide tubes per assembly	16
4. No. of in-core instr. positions per fuel assembly	1
5. Fuel rod outside diameter, in.	0.430
6. Cladding thickness, in.	0.0265
7. Fuel rod pitch, in.	0.568
8. Fuel assembly pitch spacing, in.	8.587
9. Unit cell metal/water ratio (volume basis)	0.82
10. Cladding material	Zircaloy-4 (cold worked)

C. Fuel

1. Material	UO ₂
2. Form	Dish-end, cylindrical pellets
3. Pellet diameter, in.	0.370
4. Active length, in.	144
5. Density, % of theoretical	92.5

Table 4.3-2. Nuclear Design Data

Fuel Assembly Volume Fractions

Fuel	0.303
Moderator	0.580
Zircaloy	0.102
Stainless steel	0.003
Void	<u>0.012</u>
	1.000

Total UO₂ (BOL)

First core, mtUO ₂	93.1
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Core Dimensions

Equivalent diameter, in.	128.0
Active height, in.	144.0

Unit Cell H₂O/U Atomic Ratio, Fuel Assembly

Cold/hot	2.88/2.06
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Full-Power Lifetime

First cycle, days	421
Each succeeding cycle, days	284

Fuel Irradiation

First cycle avg, Mwd/mtU	14,220
Each succeeding cycle, Mwd/mtU	9,600

Fuel Loading

Core avg first cycle, wt% ²³⁵ U	2.57
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Control Data

Control rod material	Ag-In-Cd
No. of full-length CRAs	61
No. of APSRAs	8
Worth of 61 full-length CRAs, ($\Delta k/k$)%	11.1
Control rod cladding material	SS304
No. of BPRAs	68 (first cycle only)
BPRAs cladding material	Zircaloy-4, cold-worked
BPR poison material	B ₄ C in Al ₂ O ₃

Table 4.2-1. Fuel Assembly Components, Materials and Dimensions

Item	Material	Dimensions, in.
<u>Fuel Rod (208)</u>		
Fuel	UO ₂ sintered pellets (92.5% TD)	0.370 diameter
Cladding	Zircaloy-4	0.430 OD x 0.377 ID x 153.125 long
Fuel rod pitch	--	0.568
Active fuel length	--	144
Nom. fuel-cladding gap (BOL)	--	0.007
Ceramic spacer	ZrO ₂	0.366 OD
<u>Fuel Assembly</u>		
FA pitch	--	8.587
Overall length	--	165.625
CR guide tube (16)	Zircaloy-4	0.530 OD x 0.016 wall
Instr tube (1)	Zircaloy-4	0.493 OD x 0.441 ID
End fittings (2)	SS (castings)	--
Spacer grid strips (8)	Inconel-718	--
Spacer sleeve (7)	Zircaloy-4	0.554 OD x 0.502 ID

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Fig. 4.2-2. Prepressurized Fuel Rod
Three Mile Island Nuclear Station Unit 2

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Fig. 4.2-1. Fuel Assembly
Three Mile Island Nuclear Station Unit 2

Table 4.2-4. Control Rod Assembly Data

Item	Data
Number of CRAs	61
Number of control rods per assembly	16
Outside diameter of control rod, in.	0.440
Cladding thickness, in.	0.021
Cladding material	304 SS, cold-worked
Eng plug material	304 SS, annealed
Spider material	SS grade CF3M
Poison material	80% Ag, 15% In, 5% Cd
Female coupling material	304 SS, annealed
Length of poison section, in.	134
Stroke of control rod, in.	139

Table 4.2-5. Axial Power Shaping Rod Assembly Data

Item	Data
Number of APSRAs	8
Number of APSR/assy	16
OD of APSR, in.	0.440
Cladding thickness, in.	0.021
Cladding material	304 SS, cold-worked
Plug material	304 SS, annealed
Poison material	80% Ag, 15% In, 5% Cd
Spider material	SS, grade CF3M
Female coupling material	304 SS, annealed
Length of poison section, in.	36
Stroke of APSR, in.	139

Table 4.2-6. Control Rod Drive Data

Item	Control	Axial power shaping
Number of drives	61	8
Type	Roller nut	Roller nut
Location	Top-mounted	Top-mounted
Direction of trip	Down	Does not trip
Maximum travel time for trip at full flow		
2/3 insertion, s	1.40	Does not trip
3/4 insertion, s	1.54	Does not trip
Length of stroke, in.	139	139
Design pressure, psig	2500	2500
Design temperature, F	450/650(a)	450/650(a)
Weight of mechanism, (approx), lb	940	940

(a) See 4.2.3.3.1.1

Table 4.2-7. Burnable Poison Rod Assembly Data

Item	Data
Number BPRA's	
First cycle	68
Equilibrium cycle	None
Number of burnable poison rods per assembly	16
Outside diameter of burnable poison rod, in.	0.430
Cladding thickness, in.	0.035
Cladding material	Zircaloy-4, cold-worked
End cap material	Zircaloy-4, annealed
Poison material	Al ₂ O ₃ -B ₄ C
Length of poison section, in.	126
Spider material	SS, grade CF3M
Coupling mechanism material	Type 304 SS, annealed and 17-4PH, condition H1100

Table 4.2-8. Orifice Rod Assembly Data

Item	Data
Number of ORA	97
First cycle	40
Equilibrium cycle	108
Number of OR/assy	16
OD of OR, in.	0.480
Orifice rod material	304 SS, annealed
Spider material	SS, grade CF3M
Coupling mechanism material	304 SS, annealed, and 17-4 PH, condition H1100

Fig. 4.2-8 Control Rod Assembly
Three Mile Island Nuclear Station Unit 2

Fig. 4.2-9. Axial Power Shaping Rod Assembly
Three Mile Island Nuclear Station Unit 2

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Fig. 4.2-12. Burnable Poison Rod Assembly
Three Mile Island Nuclear Station Unit 2

Fig. 4.2-13. Orifice Rod Assembly
Three Mile Island Nuclear Station Unit 2

Table 4.3-8. Excess Reactivity Conditions

Reactor core condition ^(a)	k_{eff}
Cold, 70F, clean	1.252
Hot, 532F, clean, zero power	1.205
Hot, 584F, clean, full power	1.182
Hot, 584F, full power, equilibrium xenon and samarium	1.133
Single fuel assembly ^(b) (wet)	0.70
Two fuel assemblies ^(b) (wet)	1.014
Single fuel assembly ^(b) (dry)	0.03
Two fuel assemblies ^(b) (dry)	0.04
Cold array ^(c)	0.90

^(a) First cycle at BOL, 68 BFRAs in core.
^(b) Based on highest probable enrichment of 3.5 wt%.
^(c) A center-to-center assembly pitch of 21 inches is required for this k_{eff} in cold, unborated water with no xenon or samarium.

Table 4.3-9. BOL First Cycle Reactivity Control Distribution

	Reactivity, $\beta \Delta k/k$
<u>Controlled by Soluble Boron</u>	
Moderator temp deficit (70 to 532F)	3.4
Equil Xe and Sm	3.5
Fuel burnup and fission product buildup	10.5
Transient Xe	1.0
<u>Controlled by BFRAs</u>	
Fuel burnup and fission product buildup	4.4
<u>Controlled by Movable CRAs</u>	
Doppler deficit (0 to 2772 MWt)	1.2
Moderator temp deficit (532 to 584F)	0.0
Dilution control	0.2
Shutdown margin	1.0
Xenon undershoot	0.4

Table 4.3-11. Soluble Boron Levels and Worth - First Cycle

Core Conditions	BOL Boron Level, ppm
<u>70F, $k_{eff} = 0.99$</u>	
No CRAs in	1582
All CRAs in	1057
One stuck CRA (full out)	1327
<u>532F, 0 power, $k_{eff} = 0.99$</u>	
No CRAs in	1710
All CRAs in	741
One stuck CRA (Full out)	1083
<u>584F, rated power, $k_{eff} = 1.00$</u>	
No CRAs in	1540
<u>584F, rated power, equil Xe and Sm, $k_{eff} = 1.00$</u>	
No CRAs in	1175
<u>Boron worth, $(\% \Delta k/k)/\text{ppm}$</u>	
584F, rated power	1/100
70F, zero power	1/75

Table 4.3-12. Control Rod Worths

<u>Worth at Full Power</u>			<u>Sequential worth,</u> <u>%$\Delta k/k$</u>	
<u>Group number</u>	<u>Purpose</u>	<u>No CRA's</u>	<u>BOL</u>	<u>EOL</u>
1	Safety	4	0.5	0.3
2	Safety	8	2.2	1.9
3	Safety	8	1.5	1.4
4	Safety	8	1.2	2.1
5	Reg.	12	2.4	1.8
6	Reg.	12	1.8	1.6
7	Reg.	9	1.5	1.0
	Totals	61	11.1	10.1
Maximum stuck rod worth			3.6	2.0
Maximum ejected rod worth			0.31	0.19

<u>Worth at Hot Zero Power</u>				
1	Safety	4	0.5	0.3
2	Safety	8	2.1	1.8
3	Safety	8	1.4	1.3
4	Safety	8	1.1	2.0
5	Reg.	12	2.3	1.7
6	Reg.	12	1.7	1.5
7	Reg.	9	1.4	1.0
	Totals	61	10.5	9.6
Maximum ejected rod worth			0.58	0.47

<u>Worth at Cold Conditions, 70F</u>				
1	Safety	4	0.3	0.2
2	Safety	8	1.4	1.2
3	Safety	8	1.0	0.9
4	Safety	8	0.8	1.4
5	Reg.	12	1.5	1.2
6	Reg.	12	1.2	1.0
7	Reg.	9	1.0	0.7
	Totals	61	7.2	6.6

APPENDIX B

MORSE-SGC/S Input Procedures

Copies of the card image input and certain input edits for the MORSE-SGC/S "Three Jump Slump" disrupted core model analysis are presented here. The primary purpose of this appendix is to provide an example of how arrays are nested using the MARS (Multiple Array System) in MORSE-SGC/S. Similar sets of input were prepared for the MORSE-SGC/S analyses of the benchmark critical configuration and the cold shutdown configuration. Of particular interest in this input procedure is the creation of fuel assemblies from combinatorial geometry input zones followed by the combination of fuel assemblies to form the reactor core. Through the MARS universe specifications, the base level or "null universe" consists of the entire system. This includes the $U_3O_8-H_2O + B$ mixture as an input zone and the reactor core as a truncated array. In turn, this truncated array contains the fuel assembly arrays defined as universes with negative identification numbers. The various items in this procedure are indicated in the following list:

<u>Item</u>	<u>Cards</u>	<u>Page</u>
MORSE-SGC/S Control Parameters	1-6	B3
Combinatorial Geometry Bodies	9-48	B3
Combinatorial Geometry Input Zones (Note U_3O_8 -cards 143, 144; RPP's 16-18, 37-40)	50-146	B4
MARS Universe Specifications	149	B5
Media Numbers	150-153	B5

<u>Item</u>	<u>Cards</u>	<u>Page</u>
Array Size Specifications (Note 15 x 15 x 7 for array 14, reactor core)	154-155	B5
13 Fuel Assembly Arrays (15 x 15 x 1)	156-187	B5
Seven 15 x 15 Arrays for Axial Levels in Core	188-279	B6
MORSE-SGC/S Starting Parameters	280	B7
Splitting and Russian Roulette Parameters	281	B7
Mixing Table for Macroscopic Constants	282-295	B7
Fission Neutron Energy Distribution	296-300	B7
MORSE-SGC/S Edit of Control Parameters		B7
Printer Plots of 13 Fuel Assembly Arrays (Each symbol denotes a pin type)		B8-B14
Printer Plots of 7 Axial Levels in Core (Each negative symbol denotes a fuel assembly array, note disrupted region in levels 5, 6, and 7)		B15-B18

THE FOLLOWING IS A LIST OF CARD IMAGE INPUT

CASE NO.

SECRET

[illegible]

MORSE-SGC/S Control Parameters

and

Combinatorial Geometry Bodies

50	FAZ	+2 -1
51	GAF	+3 -2
52	CAZ	+3 -2
53	AZA	+6 -3
54	LXA	+9 -4
55	CRZ	+8 -3
56	CRC	+9 -4
57	CRG	+10 -5
58	CPT	+11 -10
59	CRA	+4 -11
60	EXC	+5 -4
61	FAC	+1
62	GAP	+2 -1
63	CAC	+3 -2
64	ACA	+4 -3
65	EKA	+5 -4
66	CNA	+8
67	CRC	+6 -4
68	CRG	+10 -5
69	CPT	+11 -10
70	CRA	+4 -11
71	EXC	+5 -4
72	LBP	+6
73	LEC	+7 -6
74	LEG	+10 -7
75	LBT	+11 -10
76	LBA	+4 -11
77	EXI	+5 -4
78	FBZ	+1
79	GAF	+2 -1
80	CAZ	+3 -2
81	AZA	+6 -3
82	EXP	+5 -4
83	LBP	+6
84	LBC	+7 -6
85	LEG	+10 -7
86	LBT	+11 -10
87	LBA	+4 -11
88	EXI	+5 -4
89	PFC	+1
90	GAP	+2 -1
91	CAZ	+3 -2
92	AZC	+4 -3
93	EXC	+5 -4
94	LEF	+6
95	LBC	+7 -6
96	LEG	+10 -7
97	LBT	+11 -10
98	LBA	+4 -11
99	EXI	+5 -4
100	JNC	+12
101	INT	+13 -12
102	JNA	+4 -12
103	LXA	+5 -4
104	LBP	+6
105	LBC	+7 -6
106	LEG	+10 -7
107	LBT	+11 -10
108	LBA	+4 -11
109	EXV	+5 -4
110	PCZ	+1
111	GAF	+2 -1
112	CAZ	+3 -2
113	AZC	+4 -3
114	EXC	+5 -4
115	DOP	+10
116	RDP	+10 -16
117	RRT	+11 -10
118	RRL	+6 -11
119	EXD	+8 -4
120	IAX	+12
121	ITZ	+13 -12
122	ITT	+4 -13
123	ITB	+5 -4
124	RCZ	+14
125	RGZ	+10 -14
126	PTZ	+11 -10
127	RAZ	+6 -11
128	EXT	+5 -4
129	CRE	
130		OR +10 +21 -35 -40 -14 -17 -18
131		OR +19 +23 -39 -40 -16 -17 -18
132		OR +10 +25 -38 -40 -16 -17 -18
133		OR +19 +27 -39 -40 -16 -17 -18
134		OR +19 +29 -39 -40 -16 -17 -18
135	LIA	+22 -21 -23 OR +24 -23 -25 -21 OR +26 -25 -23 -27
136	GA	+26 -27 -28 -29 OR +30 -28 -27
137	WA1	+31 -32 -24 -26 -28 -30
138	BAR	+32 -31
139	VA2	+33 -32
140	WAB	+34 -33
141	PA3	+35 -34
142	PVS	+36 -35
143	EVV	+5 -34
144	UJC	+39 -18 CR +40 -36 -37 OR +14 -40 -38 CR +17 -40 -38
145	CR	+14 -40 -34
146	BOA	+39 +19 +18 CR +40 +19 +37 -39 OR +14 +19 +38 -40
147	CR	+17 +19 +38 -40 OR +18 +19 +38 -40
148	SNO	

Combinatorial Geometry Input Zones


```

148 9001
149 501 602 503 604 605 506 607 508 609 4010 6011 5012 5013 6014 5015 1100
150 12 6 6 6 -1000 5 10 6 6 6 -1000 3 5 4 5 -1000 9 10 5 4 5 -1000
151 7 6 6 6 6 -1000 13 6 6 6 -1000 8 6 6 6 -1000 2 5 4 5 -1000
152 8 6 6 6 6 -1000 5 4 5 -1000 7 6 6 6 6 -1000 1 5 4 5 -1000
153 10 5 4 5 -1000 6 6 6 -1000 10 6 6 6 -1000 -10 10 5 10 5 10 6 11 5
154 15 15 1 15 15 1 15 15 1 15 15 1 15 15 1 15 15 1 15 15 1 15 15 1
155 5 15 1 15 15 1 15 15 1 15 15 1 15 15 1 15 15 1 15 15 1 15 15 1
156 301 2 301 2 801 2 701 2 201 2 301 2 301 2 201 2 201 14 201 2 201 2
157 301 2 201 2 201 2 701 2 801 2 301 2 3501
158 3503 4 303 4 803 4 703 4 203 4 203 4 303 4 203 4 2002 10 2003 4 203 4
159 303 4 203 4 2003 4 703 4 803 4 303 4 3503
160 3503 13 303 13 803 13 703 13 2003 12 203 13 303 12 202 13 2002 10 2003
161 13 203 13
162 303 13 203 13 2003 13 703 13 803 13 303 13 3503
163 3506 7 306 7 806 7 706 7 2006 7 206 7 306 7 206 7 2006 14 2006 7 206 7
164 306 7 206 7 2006 7 706 7 806 7 306 7 3506
165 3508 5 308 5 808 5 708 5 2008 5 208 5 308 5 208 5 2008 10 2008 5 208 5
166 308 5 208 5 2008 5 708 5 808 5 208 5 3508
167 2506 5 306 5 806 5 706 5 2006 5 206 5 306 5 206 5 2006 14 2006 5 206 5
168 306 5 206 5 2006 5 706 5 806 5 206 5 3506
169 3506 11 306 11 806 11 706 11 2006 11 206 11 306 11 206 11 2006 10 2006
170 11 206 11
171 308 11 208 11 2008 11 708 11 808 11 308 11 3508
172 3508 4 308 4 808 4 708 4 2008 4 208 4 308 4 208 4 2008 10 2008 4 208 4
173 308 4 208 4 2008 4 708 4 808 4 208 4 3508
174 3509 2 306 2 809 2 706 2 2006 2 206 2 306 2 206 2 2006 14 2006 2 206 2
175 306 2 206 2 2006 2 706 2 809 2 206 2 3506
176 35012 13 3012 13 8012 13 7012 13 20012 13 2012 12 3012 13 2012 13
177 20012 10 20012 13 2012 13
178 3012 13 2012 13 20012 13 7012 13 8012 13 3012 13 35012
179 35012 4 3012 4 8012 4 7012 4 20012 4 2012 4 3012 4 2012 4 20012
180 10 20012 4 2012 4
181 3012 4 2012 4 20012 4 7012 4 8012 4 3012 4 35012
182 35012 11 3012 11 8012 11 7012 11 20012 11 2012 11 3012 11 2012 11
183 20012 10 20012 11 2012 11
184 3012 11 2012 11 20012 11 7012 11 8012 11 3012 11 35012
185 3501 15 301 15 801 15 701 15 2001 15 201 15 301 15 201 15 2001 14 2001
186 15 201 15
187 301 15 201 15 2001 15 701 15 801 15 301 15 3501

```

Cards

- 149 MARS Universe Specifications
- 150-153 Media Numbers
- 154-155 Array Size Specifications
- 156-187 13 Fuel Assembly Arrays (15x15x1)

[illegible]

Axial Levels in Core

```

280 600 0.0 0.0 1.0 0.0 -170.0 170.0 -170.0 170.0 0.0 370.0
281 800 27R1.5 27FC.167 27RC.50 27R0.0
282 1233
283 1 2 3 11 1 2 3 11 1 2 3 5 6 7 8 11 5 6 7 8 11 5 6 11 7
284 0 7 5 229 4R10 13 12 13 12
285 1233
286 92225 2 2 4 3F92238 8 8FR010 40302 403021 585010 585011 301001
287 28012 2 13 27 47107 47109 48000 48113 48115 24304 25035 26304 28304
288 21 31 522301 522301
289 1000
290 5.220-4 4.656-4 3.452-4 2.633-4 1.690-2 1.695-2 1.707-2 1.100-2 4.417-2
291 4.417-2 4.417-2 3.338-2 4.134-2 6.476-2 6.400-2 4.040-2 4.252-2
292 9.472-3 3.538-3 2.370-3 3.840-3 3.163-4 1.107-5 1.018-4 0.510-5
293 1.455-3 1.375-3 4.428-5 5.870-2 4.450-2 2.750-2 5.107-4 4.233-4 4.217-2
294 4.326-2 2.374-2 2.165-2 2.725-3 3.472-4 7.655-3 1.742-2 1.736-3
295 5.636-2 7.721-3 4.454-4 3.406-4 1.665-2 1.707-2
296 1700 2.10730E-02 1.0030E-01 2.14893E-01 1.24530E-01 1.66156E-01
297 1.00470E-01 4.45110E-02 1.30446E-02 1.00555E-03 7.41950E-05 5.87080E-04
298 4.12443E-07 4.55504E-07 1.29510E-07 1.46510E-06 4.31105E-10 1.30027E-10
299 6.54033E-11 1.41535E-10 2.20525E-10 3.34400E-11 3.48000E-11 3.71047E-11
300 1.00999E-11 2.95645E-12 2.07300E-12 4.94027E-13
301 T
302 TITLE AA
303 TITLE BB
304 TITLE CC
305 1500 T

```

END OF CARD INPT LIST

Cards

280 MORSE-SGC/S Starting Parameters
 281 Splitting and Russian Roulette Parameters
 282-295 Mixing Table for Macroscopic Constants
 296-300 Fission Neutron Energy Distribution

MPI CRITICAL STUDIES: JIM WEST, CPNL

CP/

1 S ARRAY				
IACUM	ADJUNCT INDICATOR	0	ASLT	SPLITTING INDICATOR
ASTAT	NUMBER OF PARTICLES PER BATCH	300	AKILL	RUSSIAN ROULETTE INDICATOR
APCST	MAX NUMBER OF PARTICLES ALLOWED	350	KEAST	EXPONENTIAL TRANSFER INDICATOR
NITS	NUMBER OF BATCHES	103	NOLEAK	NON-LEAKAGE INDICATOR
NGLIT	NUMBER OF SETS OF BATCHES	1	TEBIAS	ENERGY BIAS INDICATOR
ACCLTP	COLLISION TAP INDICATOR	0	AKCALC	BATCH USED IN K-CALCULATION
ISTAT	INDICATOR TO STORE LOGARITHM COEFF	0	KCRMF	NORMALIZATION INDICATOR
2 S ARRAY				
PECIA	NUMBER OF CROSS SECTION PECIA	13	EXREG	NUMBER OF REGIONS
APIA	NUMBER OF MIXING OPERATIONS	48	PFISTG	FISSION INDICATOR
PECALR	ALBEDO INDICATOR	0		
3 S ARRAY				
AGGA	NUMBER OF G-GS TO ANALYZE	27	ISTR	PRINT CROSS SECTIONS AS STORED
AGGA	NUMBER OF G-GS TO ANALYZE	0	IPPU	PRINT RESULTS OF MU CALC
AGGTP	COMPLETELY COUPLED INDICATOR	0	INCM	PRINT MOMENTS
ADSN	NUMBER OF N DEPENDENT SCATTERS	0	IPPIN	PRINT ANGLES AND PRCP
ADSG	NUMBER OF G DEPENDENT SCATTERS	0	IPUN	PRINT RAD GROUP RESULTS
ACCEP	NUMBER OF COEFFICIENTS	4	ISTAPE	INLET LOGICAL TAP UNIT
ASCT	NUMBER OF DISCRETE ANGLES	2	JXTAB	CUTOUT LOGICAL TAP UNIT
PAFOP	LAST OF POP FOR SPLITTING OF INCPM	27	ICGP	END LOGICAL TAP UNIT
IPDSG	PRINT CROSS SECTIONS AS CRAL	0	ICGPT	LAST OF GROUP
AGCPT	EXTRA FELTHER GROUP CRITCN	0	IGGPT	EXTRA GAMMA GROUP CRITCN

MORSE-SGC/S Edit of Control Parameters

OPTION 0 WAS USED IN CALCULATING VOLUMES FOR 1 REGION
 0-SET VOLUMES = 1, 1-CONCENTRIC SPHERES, 2-SLABS, 3-RECTANGULARS.

VOLUMES (CC) USED IN COLLISIONS DENSITY AND TRACK LENGTH ESTIMATORS.
 REG
 VOLUME 1.000E+00

ARRAY NO. 1 ARRAY SIZE IS 15 BY 15 BY 1

LEVEL		1 OF ARRAY NO. 1														
X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13		1	1	1	1	1	2	1	1	1	2	1	1	1	1	1
12		1	1	1	2	1	1	1	1	1	1	2	1	1	1	1
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10		1	1	2	1	1	2	1	1	1	2	1	1	2	1	1
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6		1	1	2	1	1	2	1	1	1	2	1	1	2	1	1
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4		1	1	1	1	1	1	1	1	1	1	1	2	1	1	1
3		1	1	1	1	1	2	1	1	1	2	1	1	1	1	1
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Fuel Assembly Arrays

ARRAY AC. 2 ARRAY SIZE 15 15 EV. 15 EV. 1

LEVEL 1 OF ARRAY AC. 2

	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Y																
15		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
13		3	3	3	3	3	4	2	3	3	4	3	3	3	3	3
12		3	3	3	4	3	3	3	3	2	3	3	4	3	3	3
11		3	3	3	3	3	3	2	3	2	3	3	3	3	3	3
10		3	3	4	3	3	4	3	3	3	4	3	3	4	2	3
9		3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
8		3	3	3	3	3	3	3	10	3	3	3	3	3	3	3
7		3	3	3	3	3	3	2	3	2	3	2	3	2	3	3
6		3	3	4	3	3	4	3	3	3	4	3	3	4	3	3
5		3	3	3	3	3	3	3	2	3	3	3	3	3	3	3
4		3	3	3	4	3	3	3	3	3	3	3	4	3	3	3
3		3	3	2	2	2	4	3	3	2	4	2	3	3	3	3
2		3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
1		3	3	3	3	3	3	2	3	2	3	2	3	3	3	3

ARRAY AC. 3 ARRAY SIZE 15 15 EV. 15 EV. 1

LEVEL 1 OF ARRAY AC. 3

	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Y																
15		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
13		3	3	3	3	3	13	3	3	3	13	3	3	3	3	3
12		3	3	3	13	3	3	3	3	3	3	13	3	3	3	3
11		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
10		3	3	13	3	3	13	3	3	3	13	3	3	13	3	3
9		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
8		3	3	3	3	3	3	3	10	3	3	3	3	3	3	3
7		3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
6		3	3	13	3	3	13	3	3	3	13	3	3	13	3	3
5		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4		3	3	3	13	3	3	3	3	3	3	13	3	3	3	3
3		3	3	3	3	3	13	3	3	3	13	3	3	3	3	3
2		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
1		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Fuel Assembly Arrays

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ARRAY NO. 4 ARRAY SIZE 15 15 BY 15 BY 1

		LEVEL 1 OF ARRAY NO. 4														
X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
13		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
12		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
11		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
10		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
9		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
8		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
7		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
5		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
4		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
3		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
1		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

ARRAY NO. 5 ARRAY SIZE 15 15 BY 15 BY 1

		LEVEL 1 OF ARRAY NO. 5														
X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
14		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
13		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
12		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
11		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
10		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
9		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
8		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
7		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
6		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
5		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
4		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
3		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
2		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
1		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Fuel Assembly Arrays

B-11

ARRAY NO. 6 ARRAY SIZE 15 15 BY 15 BY 1

LEVEL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
13	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
12	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
11	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
10	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
8	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

ARRAY NO. 7 ARRAY SIZE 15 15 BY 15 BY 1

LEVEL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
14	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
13	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
12	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
11	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
10	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
5	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
3	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
2	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
1	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Fuel Assembly Arrays

Fuel Assembly Arrays

LEVEL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

[illegible]

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ARRAY NO. 10. ARRAY SIZE IS 15 BY 15 BY 1.

LEVEL 1 OF ARRAY NO. 10

X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
14		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
13		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
11		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
10		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
9		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
8		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
7		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
6		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
5		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
4		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
3		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
2		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

ARRAY NO. 11. ARRAY SIZE IS 15 BY 15 BY 1.

LEVEL 1 OF ARRAY NO. 11

X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
14		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
13		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
11		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
10		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
9		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
8		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
7		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
6		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
5		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
4		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
3		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
2		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

Fuel Assembly Arrays

----- ARRAY NO. 12 ----- ARRAY SIZE 15 ----- 15 BY 15 BY -----

		LEVEL 1 OF ARRAY NO. 12																
		X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
14				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
13				12	12	12	12	12	11	12	12	12	11	12	12	12	12	12
12				12	12	12	11	12	12	12	12	12	12	12	12	12	12	12
11				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
10				12	12	11	12	12	11	12	12	12	11	12	12	11	12	12
9				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
8				12	12	12	12	12	12	12	10	12	12	12	12	12	12	12
7				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
6				12	12	11	12	12	11	12	12	12	11	12	12	11	12	12
5				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
4				12	12	12	11	12	12	12	12	12	12	12	11	12	12	12
3				12	12	12	12	12	11	12	12	12	11	12	12	12	12	12
2				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

----- ARRAY NO. 13 ----- ARRAY SIZE 15 ----- 15 BY 15 BY -----

		LEVEL 1 OF ARRAY NO. 13																
		X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Y																		
15		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
14		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
13		1	1	1	1	1	15	1	1	1	15	1	1	1	1	1	1	
12		1	1	1	15	1	1	1	1	1	1	1	1	15	1	1	1	
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
10		1	1	15	1	1	15	1	1	1	15	1	1	15	1	1	1	
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
6		1	1	15	1	1	15	1	1	1	15	1	1	15	1	1	1	
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
4		1	1	1	15	1	1	1	1	1	1	1	1	15	1	1	1	
3		1	1	1	1	1	15	1	1	1	15	1	1	1	1	1	1	
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Fuel Assembly Arrays

-----ARRAY NO. 14----- ARRAY SIZE IS 15 BY 15 BY 7-----

		LEVEL 1 OF ARRAY NO. 14														
Y	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		LEVEL 2 OF ARRAY NO. 14														
Y	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Axial Levels in Core

		LEVEL 3 OF ARRAY NO. 14													
X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14
15		0	0	0	0	0-10-16-10-10-10	0	0	0	0	0	0	0	0	0
14		0	0	0-10-10-11	-5-11	-5-11-10-10	0	0	0	0	0	0	0	0	0
13		0	0-10-12	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7
12		0-10-12	-2	-7	-3	-7	-2	-7	-3	-7	-2	-7	-3	-7	-2
11		0-10	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2
10		-10-11	-2	-3	-7	-2	-5	-2	-5	-2	-7	-3	-7	-11-10	0
9		-10	-5	-2	-7	-2	-5	-1	-4	-1	-5	-2	-7	-2	-5-10
8		-10-11	-2	-2	-7	-2	-4	-5	-4	-2	-7	-2	-7	-11-10	0
7		-10	-5	-2	-7	-2	-5	-1	-4	-1	-5	-2	-7	-2	-5-10
6		-10-11	-2	-3	-7	-2	-5	-2	-5	-2	-7	-3	-7	-11-10	0
5		0-10	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2
4		0-10-12	-2	-7	-3	-7	-2	-7	-3	-7	-2	-7	-3	-7	-2
3		0	0-10-12	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7
2		0	0	0-10-10-11	-5-11	-5-11-10-10	0	0	0	0	0	0	0	0	0
1		0	0	0	0	0-10-10-10-10-10	0	0	0	0	0	0	0	0	0

		LEVEL 4 OF ARRAY NO. 14													
X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14
15		0	0	0	0	0-10-10-10-10-10	0	0	0	0	0	0	0	0	0
14		0	0	0-10-10-11	-5-11	-5-11-10-10	0	0	0	0	0	0	0	0	0
13		0	0-10-12	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7
12		0-10-12	-2	-7	-3	-7	-2	-7	-3	-7	-2	-7	-3	-7	-2
11		0-10	-2	-7	-3	-6	-1	-6	-1	-6	-1	-7	-2	-10	0
10		-10-11	-2	-7	-6	-1	-4	-1	-6	-1	-6	-3	-7	-11-10	0
9		-10	-5	-2	-7	-3	-4	-1	-4	-1	-4	-1	-7	-2	-5-10
8		-10-11	-2	-2	-6	-1	-4	-5	-4	-1	-6	-2	-7	-11-10	0
7		-10	-5	-2	-7	-3	-4	-1	-4	-1	-4	-1	-7	-2	-5-10
6		-10-11	-2	-3	-6	-1	-4	-1	-4	-1	-6	-3	-7	-11-10	0
5		0-10	-2	-7	-3	-6	-1	-6	-1	-6	-1	-7	-2	-10	0
4		0-10-12	-2	-7	-3	-7	-2	-7	-3	-7	-2	-7	-3	-7	-2
3		0	0-10-12	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7	-2	-7
2		0	0	0-10-10-11	-5-11	-5-11-10-10	0	0	0	0	0	0	0	0	0
1		0	0	0	0	0-10-10-10-10-10	0	0	0	0	0	0	0	0	0

Axial Levels in Core

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		LEVEL 5 CF ARRAY NO. 14														
Y	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		LEVEL 6 CF ARRAY NO. 14														
Y	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15		0	0	0	0	0-10-10-10-10-10	0	0	0	0	0	0	0	0	0	0
14		0	0	0-10-10-11-5-11	-5-11	-5-11-10-10	0	0	0							
13		0	0-10-12	-1	-6	-1	-6	-1	-6	-1	-12-10	0	0			
12		0-10-12	-1	-6-13	-6	-1	-6-13	-6	-1	-12-10	0					
11		0-10	-1	-6	0	0	0	0	0	0	0	-6	-1-10	0		
10		-10-11	-6-13	0	0	0	0	0	0	0	0-13	-6-11-10				
9		-10	-5	-1	-6	0	0	0	0	0	0	-6	-1	-5-10		
8		-10-11	-6	-1	0	0	0	0	0	0	0	0	-1	-6-11-10		
7		-10	-5	-1	-6	0	0	0	0	0	0	0	-6	-1	-5-10	
6		-10-11	-6-13	0	0	0	0	0	0	0	0	0-13	-6-11-10			
5		0-10	-1	-6	0	0	0	0	0	0	0	0	-6	-1-10	0	
4		0-10-12	-1	-6-13	-6	-1	-6-13	-6	-1	-12-10	0					
3		0	0-10-12	-1	-6	-1	-6	-1	-6	-1	-12-10	0	0			
2		0	0	0-10-11	-5-11	-5-11-10-10	0	0	0	0						
1		0	0	0	0	0-10-10-10-10-10	0	0	0	0	0	0	0	0	0	0

Axial Levels in Core

		LEVEL 7 OF ARRAY NO. 14													
Y	X	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
15		0	0	0	0	0	0	0	0	0	0	0	0	0	0
14		0	0	0	0	0	0	0	0	0	0	0	0	0	0
13		0	0	0	0	0	0	0	0	0	0	0	0	0	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2		0	0	0	0	0	0	0	0	0	0	0	0	0	0
1		0	0	0	0	0	0	0	0	0	0	0	0	0	0

Axial Levels in Core

APPENDIX C

KENO-IV Input Procedures

Copies of the card image input and certain input edits for the KENO-IV "Displaced-Fuel Slump" and "In-Place Fuel Slump" disrupted core model analyses are presented here. The primary purpose of this appendix is to demonstrate the use of the MAKARAY module in preparing the mixed-box orientation array for KENO-IV. MAKARAY is a program developed to simplify the specification of KENO-IV input data for large arrays. The approach taken is to first specify subarrays, in this case fuel assemblies, and then combine the subarrays to form the mixed-box orientation array. The one-quarter core geometry shown in Fig. 4.3-1 of Appendix A is the core geometry specified here. It consists of a 120 x 120 array of pin lattice locations, water gaps between assemblies, and water peripheral to the core. It includes seven unique combinations of fuel types and fixed absorbers defining 15 x 15 unit subarrays interior to the core. Additionally, along the horizontal core midplanes there are five unique 15 x 8 subarrays, five unique 8 x 15 subarrays, and a central 8 x 8 subarray. Hemicylinders are used to specify the fuel and absorber rods located on the core midplanes. The various items appearing in the input are indicated in the following list:

<u>Item</u>	<u>Page</u>
NITAWL Input for Cross Section Processing	C3
MAKARAY Input for Core Midplane Arrays	C4
MAKARAY Input for 6 Full Assemblies (15 x 15)	C5
MAKARAY Input for Peripheral Water (15 x 15) and Water Gaps (1 x 8, 8 x 1, 1 x 15, 15 x 1, 1 x 1)	C5

<u>Item</u>	<u>Page</u>
MAKARAY Input for 7th Full Assembly (Fuel C-Box 6, LBP2-Box 8, 24th subarray specified)	C5
MAKARAY Input for Combining Subarrays	C6
KENO-IV Control Parameters Edit	C6
KENO-IV Mixing Table for Macroscopic Constants	C7
KENO-IV Box Type Specifications (Note Box 6 for Fuel C-Material 3, Box 8 for LBP2-Material 5, each with Zr Clad-Material 9)	C8-C9
NITAWL Table of Contents	C10
Printer Plots of MAKARAY Subarrays Core Midplane Arrays	C10-15
Full Assembly Arrays (15 x 15)	C16-C18
Peripheral Water (15 x 15)	C19
Water Gap (Subarrays 20, 21, 22, 23 omitted)	C19
24th Subarray for Fuel C-LBP2 (Note Box Type 6 and Box Type 8)	C20
Subarray Combination for Mixed-Box Orientation Array (Center of core is subarray 1, Note subarray 24)	C20
Portion of Mixed-Box Orientation Array (Note Fuel-C, LBP2 Assembly)	C21
KENO-IV Mixing Table for "Displaced-Fuel Slump" Model Analysis	C22
Input Stream for "In-Place Fuel Slump" Model Analysis (Note differences between this and previous case for NITAWL resonance processing data, KENO-IV mixing table, KENO-IV specifications for the fuel radius and height. The MAKARAY specifications are the same for both cases.	C24-C30

PRIMARY MOBILE ACCESS AND TRAIL RECORD (SCALE DRIVER - JULY 6, 1975)

MOBILE NITAWL WILL BE CALLED TIME OF DAY 9.35.47 DATE 75.241

```

051 02 E 145 A2 22 48 12 A11 1 1 1T
251 62235 -2 -3 -4 62239 -5 6216 5010 5011 6012 13827 47167
47169 48000 49113 49115 1001 49312 24204 25055 26314 28304
344
25155 253 1 0.05 0.053 6286.7 1.736-2 1 55.95 285.6 1 58.85 77.4 1 1
47167 253 2 0.56 0.053 142 2.37-2 1 108.5 56.5 1 114.6 2.53 1 1
47169 253 2 0.56 0.053 157 2.15-2 1 106.9 6 1 114.6 2.78 1 1
49113 253 2 0.56 0.053 6786.6 3.47-4 1 108.6 6611.1 106.6 374.6 1 1
49115 253 2 0.56 0.053 444 7.65-3 1 108.9 300 1 106.6 17 1 1
40302 253 1 0.067 0.029 181.7 4.25-2 1 620 1
92235 253 2 0.47 0.226 3.14-2 4.53-4 1 15.554 374 1 238.125 406 1 1
2 253 2 0.47 0.226 2354 6.04-4 1 15.554 281 1 238.125 302 1 1
3 253 2 0.47 0.226 2095 6.75-7 1 15.554 250 1 238.125 265 1 1
4 253 340 2206 2.54-4 1 1.004 1444 1 15.554 517 1 1
92235 253 2 0.47 0.226 64.18 0.0221 1 15.554 7.05 1 235 0.215 1 1
2 253 340 60.55 3.411 1 1.004 38.6 1 15.554 13.76 1 1
444 F253.0 2T
END

```

NITAWL Input for Cross Section Processing

C-4

141 INITIAL CORE VISC CORE ARRAY									
2	2	1							
5	2	1	2	1	1	1	1	0	
19	1	1	1	1	1	1	1	0	
22	2	1	1	1	1	1	1	0	
13	1	1	1	2	1	1	1	0	
10	3	6	3	3	3	1	1	1	0
10	5	5	4	5	5	1	1	1	0
10	3	3	1	6	6	1	1	1	1
15	8	1							
5	1	15	1	2	1	1	1	1	0
22	1	15	1	1	1	1	1	1	0
16	2	1	1	1	1	1	1	1	0
7	3	6	3	3	3	1	1	1	0
7	10	13	3	3	3	1	1	1	0
7	4	12	8	5	5	1	1	1	0
7	6	10	4	6	6	1	1	1	1
15	8	1							
5	1	15	1	2	1	1	1	1	0
22	1	15	1	1	1	1	1	1	0
16	2	1	1	1	1	1	1	1	0
8	3	6	3	3	3	1	1	1	0
8	10	13	3	3	3	1	1	1	0
8	4	12	8	5	5	1	1	1	0
8	6	10	4	6	6	1	1	1	1
15	8	1							
4	1	15	1	2	1	1	1	1	0
21	1	15	1	1	1	1	1	1	0
16	2	1	1	1	1	1	1	1	0
10	3	6	3	3	3	1	1	1	0
10	10	13	3	3	3	1	1	1	0
10	4	12	8	5	5	1	1	1	0
10	6	10	4	6	6	1	1	1	1
15	8	1							
23	1	15	1	1	1	1	1	1	0
16	2	1	1	1	1	1	1	1	0
10	3	6	3	3	3	1	1	1	0
10	10	13	3	3	3	1	1	1	0
10	4	12	8	5	5	1	1	1	0
10	6	10	4	6	6	1	1	1	1
15	8	1							
6	1	15	1	2	1	1	1	1	0
23	1	15	1	1	1	1	1	1	0
16	2	1	1	1	1	1	1	1	0
11	3	6	3	3	3	1	1	1	0
11	10	13	3	3	3	1	1	1	0
11	4	12	8	5	5	1	1	1	0
11	6	10	4	6	6	1	1	1	1
15	8	1							
5	2	1	1	15	1	1	1	1	0
13	1	1	1	1	15	1	1	1	0
15	1	1	1	2	1	1	1	1	0
7	3	6	3	3	3	1	1	1	0
7	10	13	3	3	3	1	1	1	0
7	4	12	8	5	5	1	1	1	0
7	6	10	4	6	6	1	1	1	1
15	8	1							
5	2	1	1	15	1	1	1	1	0
13	1	1	1	1	15	1	1	1	0
15	1	1	1	2	1	1	1	1	0
7	3	6	3	3	3	1	1	1	0
7	10	13	3	3	3	1	1	1	0
7	4	12	8	5	5	1	1	1	0
7	6	10	4	6	6	1	1	1	1
15	8	1							
6	2	1	1	15	1	1	1	1	0
14	1	1	1	1	15	1	1	1	0
15	1	1	1	2	1	1	1	1	0
10	3	6	3	3	3	1	1	1	0
10	10	13	3	3	3	1	1	1	0
10	4	12	8	5	5	1	1	1	0
10	6	10	4	6	6	1	1	1	1
15	8	1							
14	2	1	1	15	1	1	1	1	0
15	1	1	1	1	15	1	1	1	0
11	3	6	3	3	3	1	1	1	0
11	10	13	3	3	3	1	1	1	0
11	4	12	8	5	5	1	1	1	0
11	6	10	4	6	6	1	1	1	1

MAKARAY Input for Core Midplane Arrays

15	15	1							
4	1	15	1	1	15	1	1	1	1
24	8	8	1	8	8	1	1	1	0
10	6	10	4	3	13	10	1	1	1
10	4	12	8	4	12	8	1	1	1
10	3	6	3	6	10	4	1	1	1
10	10	13	3	6	10	4	1	1	1
15	15	1							
5	1	15	1	1	15	1	1	1	1
24	8	8	1	8	8	1	1	1	0
7	6	10	4	3	13	10	1	1	1
7	4	12	8	4	12	8	1	1	1
7	3	6	3	6	10	4	1	1	1
7	10	13	3	6	10	4	1	1	1
15	15	1							
5	1	15	1	1	15	1	1	1	1
24	8	8	1	8	8	1	1	1	0
8	6	10	4	3	13	10	1	1	1
8	4	12	8	4	12	8	1	1	1
8	3	6	3	6	10	4	1	1	1
8	10	13	3	6	10	4	1	1	1
15	15	1							
5	1	15	1	1	15	1	1	1	1
24	8	8	1	8	8	1	1	1	0
9	6	10	4	3	13	10	1	1	1
9	4	12	8	4	12	8	1	1	1
9	3	6	3	6	10	4	1	1	1
9	10	13	3	6	10	4	1	1	1
15	15	1							
6	1	15	1	1	15	1	1	1	1
24	8	8	1	8	8	1	1	1	0
10	6	10	4	3	13	10	1	1	1
10	4	12	8	4	12	8	1	1	1
10	3	6	3	6	10	4	1	1	1
10	10	13	3	6	10	4	1	1	1
15	15	1							
6	1	15	1	1	15	1	1	1	1
24	8	8	1	8	8	1	1	1	0
11	6	10	4	3	13	10	1	1	1
11	4	12	8	4	12	8	1	1	1
11	3	6	3	6	10	4	1	1	1
11	10	13	3	6	10	4	1	1	1

MAKARAY Input for Six Full Assemblies

15	15	1							
20	1	15	1	1	15	1	1	1	1
1	8	1							
26	1	1	1	1	1	1	1	1	0
2	1	1	1	1	2	1	1	1	1
8	1	1							
25	1	1	1	1	1	1	1	1	0
1	2	8	1	1	1	1	1	1	1
1	15	1							
2	1	1	1	1	15	1	1	1	1
15	1	1							
1	1	15	1	1	1	1	1	1	1
1	1	1							
3	1	1	1	1	1	1	1	1	1

MAKARAY Input for Peripheral Water and Water Gaps

15	15	1							
4	1	15	1	1	15	1	1	1	1
24	8	8	1	8	8	1	1	1	0
8	6	10	4	3	13	10	1	1	1
8	4	12	8	4	12	8	1	1	1
8	3	6	3	6	10	4	1	1	1
8	10	13	3	6	10	4	1	1	1

MAKARAY Input for 7th Full Assembly

ENC

MAKARAY Input for Combining Subarrays

TPI		HALF CONE		HALF CRUISE									
2.15	100	300	3	27	27	20	11	44	81	24	120	120	-20
0	100C	0	C	1	72								
0	-1.0C	0	-1.0										

KENO-IV Control Parameters

1	52235	2.04701-4
2	52235	2.04367-4
3	52235	2.77416-4
4	52235	2.54245-4
1	52235	2.21603-2
2	52235	2.20044-2
3	52235	2.15334-2
4	52235	1.10135-2
1	5016	4.52106-2
2	5016	4.52214-2
3	5016	4.52231-2
4	5016	4.46525-2
5	5016	6.47999-2
6	5016	6.46932-2
7	5016	4.46925-2
8	5016	3.32497-2
9	5016	4.23475-4
10	5016	3.24453-4
11	5016	3.18333-4
12	5016	1.10700-5
13	5016	3.63406-5
14	5011	1.42732-3
15	5011	1.45877-3
16	5011	1.37463-3
17	5011	4.43444-3
18	5011	1.85704-3
19	5012	5.62600-4
20	5012	5.10765-4
21	5012	4.23312-4
22	13027	4.31015-2
23	13027	4.31728-2
24	13027	4.32545-2
25	47167	2.37766-2
26	47168	2.16527-2
27	46660	2.72460-3
28	46113	3.47191-4
29	46113	7.64441-3
30	1001	2.44477-2
31	1001	6.47553-2
32	40302	4.25171-2
33	20300	1.74246-2
34	20305	1.73044-2
35	20304	5.93540-2
36	20304	7.72081-3

KENO-IV Mixing Table for Macroscopic Constants

BOX TYPE	1						
CUBIC	11	1.003	C	.17	0	102.0673	0
2700.5							
BOX TYPE	2						
CUBIC	11	.17	C	1.003	0	102.0673	0
2700.5							
BOX TYPE	3						
CUBIC	11	.17	C	.17	C	102.0673	0
2700.5							
BOX TYPE	4						
CYLINDER	1	.47		102.0673	0		
2700.5							
CYLINDER	0	.476		102.0673	0		
2700.5							
CYLINDER	9	.506		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 C
2700.5							
BOX TYPE	5						
CYLINDER	2	.47		102.0673	0		
2700.5							
CYLINDER	0	.479		102.0673	0		
2700.5							
CYLINDER	9	.506		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							
BOX TYPE	6						
CYLINDER	3	.47		102.0673	0		
2700.5							
CYLINDER	0	.479		102.0673	0		
2700.5							
CYLINDER	6	.506		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							
BOX TYPE	7						
CYLINDER	4	.4572		102.0673	0		
2700.5							
CYLINDER	9	.506		102.0673	0		
2700.5							
CYLINDER	11	.63246		102.0673	0		
2700.5							
CYLINDER	9	.67310		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							
BOX TYPE	8						
CYLINDER	5	.4879		102.0673	0		
2700.5							
CYLINDER	9	.506		102.0673	0		
2700.5							
CYLINDER	11	.63246		102.0673	0		
2700.5							
CYLINDER	9	.67310		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							
BOX TYPE	9						
CYLINDER	6	.4572		102.0673	0		
2700.5							
CYLINDER	9	.506		102.0673	0		
2700.5							
CYLINDER	11	.63246		102.0673	0		
2700.5							
CYLINDER	9	.67310		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							
BOX TYPE	10						
CYLINDER	11	.56		102.0673	0		
2700.5							
CYLINDER	10	.61		102.0673	0		
2700.5							
CYLINDER	11	.63246		102.0673	0		
2700.5							
CYLINDER	9	.67310		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							
BOX TYPE	11						
CYLINDER	10	.6096		102.0673	0		
2700.5							
CYLINDER	11	.63246		102.0673	0		
2700.5							
CYLINDER	9	.67310		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							
BOX TYPE	12						
ZHEMICVLX	1	.47		102.0673	0		
2700.5							
ZHEMICVLX	0	.479		102.0673	0		
2700.5							
ZHEMICVLX	9	.506		102.0673	0		
2700.5							
CUBIC	11	.7215		-.7215	.7215	-.7215	102.0673 0
2700.5							

KENO-IV Box Type Specifications

(continued)

BOX TYPE	13						
ZHEICVL+A	2	.47	182.8673	0			
2700.5							
ZHEICVL+A	0	.478	182.8673	0			
2700.5							
ZHEICVL+A	9	.546	182.8673	0			
2700.5							
CUBIC	11	.7215	0	.7215	-.7215	182.8673	0
2700.5							
BOX TYPE	14						
ZHEICVL+A	3	.47	182.8673	0			
2700.5							
ZHEICVL+A	0	.478	182.8673	0			
2700.5							
ZHEICVL+A	9	.546	182.8673	0			
2700.5							
CUBIC	11	.7215	0	.7215	-.7215	182.8673	0
2700.5							
BOX TYPE	15						
ZHEICVL+A	11	.56007	182.8673	0			
2700.5							
ZHEICVL+A	9	.62611	182.8673	0			
2700.5							
CUBIC	11	.7215	0	.7215	-.7215	182.8673	0
2700.5							
BOX TYPE	16						
ZHEICVL+A	11	.56007	182.8673	0			
2700.5							
ZHEICVL+A	9	.62611	182.8673	0			
2700.5							
CUBIC	11	.7215	0	.7215	-.7215	182.8673	0
2700.5							
BOX TYPE	17						
CUBIC	11	.7215	0	.17	0	182.8673	0
2700.5							
BOX TYPE	18						
CUBIC	11	.17	0	.7215	0	182.8673	0
2700.5							
BOX TYPE	19						
CUBIC	11	.7215	0	.7215	0	182.8673	0
2700.5							
BOX TYPE	20						
CUBIC	11	1.443	0	1.443	0	182.8673	0
2700.5							
BOX TYPE	21						
ZHEICVL+A	1	.47	182.8673	0			
2700.5							
ZHEICVL+A	0	.478	182.8673	0			
2700.5							
ZHEICVL+A	9	.546	182.8673	0			
2700.5							
CUBIC	11	.7215	-.7215	.7215	0	182.8673	0
2700.5							
BOX TYPE	22						
ZHEICVL+A	3	.47	182.8673	0			
2700.5							
ZHEICVL+A	0	.478	182.8673	0			
2700.5							
ZHEICVL+A	9	.546	182.8673	0			
2700.5							
CUBIC	11	.7215	-.7215	.7215	0	182.8673	0
2700.5							
BOX TYPE	23						
ZHEICVL+A	3	.47	182.8673	0			
2700.5							
ZHEICVL+A	0	.478	182.8673	0			
2700.5							
ZHEICVL+A	9	.546	182.8673	0			
2700.5							
CUBIC	11	.7215	-.7215	.7215	0	182.8673	0
2700.5							
BOX TYPE	24						
CYLINDER	11	.56007	182.8673	0			
2700.5							
CYLINDER	9	.62611	182.8673	0			
2700.5							
CUBIC	11	.7215	-.7215	.7215	-.7215	182.8673	0
2700.5							
BOX TYPE	25						
CUBIC	11	.7215	0	.17	0	182.8673	0
2700.5							
BOX TYPE	26						
CUBIC	11	.17	0	.7215	0	182.8673	0
2700.5							
CCP	0	163.5275	0	163.5275	0	182.8673	0
2700.5							
CUBIC	0	163.5275	0	163.5275	0	304.8	0
2700.5							
CUBIC	11	183.5275	0	183.5275	0	385.7346	-20.
2700.5							
END							

KENO-IV Box Type Specifications

TABLE ID	NUMBER OF NEUTRON CYCLES	TABLE OF CONTENTS	NUMBER OF NEUTRON CYCLES	NUMBER OF GAMMA CYCLES
1000	1000	1000	1000	1000
1001	1001	1001	1001	1001
1002	1002	1002	1002	1002
1003	1003	1003	1003	1003
1004	1004	1004	1004	1004
1005	1005	1005	1005	1005
1006	1006	1006	1006	1006
1007	1007	1007	1007	1007
1008	1008	1008	1008	1008
1009	1009	1009	1009	1009
1010	1010	1010	1010	1010
1011	1011	1011	1011	1011
1012	1012	1012	1012	1012
1013	1013	1013	1013	1013
1014	1014	1014	1014	1014
1015	1015	1015	1015	1015
1016	1016	1016	1016	1016
1017	1017	1017	1017	1017
1018	1018	1018	1018	1018
1019	1019	1019	1019	1019
1020	1020	1020	1020	1020
1021	1021	1021	1021	1021
1022	1022	1022	1022	1022
1023	1023	1023	1023	1023
1024	1024	1024	1024	1024
1025	1025	1025	1025	1025
1026	1026	1026	1026	1026
1027	1027	1027	1027	1027
1028	1028	1028	1028	1028
1029	1029	1029	1029	1029
1030	1030	1030	1030	1030
1031	1031	1031	1031	1031
1032	1032	1032	1032	1032
1033	1033	1033	1033	1033
1034	1034	1034	1034	1034
1035	1035	1035	1035	1035
1036	1036	1036	1036	1036
1037	1037	1037	1037	1037
1038	1038	1038	1038	1038
1039	1039	1039	1039	1039
1040	1040	1040	1040	1040
1041	1041	1041	1041	1041
1042	1042	1042	1042	1042
1043	1043	1043	1043	1043
1044	1044	1044	1044	1044
1045	1045	1045	1045	1045
1046	1046	1046	1046	1046
1047	1047	1047	1047	1047
1048	1048	1048	1048	1048
1049	1049	1049	1049	1049
1050	1050	1050	1050	1050
1051	1051	1051	1051	1051
1052	1052	1052	1052	1052
1053	1053	1053	1053	1053
1054	1054	1054	1054	1054
1055	1055	1055	1055	1055
1056	1056	1056	1056	1056
1057	1057	1057	1057	1057
1058	1058	1058	1058	1058
1059	1059	1059	1059	1059
1060	1060	1060	1060	1060
1061	1061	1061	1061	1061
1062	1062	1062	1062	1062
1063	1063	1063	1063	1063
1064	1064	1064	1064	1064
1065	1065	1065	1065	1065
1066	1066	1066	1066	1066
1067	1067	1067	1067	1067
1068	1068	1068	1068	1068
1069	1069	1069	1069	1069
1070	1070	1070	1070	1070

NITAWL Table of Contents

INITIAL CODE MIXED CORE ARRAY					
	MIXED	DCN	ARRAY	DESCRIPTION	
Z LAYER	1 TO 8	COLUMN	1 TO 8	LEFT TO RIGHT	Y ROW 1 TO 8 SECTION 1C TOP
13	5	5	5	5	5
13	5	5	5	5	5
13	5	10	5	5	5
13	5	5	10	5	5
13	5	5	5	5	5
13	5	10	5	5	5
13	5	5	5	5	5
19	22	22	22	22	22

MAKRAY Subarrays Core Midplane Arrays

[illegible]

MAKARAY Subarrays Core Midplane Arrays

[illegible]

----- MIXED BGA ARRAY DESCRIPTION -----											
1M1 INITIAL CORE MIXED CORE ARRAY											
Z LAYER	1	2	3	4	5	6	7	8	9	10	11
	1	2	3	4	5	6	7	8	9	10	11
1	1	2	3	4	5	6	7	8	9	10	11
2	1	2	3	4	5	6	7	8	9	10	11
3	1	2	3	4	5	6	7	8	9	10	11
4	1	2	3	4	5	6	7	8	9	10	11
5	1	2	3	4	5	6	7	8	9	10	11
6	1	2	3	4	5	6	7	8	9	10	11
7	1	2	3	4	5	6	7	8	9	10	11
8	1	2	3	4	5	6	7	8	9	10	11
9	1	2	3	4	5	6	7	8	9	10	11
10	1	2	3	4	5	6	7	8	9	10	11
11	1	2	3	4	5	6	7	8	9	10	11
12	1	2	3	4	5	6	7	8	9	10	11

MAKARAY Subarrays Core Midplane Arrays

[illegible][illegible]

MAKARAY Subarrays Core Midplane Arrays

TPI INITIAL CORE MIXED CORE ARRAY									
----- MIXED PCX ARRAY DESCRIPTION -----									
Z LAYER	10 X COLUMN							1 TC 8 LEFT TC RIGHT	Y ROW 1 TC 15 BOTTOM TC TOP
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		
13	5	5	5	5	5	5	5		

TPI INITIAL CORE MIXED CORE ARRAY									
----- MIXED PCX ARRAY DESCRIPTION -----									
Z LAYER	10 X COLUMN							1 TC 8 LEFT TC RIGHT	Y ROW 1 TC 15 BOTTOM TC TOP
12	4	4	4	4	4	4	4		
12	4	4	4	4	4	4	4		
12	4	10	4	4	4	4	4		
12	4	4	4	10	4	4	4		
12	4	4	4	4	4	4	4		
12	4	10	4	4	10	4	4		
12	4	4	4	4	4	4	4		
15	4	4	4	4	4	4	4		
12	4	4	4	4	4	4	4		
12	4	10	4	4	10	4	4		
12	4	4	4	4	4	4	4		
12	4	4	4	10	4	4	4		
12	4	10	4	4	4	4	4		
12	4	4	4	4	4	4	4		
12	4	4	4	4	4	4	4		

THE INITIAL CORE MIXED CORE ARRAY									
----- MIXED BOX ARRAY DESCRIPTION -----									
Z LAYER	1	X	COLUMN	1	TO	2	LEFT	TO	RIGHT
14	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	10	6	6	6	6	6	6	6
14	6	6	6	10	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	10	6	6	10	6	6	6	6
14	6	6	6	6	6	6	6	6	6
15	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	10	6	6	10	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	6	6	10	6	6	6	6	6
14	6	10	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6

THE INITIAL CORE MIXED CORE ARRAY									
----- MIXED BOX ARRAY DESCRIPTION -----									
Z LAYER	1	X	COLUMN	1	TO	2	LEFT	TO	RIGHT
14	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	11	6	6	6	6	6	6	6
14	6	6	6	11	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	11	6	6	11	6	6	6	6
14	6	6	6	6	6	6	6	6	6
15	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	11	6	6	11	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	6	6	11	6	6	6	6	6
14	6	11	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6

MAKARAY Subarrays Core Midplane Arrays

INI INITIAL CORE VIXFC CORE SHAWY

----- FIXED FCX ARRAY DESCRIPTION. -----

[illegible]

THE INITIAL CORE MINED CORE ARRAY

```

***** MIXED PCA ARRAY DESCRIPTION *****

```

[illegible]

THE INITIAL CORE FIXED CORE ARRAY														
----- FIXED RCX ARRAY DESCRIPTION -----														
Z LAYER	1, X COLUMN					1 TO 15	LEFT TO RIGHT					Y ROW	1 TO 15	BOTTOM TO TOP
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

THE INITIAL CORE FIXED CORE ARRAY														
----- FIXED RCX ARRAY DESCRIPTION -----														
Z LAYER	1, X COLUMN					1 TO 15	LEFT TO RIGHT					Y ROW	1 TO 15	BOTTOM TO TOP
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

THE INITIAL CCPE INDEX CCPE ARRAY

```

----- FIXED PC# ARRAY DESCRIPTION -----

```

[illegible]

THE INITIAL CCRE MIXED CCRE ARRAY

```

***** MIXED PCX ARRAY DESCRIPTION *****

```

Z	LAYER	10	X	COLUMN	1	TC	15	LEFT	TC	RIGHT	V	RCN	1	TC	15	BOTTOM	TC	TCP
6	6	6	6	6	6	E	E	6	6	6	E	E	6	6				
6	6	E	E	6	E	E	6	6	6	6	E	E	6	6				
6	6	6	E	6	11	6	E	6	11	6	E	E	E	6				
6	6	6	11	6	6	6	6	6	6	E	11	6	E	6				
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6				
6	6	11	6	6	11	6	6	6	11	6	6	11	E	6				
6	6	6	6	6	E	6	E	6	6	6	6	E	E	6				
6	6	6	6	6	6	6	24	6	6	6	6	6	6	6				
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6				
6	6	11	6	6	11	6	6	6	11	6	6	11	E	6				
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6				
6	6	6	11	6	6	6	6	6	6	6	11	6	6	6				
6	6	6	6	6	11	6	6	6	11	6	6	6	6	6				
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6				
6	6	6	E	6	6	6	6	6	6	6	6	6	6	6				

INITIAL CORE PILED CORE ARRAY
----- PILED FOR ARRAY DESCRIPTION -----

[illegible]

Peripheral Water

THE INITIAL CONE FIXED CORE ARRAY

***** FIXED PCN ARRAY DESCRIPTION *****

Z LAYER	J, X COLUMN	I TC	I LEFT TC	RIGHT	Y RCH	I TC	B BOTTOM TC	TOP
2								
2								
2								
2								
2								
2								
2								
2								
20								
1								
1								

Water Gap

THE INITIAL CORE MIXED CODE ARRAY
 MIXED BOX ARRAY DESCRIPTION

Z LAYER	1	X	COLUMN	1	TC	15	LEFT	TC	RIGHT	Y	PCB	1	TC	15	BOTTOM	TC	TOP
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

24th Subarray for Fuel C - LBP2

THE INITIAL CORE MIXED CODE ARRAY
 MIXED BOX ARRAY DESCRIPTION

Z LAYER	1	X	COLUMN	1	TC	15	LEFT	TC	RIGHT	Y	PCB	1	TC	15	BOTTOM	TC	TOP
11	21	17	21	17	21	18	21	18	21	18	21	18	21	18	21	18	21
20	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23
16	21	13	21	16	21	17	21	17	21	16	21	16	21	16	21	16	21
20	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23
8	21	12	21	14	21	12	21	14	21	17	21	16	21	16	21	16	21
20	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23
9	21	14	21	12	21	15	21	12	21	14	21	17	21	16	21	16	21
20	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23
8	21	12	21	15	21	12	21	15	21	12	21	17	21	16	21	16	21
20	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23
9	21	13	21	12	21	15	21	12	21	14	21	16	21	16	21	16	21
20	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23
7	21	12	21	13	21	12	21	14	21	12	21	13	21	13	21	13	21
20	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23	22	23
1	19	2	19	4	19	3	19	4	19	3	19	5	19	6			

Subarray Combination for Mixed-Box Orientation Array

Portion of Mixed-Box Orientation Array

TPI HALF CCPE HALF OXIDE		
MIXTURE	NUCLIDE	DENSITY
1	-92235	4.48701E-04
2	-92235	6.64367E-04
3	-92235	6.77616E-04
4	-92235	2.64245E-04
1	92238	2.21663E-02
2	92238	2.20064E-02
3	92238	2.19336E-02
4	92238	1.10139E-02
1	8616	4.52180E-02
2	8616	4.52214E-02
3	8616	4.52231E-02
4	8616	6.46526E-02
5	8616	6.47592E-02
6	8616	6.48832E-02
7	8616	4.06029E-02
11	8616	3.33797E-02
1	5010	4.23075E-04
5	5010	3.84053E-04
6	5010	3.18333E-04
8	5010	1.10700E-03
11	5010	3.63700E-03
4	5011	1.62732E-03
5	5011	1.65970E-03
6	5011	1.27463E-03
11	5011	4.43800E-03
1	5011	1.85764E-03
4	6012	2.62406E-04
5	6012	2.16709E-04
6	6012	4.23315E-04
4	13027	4.21110E-02
5	13027	4.21728E-02
6	13027	4.32555E-02
7	47107	2.37766E-02
7	47109	2.16527E-02
7	48000	2.72460E-03
7	49113	2.47191E-04
7	49115	7.48451E-03
8	1001	2.69957E-02
11	1001	6.67593E-02
9	40302	4.25101E-02
10	26304	1.74245E-02
10	26055	1.73644E-03
10	26304	9.63560E-02
10	28304	7.72081E-03

CROSS-SECTIONS READ FROM TAPE		
NUCLIDE #	1001	P-1269 F-1002 T-218 G-032476(2)
NUCLIDE #	5010	E-10 1273 218AGP 042375 P-3 293K
NUCLIDE #	5011	E-11 1166 K-1 1/EST 218AGP P-3 293K RE(042375)
NUCLIDE #	6012	C-12 1274 F-1005 T-218 G-032476(7)
NUCLIDE #	8616	C-16 1276 218 G-030476(7)
NUCLIDE #	13027	AL-27 1193 218 G-040375(5)
NUCLIDE #	26304	CR-1191 H-1 85-304(1/EST) P-3 293K SP=54(042375)
NUCLIDE #	26055	HA-55 1197 SIGP=54 AEXLACS 218AGP P-3 293K
NUCLIDE #	26304	FF-1192 A-1 85-304(1/EST) P-3 293K SP=54(042375)
NUCLIDE #	29304	FI-1191 A-1 85-304(1/EST) P-3 293K SP=54(042375)
NUCLIDE #	40302	Z-21122(4) SIGP=54 AEXLACS 293, S-20-77 1/E HT.
NUCLIDE #	47107	AG-107 1138 SIGP=54 AEXLACS 218AGP P-3 293K
NUCLIDE #	47109	AG-109 1139 SIGP=54 AEXLACS 218AGP P-3 293K
NUCLIDE #	48000	CO-1241 A-1 1/EST 218AGP P-3 293K RE(042375)
NUCLIDE #	49113	IA-113 1005 SIGP=54 AEXLACS 218AGP P-3 293K
NUCLIDE #	49115	IA-115 1005 SIGP=54 AEXLACS 218AGP P-3 293K
NUCLIDE #	92235	L-235 1261 SIGP=54 AEXLACS 218AGP P-3 293K(3)
NUCLIDE #	92238	C-238 218GP RE S-17-70(1)

KENO-IV Mixing Table for "Displaced-Fuel
Slump" Model Analysis

C-24

MODULE HITA-L

```

053 02 E 155 A2 20 23 14 A11 1 1 17
255 02235 -2 -3 02230 0016 5310 0011 0012 13027 47107 47109 48000
09113 09115 003.2 20304 28055 20304 20304 1001
300
02235 293 2 0.07 0.452 0.00221 1 15.994 7.7 1 235.117 0.28 1 1
02235 293 2 0.07 0.452 0.432 0.53-4 1 15.994 403 1 230.129 527 1 1
2 293 2 0.07 0.452 1.024 0.004 1 15.994 209 1 230.129 311 1 1
3 293 2 0.07 0.452 1.625 0.074 1 15.994 209 1 230.129 260 1 1
25-55 293 1 0.05 7.033 6250.7 1.730-3 1 55.05 309.6 1 50.60 77.4 1 1
071-17 293 2 0.56 0.0033 143 2.378-2 1 100.0 26.5 1 114.9 2.53 1 1
071-19 293 2 0.56 0.0033 127 2.165-2 1 100.0 6 1 114.9 2.78 1 1
09113 293 2 0.56 0.0033 9749.9 3.47-0 1 100.0 4611 1 104.9 374.6 1 1
09115 293 2 0.56 0.0033 444 7.65-3 1 100.0 300 1 104.9 17 1 1
06352 293 1 0.007 0.329 181.7 0.25-2 1 600 1
000 P093.C
27
END

```

MODULE HAKARAY

```

THE INITIAL CORE HEARD COPE ARRAY
2 25
0 1
5 2 1 1 2 0 1 1 1 1 0
19 1 1 1 1 1 1 1 1 1 0
22 2 0 1 1 1 1 1 1 1 0
13 1 1 1 2 0 1 1 1 1 0
10 3 6 3 3 3 1 1 1 1 0
10 5 3 1 5 5 1 1 1 1 0
7 3 3 1 0 6 1 1 1 1 1
15 0 1
5 1 15 1 2 0 1 1 1 1 0
22 1 15 1 1 1 1 1 1 1 0
16 0 0 1 1 1 1 1 1 1 0
7 0 0 3 3 3 1 1 1 1 0
7 10 13 3 3 3 1 1 1 1 0
7 0 12 0 5 5 1 1 1 1 0
7 0 10 4 6 6 1 1 1 1 1
15 0 1
5 1 15 1 2 0 1 1 1 1 0
22 1 15 1 1 1 1 1 1 1 0
16 0 0 1 1 1 1 1 1 1 0
10 0 0 3 3 3 1 1 1 1 0
10 10 13 3 3 3 1 1 1 1 0
10 0 12 0 5 5 1 1 1 1 0
10 0 10 4 6 6 1 1 1 1 1
15 0 1
5 1 15 1 2 0 1 1 1 1 0
22 1 15 1 1 1 1 1 1 1 0
16 0 0 1 1 1 1 1 1 1 0
10 0 0 3 3 3 1 1 1 1 0
10 10 13 3 3 3 1 1 1 1 0
10 0 12 0 5 5 1 1 1 1 0
10 0 10 4 6 6 1 1 1 1 1
15 0 1
5 1 15 1 2 0 1 1 1 1 0
22 1 15 1 1 1 1 1 1 1 0
16 0 0 1 1 1 1 1 1 1 0
10 0 0 3 3 3 1 1 1 1 0
10 10 13 3 3 3 1 1 1 1 0
10 0 12 0 5 5 1 1 1 1 0
10 0 10 4 6 6 1 1 1 1 1
15 0 1
5 1 15 1 2 0 1 1 1 1 0
22 1 15 1 1 1 1 1 1 1 0
16 0 0 1 1 1 1 1 1 1 0
10 0 0 3 3 3 1 1 1 1 0
10 10 13 3 3 3 1 1 1 1 0
10 0 12 0 5 5 1 1 1 1 0
10 0 10 4 6 6 1 1 1 1 1

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Input Stream for "In-Place Fuel Slump" Model Analysis

C-25
(continued)

[illegible]

Input Stream for "In-Place Fuel Jump" Model Analysis

(continued)

[illegible]

Input Stream for "In-Place Fuel Slump" Model Analysis

(continued)

POPULUS KEIM

THI COLO SWUTONH		FUEL SLUMPED PER STRATTON				3180 PPM BORDO CR IN			
2.5	100	300	3	27	27	20	11	39.70	20 120 120 1.1 20 1
0	1.000	0	02						
0	-1.0	0	-1.0	0	0				
1	-92235	0.40701-2							
2	-2	0.09367-2							
3	-3	0.77016-4							
1	92234	2.21603-2							
2	92238	2.20064-02							
3	92238	2.19339-2							
1	8.116	4.5210-2							
2	8.116	4.5221-2							
3	8.116	4.52231-2							
4	8.116	6.46529-2							
5	8.116	6.47592-2							
6	8.116	6.48032-2							
11	8.116	3.336-2							
4	5010	6.23079-2							
5	5010	3.44053-2							
6	5010	3.10333-2							
11	5010	3.533-5							
4	5.11	1.02732-3							
5	5.11	1.55078-3							
6	5.11	1.37493-3							
11	5.11	1.418-4							
4	6.12	5.626-4							
5	6.12	5.10709-4							
6	6.12	4.23315-4							
4	13027	4.31010-2							
5	13027	4.31728-2							
6	13027	3.32555-2							
7	47107	2.37765-2							
8	47107	2.37766-2							
7	47109	2.16527-2							
7	40960	2.7246-3							
7	49113	3.47101-4							
7	49115	7.05451-3							
9	40302	4.25181-2							
10	24304	1.74249-2							
10	25055	1.73444-3							
10	26304	5.9356-2							
10	24304	7.72081-3							
11	1931	6.676-2							
BOX TYPE	1								
CUBOID	11	1.443	0	.17	0	365.7346	0		
270.5									
BOX TYPE	2								
CUBOID	11	.17	0	1.443	0	365.7346	0		
270.5									
BOX TYPE	3								
CUBOID	11	.17	0	.17	0	365.7346	0		
270.5									
BOX TYPE	4								
CYLINDER	1	.6275	205.2	0					
270.5									
CYLINDER	0	.6275	365.7346	0					
270.5									
CYLINDER	9	.680	365.7346	0					
270.5									
CUBOID	11	.7215	-.7215	.7215	-.7215	365.7346	0		
270.5									
BOX TYPE	5								
CYLINDER	2	.6275	205.2	0					
270.5									
CYLINDER	0	.6275	365.7346	0					
270.5									
CYLINDER	9	.680	365.7346	0					
270.5									
CUBOID	11	.7215	-.7215	.7215	-.7215	365.7346	0		
270.5									
BOX TYPE	6								
CYLINDER	3	.6275	205.2	0					
270.5									
CYLINDER	0	.6275	365.7346	0					
270.5									
CYLINDER	9	.680	365.7346	0					
270.5									
CUBOID	11	.7215	-.7215	.7215	-.7215	365.7346	0		
270.5									
BOX TYPE	7								
CYLINDER	4	.4572	365.7346	0					
270.5									
CYLINDER	9	.646	365.7346	0					
270.5									
CUBOID	11	.7215	-.7215	.7215	-.7215	365.7346	0		
270.5									
BOX TYPE	8								
CYLINDER	5	.4572	365.7346	0					
270.5									
CYLINDER	2	.646	365.7346	0					
270.5									
CUBOID	11	.7215	-.7215	.7215	-.7215	365.7346	0		
270.5									
BOX TYPE	9								
CYLINDER	6	.4572	365.7346	0					
270.5									
CYLINDER	9	.646	365.7346	0					
270.5									
CUBOID	11	.7215	-.7215	.7215	-.7215	365.7346	0		
270.5									
BOX TYPE	10								
CYLINDER	7	.68	365.7346	0					
270.5									
CYLINDER	10	.61	365.7346	0					
270.5									
CUBOID	11	.7215	-.7215	.7215	-.7215	365.7346	0		
270.5									

Input: Stream for "In-Place Fuel Slump" Model Analysis

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(continued)

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BOX TYPE 11
CYLINDER 11 .6496 365.7346 0
2700.5
CUBOID 11 .7215 -.7215 .7215 -.7215 365.7346 0
2700.5
BOX TYPE 12
ZMERICVL+X 1 .6275 205.2 0
2700.5
ZMERICVL+X 0 .6275 365.7346 0
2700.5
ZMERICVL+X 9 .68 365.7346 0
2700.5
CUBOID 11 .7215 0 .7215 -.7215 365.7346 0
2700.5
BOX TYPE 13
ZMERICVL+X 2 .6275 205.2 0
2700.5
ZMERICVL+X 0 .6275 365.7346 0
2700.5
ZMERICVL+X 9 .68 365.7346 0
2700.5
CUBOID 11 .7215 0 .7215 -.7215 365.7346 0
2700.5
BOX TYPE 14
ZMERICVL+X 3 .6275 205.2 0
2700.5
ZMERICVL+X 0 .6275 365.7346 0
2700.5
ZMERICVL+X 9 .68 365.7346 0
2700.5
CUBOID 11 .7215 0 .7215 -.7215 365.7346 0
2700.5
BOX TYPE 15
ZMERICVL+X 11 .56067 365.7346 0
2700.5
ZMERICVL+X 9 .62611 365.7346 0
2700.5
CUBOID 11 .7215 0 .7215 -.7215 365.7346 0
2700.5
BOX TYPE 16
ZMERICVL+Y 11 .56067 365.7346 0
2700.5
ZMERICVL+Y 9 .62611 365.7346 0
2700.5
CUBOID 11 .7215 -.7215 .7215 0 365.7346 0
2700.5
BOX TYPE 17
CUBOID 11 .7215 0 .17 0 365.7346 0
2700.5
BOX TYPE 18
CUBOID 11 .17 0 .7215 0 365.7346 0
2700.5
BOX TYPE 19
CUBOID 11 .7215 0 .7215 0 365.7346 0
2700.5
BOX TYPE 20
CUBOID 11 1.443 0 1.443 0 365.7346 0
2700.5
BOX TYPE 21
ZMERICVL+Y 1 .6275 205.2 0
2700.5
ZMERICVL+Y 0 .6275 365.7346 0
2700.5
ZMERICVL+Y 9 .68 365.7346 0
2700.5
CUBOID 11 .7215 -.7215 .7215 0 365.7346 0
2700.5
BOX TYPE 22
ZMERICVL+Y 2 .6275 205.2 0
2700.5
ZMERICVL+Y 0 .6275 365.7346 0
2700.5
ZMERICVL+Y 9 .68 365.7346 0
2700.5
CUBOID 11 .7215 -.7215 .7215 0 365.7346 0
2700.5
BOX TYPE 23
ZMERICVL+Y 3 .6275 205.2 0
2700.5
ZMERICVL+Y 0 .6275 365.7346 0
2700.5
ZMERICVL+Y 9 .68 365.7346 0
2700.5
CUBOID 11 .7215 -.7215 .7215 0 365.7346 0
2700.5
BOX TYPE 24
CYLINDER 11 .56067 365.7346 0
2700.5
CYLINDER 9 .62611 365.7346 0
2700.5
CUBOID 11 .7215 -.7215 .7215 -.7215 365.7346 0
2700.5
BOX TYPE 25
CUBOID 11 .7215 0 .17 0 365.7346 0
2700.5
BOX TYPE 26
CUBOID 11 .17 0 .7215 0 365.7346 0
2700.5
CORE BODY 0 163.5275 0 163.5275 0 365.7346 0
2700.5
CUBOID 11 163.5275 0 163.5275 0 365.7346 -20.
2700.5
END

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MODULE NENO IS FINISHED.

Input Stream for "In-Place Fuel Slump" Model Analysis

THE COLD SHUTDOWN FUEL SLUMPED PER STRATTON 3180 PPM BORON CR IN

NUMBER OF GENERATIONS	100	START TYPE	0
NUMBER PER GENERATION	300	GENERATIONS BETWEEN CHECKPOINTS	0
NUMBER OF GENERATIONS TO BE SKIPPED	3	LIST INPUT X-SECTIONS READ FROM TAPE	NO
NUMBER OF ENERGY GROUPS	27	LIST 1-0 MIXTURE X-SECTIONS	YES
MAX. NUMBER OF ENERGY TRANSFERS	27	LIST 2-0 MIXTURE X-SECTIONS	NO
NUMBER OF INPUT NUCLIDES	20	LIST PHYS. AND AER. BY REGION	NO
NUMBER OF MIXTURES	11	USE X-SECTIONS FROM PREVIOUS CASE	NO
NUMBER OF MIXING TABLE ENTRIES	30	USE GEOMETRY FROM PREVIOUS CASE	NO
NUMBER OF KECHETRY CARDS	70	USE VELOCITIES FROM PREVIOUS CASE	NO
NUMBER OF BOX TYPES	26	COMPUTE MATRIX K-EFFECTIVE BY UNIT	NO
NUMBER OF UNITS IN X DIRECTION	120	COMPUTE MATRIX K-EFFECTIVE BY BOX TYPE	NO
NUMBER OF UNITS IN Y DIRECTION	120	LIST PHYS FROM MATRIX BY UNIT	NO
NUMBER OF UNITS IN Z DIRECTION	1	ADJOINT CALCULATION	NO
NUMBER OF NUCLIDES READ FROM TAPE	-20	USE EXPONENTIAL TRANSFORM	NO
ALSCO TYPE	1	CALCULATE FLUX	YES
SEARCH TYPE	0	CALCULATE FISSION DENSITIES	YES
THIS PROBLEM WILL BE RUN WITH SPECULARLY REFLECTING BOUNDARY CONDITION			
THE ALSCOS ARE +X = 0.0 -X = 1.00000E+00 +Y = 0.0 -Y = 1.00000E+00 +Z = 0.0 -Z = 0.0			
MAXIMUM TIME = 2.0000 MINUTES			
STORAGE LOCATIONS REQUIRED FOR THIS JOB = 49031			
REMAINING AVAILABLE LOCATIONS = 3393			

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Input Stream for "In-Place Fuel Slump" Model Analysis