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**SCALE-4 Analysis of LaSalle
Unit 1 BWR Commercial
Reactor Critical
Configurations**

I. C. Gauld

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Computational Physics and Engineering Division (10)

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ABSTRACT

Five commercial reactor criticals (CRCs) for the LaSalle Unit 1 boiling-water reactor have been analyzed using KENO V.a, the Monte Carlo criticality code of the SCALE 4 code system. The irradiated fuel assembly isotopics for the criticality analyses were provided by the Waste Package Design team at the Yucca Mountain Project in the United States, who performed the depletion calculations using the SAS2H sequence of SCALE 4. The reactor critical measurements involved two beginning-of-cycle and three middle-of-cycle configurations. The CRCs involved relatively low-cycle burnups, and therefore contained a relatively high gadolinium poison content in the reactor assemblies. This report summarizes the data and methods used in analyzing the critical configurations and assesses the sensitivity of the results to some of the modeling approximations used to represent the gadolinium poison distribution within the assemblies. The KENO V.a calculations, performed using the SCALE 44GROUPNDF5 ENDF/B-V cross-section library, yield predicted k_{eff} values within about 1% $\Delta k/k$ relative to reactor measurements for the five CRCs using general 8-pin and 9-pin heterogeneous gadolinium poison pin assembly models.

1. INTRODUCTION

As part of an ongoing program to develop and validate the criticality safety analysis methodology for the disposal of commercial spent nuclear fuel by the U.S. Department of Energy Office of Civilian Radioactive Waste Management (OCRWM), commercial reactor criticality (CRC) data for the LaSalle Unit 1 (LS1) boiling-water reactor (BWR) have been compiled to provide a database for code validation studies involving BWR-type fuel assemblies.¹

The critical reactor configurations for LS1 have been analyzed using the KENO V.a Monte Carlo criticality analysis code,² developed as part of the SCALE system.³ The reactor critical measurements were all performed following reactor shutdown, either at the beginning-of-cycle (BOC) or after a reactor trip during a cycle. The reactor conditions and state at the time the reactor first attains criticality is referred to as a statepoint (SP). These states involve zero-power conditions and are attained after sufficient cooling time to allow the fission product xenon inventory to decay. A total of five statepoints have been analyzed: two involving BOC conditions, and the remaining three involving a cycle burnup of less than 8000 MWd/MTU.

The GE8×8NB-type fuel assemblies in the LS1 reactor incorporate an integral burnable gadolinia (Gd_2O_3) poison in some of the fuel pins. The statepoint criticals were performed at BOC, or relatively low-cycle burnups, and consequently these measurements involved a significant number of reactor fuel assemblies with high concentrations of the burnable poison still present. The presence of gadolinium poison in the assemblies introduces a significant level of heterogeneity in the calculations. In addition, the critical statepoints were achieved with approximately 70% insertion of the boron carbide (B_4C) control blades in the core, making these highly heterogeneous critical configurations.

The primary objective of this report is to provide an independent criticality assessment of the LS1 statepoint criticals to verify previous analyses performed by the Yucca Mountain Project Waste Package Design team under OCRWM. The irradiated fuel assembly isotopics for the criticality analyses were obtained directly from the Waste Package Design team and served as a common reference point for the analyses. This report summarizes the calculated results obtained using KENO V.a, discusses the methods and approximations used in the criticality assessment model, and provides a brief discussion of the sensitivity of the criticality results to the methods and approximations used in representing the integrated burnable gadolinia rods in the assemblies.

2. REACTOR DESCRIPTION

LaSalle Unit 1 is a General Electric BWR with a rated power of 3323 MWt. Control of reactivity is accomplished in part by a combination of control blade movements and integral burnable gadolinia (Gd_2O_3) absorbers. The core has a total of 185 control blades. The reactor vessel internal shroud is a stainless steel cylinder, which surrounds the reactor core and serves as a barrier to separate the upward flow of the coolant through the reactor core from the downward flow of the coolant outside the core.

This section describes the general LS1 reactor design information relevant to the reactor configuration during the SP measurements and includes the fuel assembly design, control blade design, and fuel assembly compositions.

2.1. FUEL ASSEMBLY DESIGN DESCRIPTION

The LS1 reactor core contains 764 fuel assemblies. All fuel assemblies used in the LS1 reactor critical SP measurements were of the GE8×8NB (GE9)-type, designed and manufactured by General Electric. The assembly has ferrule-type spacer grids, a large-diameter central water rod that spans four fuel pin positions, axially zoned enrichment, and integral burnable gadolinia (Gd_2O_3) absorbers. Additionally, this fuel assembly has a 12-in. natural uranium blanket at the top of the assembly. The fuel assembly and fuel channel specifications are listed in Table 1. Figure 1 illustrates the GE8×8NB fuel-assembly and control-blade arrangement. Figure 2 illustrates some of the axial detail of the assembly.

The burnable gadolinia (Gd_2O_3) poison in the GE8×8NB fuel assemblies is integrated with the enriched uranium in a limited number (between 7 and 12) of assembly pins to reduce the reactivity of the fuel during the initial phase of reactor operation. In general, the effect of the gadolinium poison on k_{eff} is most significant during the initial 10 GWd/MTU of operation, after which the gadolinium absorber has been typically depleted to low concentrations.

The axially zoned enrichment of the fuel assemblies is approximated using 10 axial zones to represent the axial depletion effects. The height of each axial zone and fuel zone identifiers for each assembly type residing in the reactor during the critical measurements (Cycles 7 and 8) are listed in Table 2. The table provides composition identifiers or “cross sections” for each axial zone of the nine assembly types that resided in the reactor core during the five-statepoint measurements. These identifiers are used to cross reference the actual fuel zone compositions and configurations which are listed in Table 3. The assembly types, characterized by their unique axial enrichment and gadolinium poison pin arrangement, are referenced by number (1, 2, 4, 5, and 8–12) and also by alphanumeric designations (A-H, and J).

Table 1. LaSalle Unit 1 fuel assembly and reactor data

Description	Data
Fuel assembly array size and type	GE8×8NB (GE9B)
Number of fuel pins / assembly	60 (enriched axial zones) 48 – 60 (natural uranium axial end zones)
Number of water rods / assembly	1
Number of assemblies in core	764
Number of control blades in core	185
System pressure	1020 psia (7.03266 MPa)
Active fuel height (H)	381.00 cm
Pin pitch	1.6256 cm
Assembly pitch (P)	15.24 cm
Fuel pin cladding outer diameter (OD)	1.2268 cm
Fuel pin cladding inner diameter (ID)	1.06426 cm
Fuel pin clad thickness	0.08128 cm
Fuel pin cladding material	Zircaloy
Fuel pellet diameter	1.04394 cm
Fuel material	UO ₂
Water rod outside diameter	3.4036 cm
Water rod inside diameter	3.2004 cm
Water rod material	Zircaloy
Channel - inner width	13.4061 cm
- thickness Cycles 4–7	0.254 cm
- thickness Cycle 8	0.203 cm
Channel material	Zircaloy

Table 2. Fuel assembly descriptions for 10 axial zones

Cross-Section Reference Number by Zone										
Axial zone	Length (cm)	Type 8 (B) fuel	Type 9 (A) fuel	Type 10 (C) fuel	Type 11 (D) fuel	Type 12 (E) fuel	Type 1 (G) fuel	Type 2 (F) fuel	Type 4 (J) fuel	Type 5 (H) fuel
10 (Top)	15.24	106	100	112	127	122	117	145	145	139
9	15.24	107	101	113	128	123	150	134	146	140
8	45.72	108	102	114	129	124	118	135	147	141
7	45.72	109	103	115	130	125	119	136	148	142
6	45.72	110	104	115	131	126	120	137	149	143
5	45.72	110	104	115	131	126	120	137	149	143
4	45.72	110	104	115	131	126	120	137	149	143
3	60.96	111	105	116	132	124	121	138	147	144
2	45.72	111	105	116	132	124	121	138	147	144
1 (Bottom)	15.24	107	101	113	128	123	150	134	146	140
Total	381.0									

Table 3. Fuel assembly cross-section properties

Cross section ID	Number of fuel pins	Average enrichment (wt % ²³⁵U)	Number of gadolinia pins	Gadolinia enrichment (wt %)	Channel thickness (in.)
100	48	0.71	0	0	0.100
101	60	0.71	0	0	0.100
102	60	3.50	4 / 6	5.0 / 4.0	0.100
103	60	3.65	6 / 6	5.0 / 4.0	0.100
104	60	3.65	4 / 6	5.0 / 4.0	0.100
105	60	3.50	7 / 3	5.0 / 4.0	0.100
106	49	0.71	0	0	0.100
107	60	0.71	0	0	0.100
108	60	3.23	9	3.0	0.100
109	60	3.37	2 / 9	4.0 / 3.0	0.100
110	60	3.37	9	3.0	0.100
111	60	3.23	5/4	4/3	0.100
112	51	0.71	0	0	0.100
113	60	0.71	0	0	0.100
114	60	3.27	4 / 5	5.0 / 4.0	0.100
115	60	3.38	4 / 5	5.0 / 4.0	0.100
116	60	3.27	9	5.0	0.100
117	49	0.71	0	0	0.100
150	60	0.71	0	0	0.100
118	60	3.45	9	4.0	0.100
119	60	3.62	2 / 9	5.0 / 4.0	0.100
120	60	3.62	9	4.0	0.100
121	60	3.45	5 / 4	5.0 / 4.0	0.100
122	51	0.71	0	0	0.100
123	60	0.71	0	0	0.100
124	60	3.39	7	4.0	0.100
125	60	3.50	9	4.0	0.100
126	60	3.50	7	4.0	0.100
127	51	0.71	0	0	0.100
128	60	0.71	0	0	0.100
129	60	3.39	2 / 5	4.0 / 3.0	0.100
130	60	3.50	4 / 5	4.0 / 3.0	0.100
131	60	3.50	2 / 5	4.0 / 3.0	0.100
132	60	3.39	7	4.0	0.100
133	51	0.71	0	0	0.100
134	60	0.71	0	0	0.100
135	60	3.46	7	4.0	0.100
136	60	3.58	2 / 7	5.0 / 4.0	0.100
137	60	3.58	7	4.0	0.100
138	60	3.46	4 / 3	5.0 / 4.0	0.100
139	50	0.71	0	0	0.080
140	60	0.71	0	0	0.080
141	60	3.63	8	4.0	0.080
142	60	3.88	2 / 8	5.0 / 4.0	0.080
143	60	3.88	8	4.0	0.080
144	60	3.63	8	5.0	0.080
145	48	0.71	0	0	0.080
146	60	0.71	0	0	0.080
147	60	3.63	10	5.0	0.080
148	60	3.90	12	5.0	0.080
149	60	3.90	10	5.0	0.080

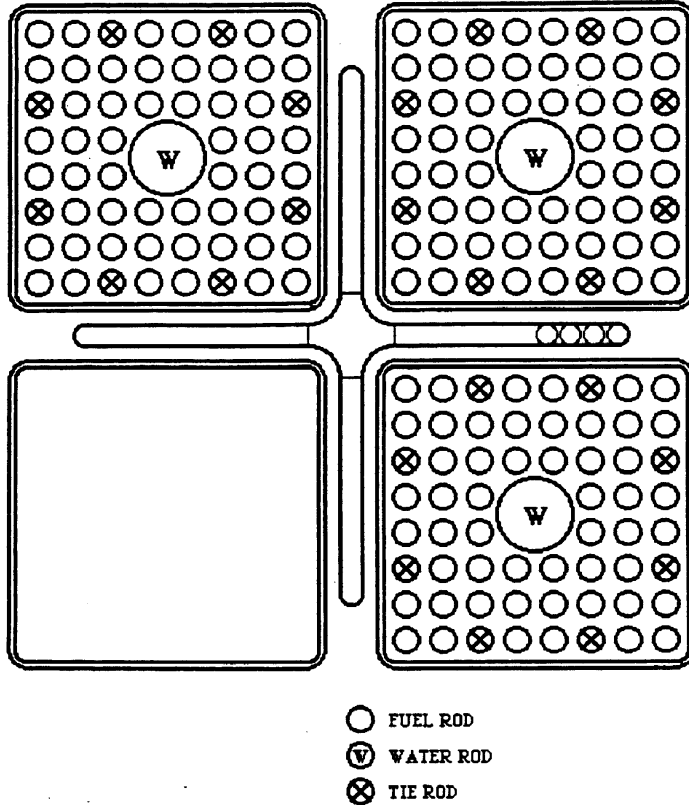


Fig. 1. GE8-8NB assemblies and control blade arrangement.

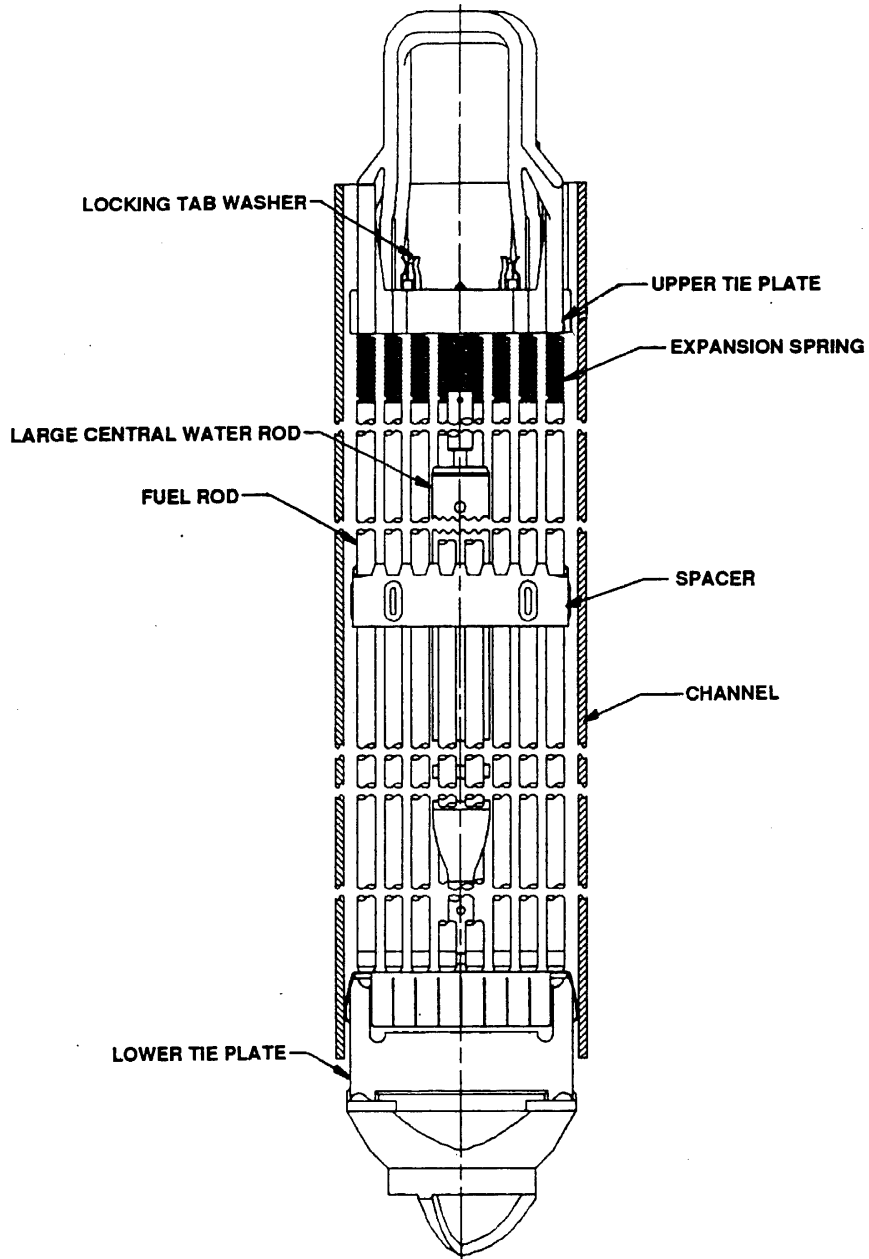


Fig. 2. GE8 8NB assembly axial section.

2.2. CONTROL BLADES

The control blades used in LS1 during the statepoint criticals are bottom-entry blades having a cruciform shape (see Fig. 1). Each control blade has 84 stainless steel tubes containing B₄C as the active absorbing material. The reactor contains a total of 185 control blades, sufficient to cover most of the assembly groups (4 assemblies) in the core. The control-blade specifications were obtained from EPRI Report NP-240 (ref. 4) and are listed in Table 4. The control-blade design is shown in Fig. 3, and the arrangement of the blades with respect to the reactor core (bottom entry) is shown in Fig. 4.

In general, criticality is achieved with about 70 to 75% blade insertion (i.e., 25 to 30% of the blades withdrawn) for the cold critical conditions of the statepoint measurements. During full-power operation, however, significantly fewer control blades are required due to the changes in reactor conditions.

Table 4. Control blade specifications

Parameter	Specification
Shape	Cruciform
Structural material	SS-304
Control material	B ₄ C in SS-304 tubes
B ₄ C density (g/cm ³)	70.6% theoretical density = 1.78 g/cm ³ (0.706 H 2.52 g/cm ³)
Boron isotopic distribution	Natural abundance ¹⁰ B (18.431 wt %), ¹¹ B (81.569 wt %)
Active control length (cm)	363.2
Number of tubes per control blade group	84 (21 per individual blade)
Inner diameter of B ₄ C tubes (mm)	3.505
Outside diameter of tube sheath (mm)	4.775
Control blade full thickness (mm)	7.925
Control blade full span – from center (mm)	123.83
Control blade sheath thickness (mm)	1.422
Control blade inner thickness (mm)	5.081
Control blade inside length (mm)	102.55

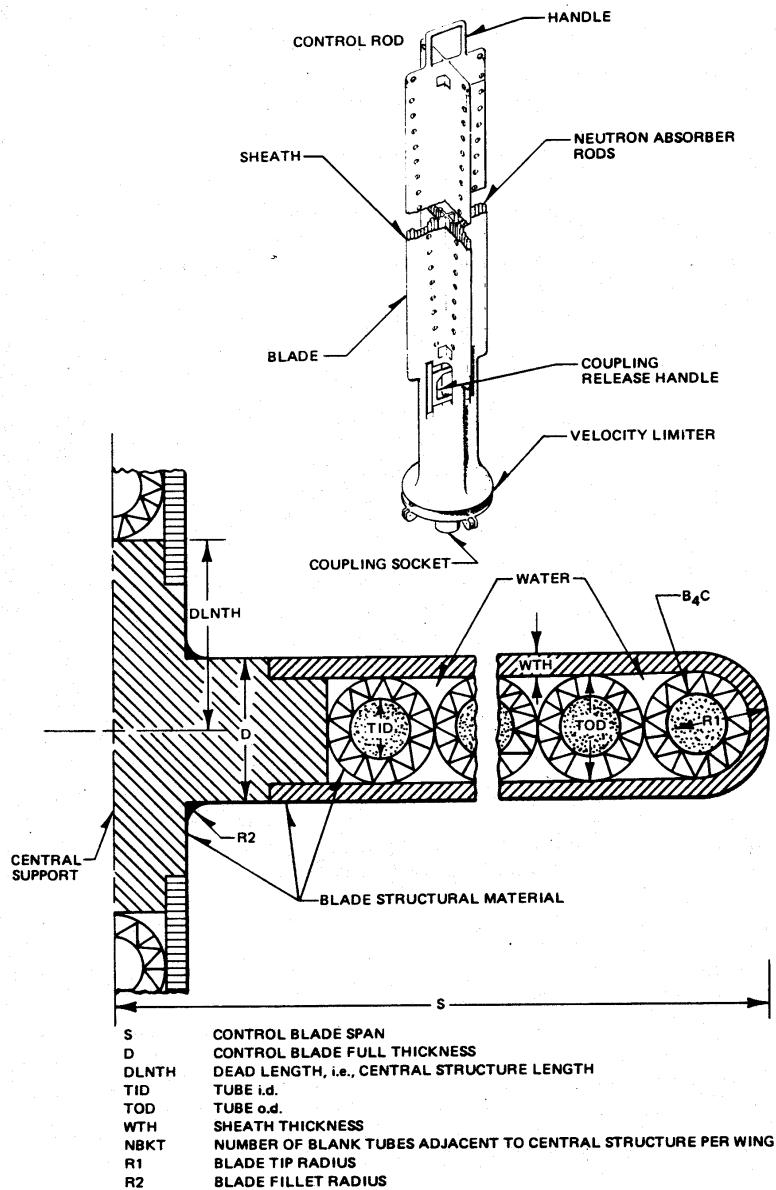


Fig. 3. B₄C control-blade assembly.

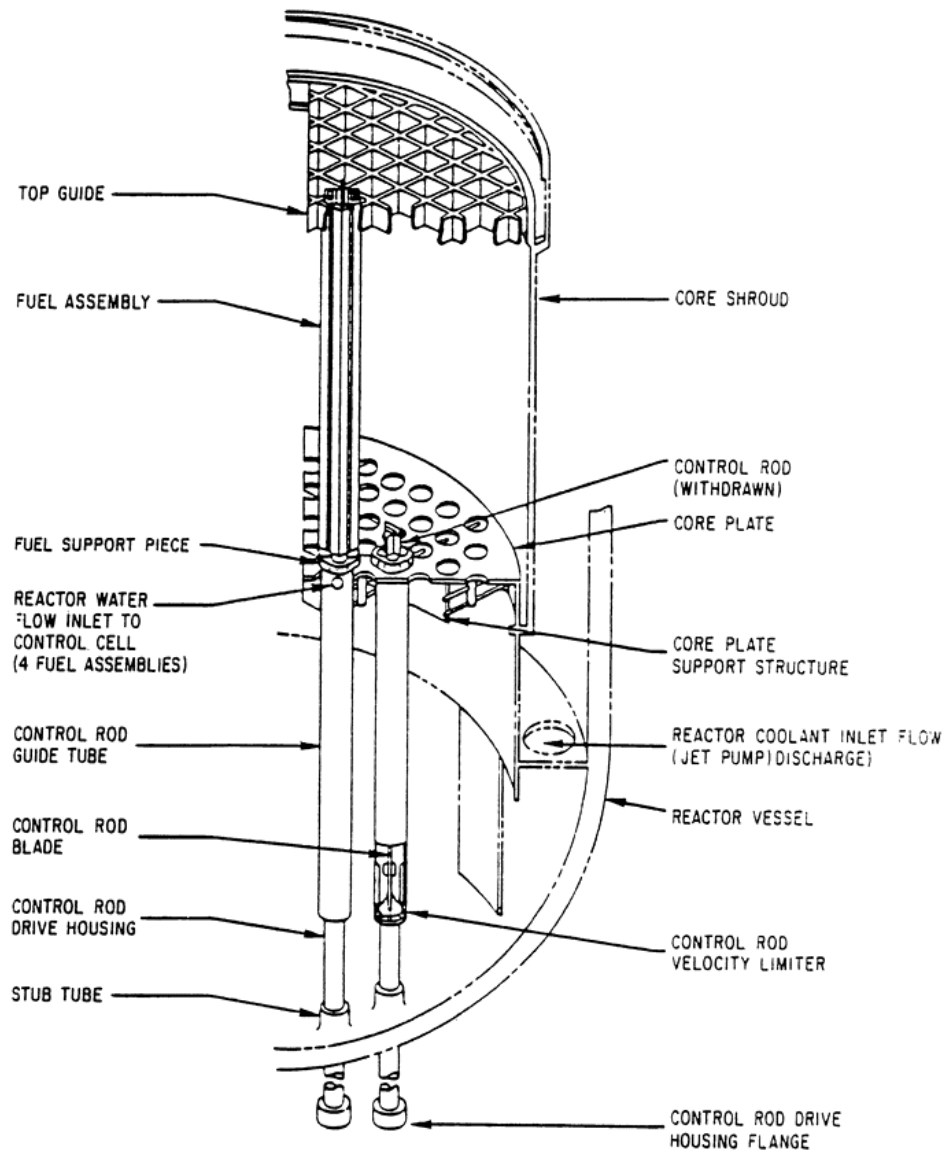


Fig. 4. LS1 reactor core structure and control-blade arrangement.

3. LASALLE UNIT 1 CRITICAL STATEPOINT DATA

A reactor SP is defined as a point at which a reactor first achieves criticality during the startup (e.g., the critical state at the BOC or a restart during cycle operation). For restarts, these points are obtained after sufficient time following a reactor trip to allow the transient fission product xenon poison to decay. The reactor is considered to be at zero power at the statepoint, and thus there is no appreciable buildup of short-lived fission products associated with normal reactor operation. The reactor coolant temperature at the statepoints, and therefore the density, is also more closely associated with cold conditions than normal operating conditions.

3.1. REACTOR STATEPOINT CONDITIONS

This report assesses five reactor statepoints measured for the LS1 reactor. The SP data include the BOC of Cycle 7, two restarts during Cycle 7, the BOC for Cycle 8, and one restart during Cycle 8. A summary of the measured reactor conditions at each of the five reactor statepoints (designated SP7 – SP11) is provided in Table 5. The cycle number, the effective full-power days (EFPDs) during the cycle at which the startup occurred, the elapsed time since the reactor was shutdown, moderator temperature, and measured neutron multiplication factor (slightly supercritical based on the reactor period at the time of the statepoint), are provided for each statepoint.

3.2. FUEL ASSEMBLY CONFIGURATION

The LS1 reactor core contains a total of 764 fuel assemblies. The core loading configuration is approximately eighth-core symmetric, in general, because the control blades are moved in eighth-core symmetry. The analysis applied core symmetry to reduce the number of assemblies required for the depletion calculations from 764 to 119 assemblies for the Cycle 7 statepoints, and 116 assemblies for the Cycle 8 statepoints. The LS1 assembly configuration for the Cycle 7 statepoint criticals is shown in Fig. 5, and the configuration for the Cycle 8 statepoints is shown in Fig. 6. The nonsymmetric assemblies are shown explicitly in the quarter-core layout in the figures. The assembly sites shown in these figures with no assembly designation are eighth-core symmetric. The assembly types for each alphanumeric designation are defined in Table 2.

3.3. CONTROL CONFIGURATION

Figures 7 through 11 provide the LS1 core maps with the control blade group positions for each statepoint. Each box in the figures represents a control blade site (see Fig. 1) that includes four fuel assemblies.

The control blade positions in these figures are given in units of “notches” withdrawn. A notch represents 7.62 cm (3 in.) of blade movement. A “0” in a control blade site indicates the blade is fully inserted (from the bottom), with the bottom of the blade aligned with the bottom of the active fuel assembly. A total of 48 notch positions represent 365.8 cm; of axial control blade

coverage. The total active fuel length is 381.0 cm; therefore, with the blades fully inserted, the upper 15.2 cm of the fuel is not bladed. This portion of the GE8×8NB assemblies contains only natural enrichment uranium fuel. A control blade at position 20 indicates the blades are withdrawn, or lowered, 20 notches (152.4 cm) below the fully inserted position. A double-dash "--" in a control blade site represents a blade that is fully withdrawn. In general, about 140 of the 185 total control blades are fully inserted in the core at statepoint criticality.

Table 5. Statepoint criticality data

State point	Cycle	Criticality date (m/d/y)	Burnup (MWd/MTU)	EFPD	Down time (h)	k_{eff}^a	Moderator temperature (K)	Reactor period (s)
SP7	7	06/24/94	0.00	0.00	3024	1.00584	330.2	147
SP8	7	02/14/95	4728.4	193.20	120	1.00519	369.3	166
SP9	7	06/17/95	7507.28	306.75	140	1.00875	378.4	420
SP10	8	04/21/96	0.00	0.00	2064	1.00605	342.5	130
SP11	8	05/16/96	89.8	3.67	120	1.00574	351.2	327

^a k_{eff} determined from the measured reactor period.

j =	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
i = 16	C17 10	G15 1	D8 11	C19 10	C5 10	G16 1	D10 11	C25 10	C20 10	F17 2	C30 10	F18 2	D7 11	C29 10	A11 9
17		B10 8	G11 1	D5 11	G12 1	C7 10	G13 1	E8 12	G14 1	C23 10	F15 2	F16 2	C26 10	E9 12	A5 9
18	D1 11	G7 1	B2 8	G8 1	C27 10	G9 1	C6 10	G10 1	D9 11	F13 2	A6 9	F14 2	D19 11	D11 11	A12 9
19		D3 11	G4 1	C18 10	E12 12	E3 12	G5 1	D21 11	C15 10	G6 1	F12 2	C16 10	D17 11	E6 12	A8 9
20					C10 10	G3 1	E10 12	C24 10	E1 12	C1 10	F11 2	C9 10	D14 11	C21 10	B7 8
21						C11 10	F8 2	C12 10	F9 2	G2 1	F10 2	D15 11	E4 12	A1 9	B3 8
22					E5 12	F5 2	C13 10	F6 2	D20 11	F7 2	A4 9	D13 11	A3 9	A7 9	B9 8
23			G1 1			C3 10		D16 11	C28 10	D6 11	D18 11	C8 10	A9 9	B4 8	
24								C22 10	C2 10	E11 12	A2 9	C14 10	B5 8		
25			F4 2						E7 10	D12 11	A10 9	B1 8	B8 8		
26				F2 2		F3 2		D4 11				B6 8			
27	F1 2							C4 10							
28					D2 11	E2 12									
29															
30															

Fi	Fuel Assembly Designation (Fi and Gi are fresh fuel assemblies in Cycle 7)
N	Fuel Type (Types 1 and 2 are fresh fuel assemblies in Cycle 7)

Fig. 5. LS1 assembly locations for the Cycle 7 statepoint criticals.

j =	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
i = 16	D4 11	H18 5	F3 2	D13 11	E6 12	J5 4	F17 2	E9 12	D15 11	J11 4	F6 2	F2 2	D10 11	E5 12	C4 10
17		D16 11	J6 4	G7 1	J12 4	F7 2	J4 4	F1 2	H10 5	E7 12	J10 4	H6 5	H7 5	E1 12	C5 10
18	F10 2		F4 2	H9 5	G12 1	J8 4	F14 2	J9 4	G14 1	H16 5	F16 2	H12 5	F15 2	D7 11	C2 10
19		G11 1		D12 11	D2 11	G15 1	J2 4	D3 11	E2 12	G5 1	H15 5	G9 1	D19 11	D21 11	C19 10
20				D14 11	G1 1	J13 4	G6 1	D11 11	G3 1	J7 4	H1 5	D20 11	D6 11	D9 11	C29 10
21						G10 1	H5 5	G4 1	J1 4	H2 5	C14 10	H11 5	F9 2	E8 12	C25 10
22							D8 11	J3 4	H13 5	G2 1	H17 5	H3 5	G16 1	E3 12	C1 10
23		F18 2		D5 11		G8 1		D18 11	D17 11	H8 5	H14 5	H4 5	E12 12	C26 10	
24				E4 12					D1 11	F11 2	G13 1	F5 2	C3 10		
25		E11 12								F13 2	C21 10	C27 10	C22 10		
26											C9 10				
27	F12 2								F8 2						
28									C12 10	C28 10					
29	E10 12														
30	C8 10			C17 10											

Fi	Fuel Assembly Designation (Hi and Ji are fresh fuel assemblies in Cycle 8)
N	Fuel Type (Types 4 and 5 are fresh fuel assemblies in Cycle 8)

Fig. 6. LS1 assembly locations for the Cycle 8 statepoint criticals.

	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	
59					0	0	0	0	0	0	0					59
55				0	--	0	--	0	18	0	--	0				55
51			0	0	0	0	0	0	0	0	0	0	0			51
47		0	--	0	0	0	--	0	--	0	0	0	--	0		47
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
39	--	0	0	0	--	0	0	0	0	0	--	0	0	0	--	39
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
31	--	0	--	0	0	0	--	0	--	0	0	0	--	0	--	31
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
23	--	0	0	0	--	0	0	0	0	0	--	0	0	0	--	23
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
15		0	--	0	0	0	--	0	--	0	0	0	--	0		15
11			0	0	0	0	0	0	0	0	0	0	0	0		11
7				0	--	0	--	0	0	0	--	0				7
3					0	0	0	0	0	0	0					3

Fig. 7. LS1 SP7 criticality control-blade configuration.

	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	
59					0	0	0	0	0	0	0					59
55				0	--	0	--	0	--	0	--	0				55
51			0	0	0	0	0	0	0	0	0	0	0			51
47		0	--	0	22	0	--	0	--	0	0	0	--	0		47
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
39	--	0	0	0	--	0	0	0	0	0	--	0	0	0	--	39
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
31	--	0	--	0	0	0	--	0	--	0	0	0	--	0	--	31
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
23	--	0	0	0	--	0	0	0	0	0	--	0	0	0	--	23
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
15		0	--	0	0	0	--	0	--	0	0	0	--	0		15
11			0	0	0	0	0	0	0	0	0	0	0	0		11
7				0	--	0	--	0	--	0	--	0				7
3					0	0	0	0	0	0	0					3

Fig. 8. LS1 SP8 criticality control-blade configuration.

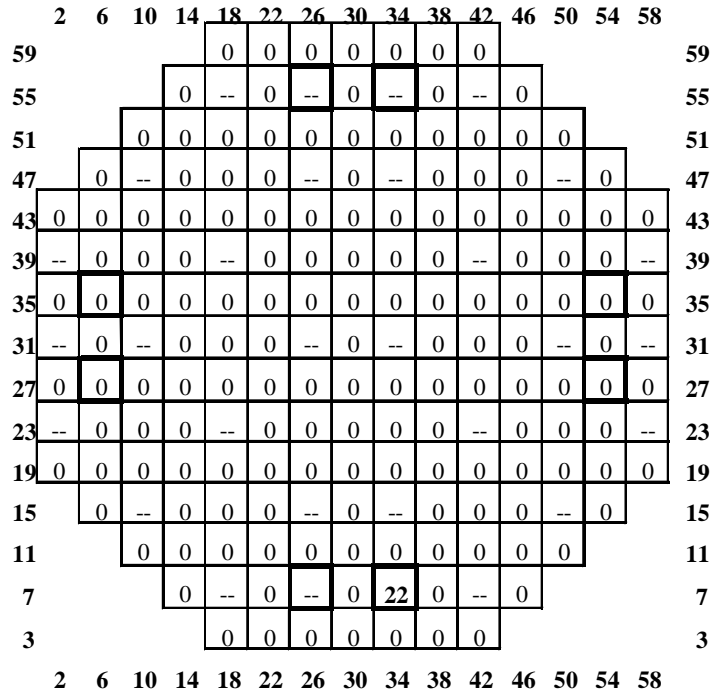


Fig. 9. LS1 SP9 criticality control-blade configuration.

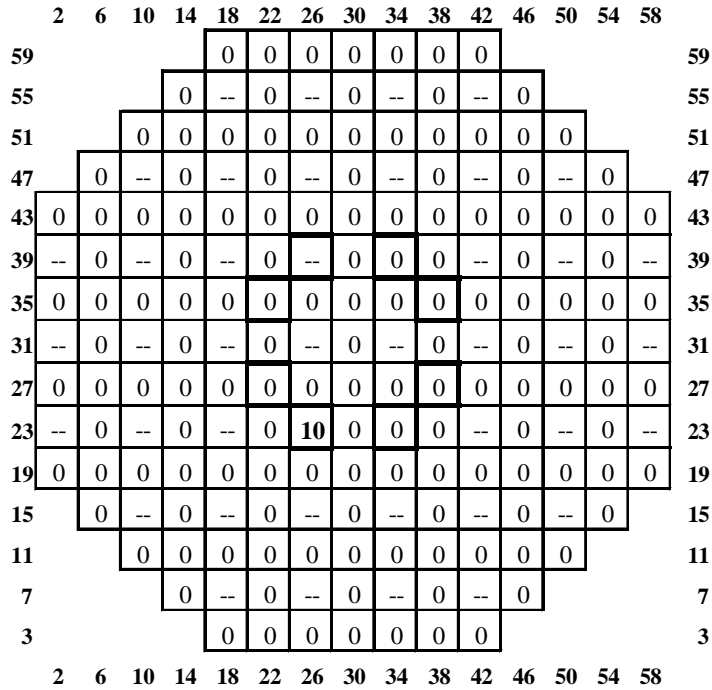


Fig. 10. LS1 SP10 criticality control-blade configuration.

	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	
59					0	0	0	0	0	0	0					59
55				0	--	0	--	0	--	0	--	0				55
51			0	0	0	0	0	0	0	0	0	0	0			51
47		0	--	0	--	0	--	0	--	0	--	0	--	0		47
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
39	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	39
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
31	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	31
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
23	--	0	--	0	--	0	20	0	0	0	--	0	--	0	--	23
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
15		0	--	0	--	0	--	0	--	0	--	0	--	0		15
11			0	0	0	0	0	0	0	0	0	0	0			11
7			0	--	0	--	0	--	0	--	0					7
3					0	0	0	0	0	0	0					3
	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	

Fig. 11. LS1 SP11 criticality control-blade configuration.

4. CRITICALITY ANALYSES

This section discusses the KENO V.a criticality analysis models, fuel assembly composition data processing, cross-section processing, and the approximations used in the criticality analysis of the LS1 statepoint critical configurations.

4.1. OVERVIEW OF THE METHODOLOGY

The reactor criticality analyses were performed using a full-core model of the LS1 reactor with the Monte Carlo criticality code KENO V.a and the 44GROUPNDF5 cross-section library.⁵ The quasi eighth-core symmetry applied in the calculation of the irradiated fuel assembly compositions was also applied in the criticality calculations. This method reduced the number of unique assemblies from 764 to 119 for the Cycle 7 criticals, and 116 for the Cycle 8 criticals. The axial burnup variation of the assemblies was represented using 10 axial zones. Each criticality calculation therefore involved approximately 1200 unique-composition assembly zones.

Irradiated fuel compositions were not calculated as part of this study, but were generated by the Yucca Mountain Project Waste Package Design team.⁶ The depletion calculations were made using the SAS2H sequence of the SCALE 4 code system. These calculations followed the complete irradiation history for the assemblies that resided in the core for each of the SP measurements, during all cycles leading up to the measurements. The composition data were transmitted as data files consisting mainly of ORIGEN-S output for each fuel zone of each assembly.

The criticality analysis methodology involved the following steps:

1. obtaining the irradiated fuel assembly nuclide compositions from the data files,
2. processing the data into units and formats suitable for input to the SCALE Material Information Processor routines,
3. generating cross sections for each assembly axial zone based on the zone compositions and geometry using the Critical Safety Analysis Sequence CSASI,
4. preparing the KENO V.a full-core model based on the assembly locations and control blade configurations for the statepoints, and
5. using the KENO V.a model to calculate the effective multiplication factor k_{eff} for the system, and compare the results against the measured value.

4.2. CODE VERSIONS AND COMPUTER PLATFORM

The cross-section processing and criticality calculations were performed using the SCALE 4.4 code system, run on a DEC Alpha Workstation. Cross-section processing was performed using CSASI, version 4.3, and criticality calculations were performed using KENO V.a, version 4.1.

4.3. LS1 FUEL ASSEMBLY COMPOSITIONS

The fuel assembly compositions for each axial zone of the unirradiated fuel assemblies in the BOC critical configurations (SP7 and SP10) were obtained from the assembly composition data in Tables 2 and 3. All other assembly compositions were obtained from ref. 6.

The assembly locations in the Cycles 7 and 8 statepoint criticals are shown in the quarter-core layout in Figs. 5 and 6, respectively. The Cycle 7 core had 208 fresh fuel assemblies of type F and G; the Cycle 8 core had 248 fresh assemblies of type H and J. The assembly sites in these figures that have no assembly designation are symmetric in the one-eighth core. The nonsymmetric assemblies are shown in the lower quadrant of the core layout and were explicitly represented in the criticality model. Even though the reactor is quarter-core assembly symmetric, the KENO V.a model used in the analyses was based on a full-core representation in order to accurately capture the nonsymmetric control blade configuration.

4.4. COMPOSITION DATA PROCESSING

The irradiated fuel compositions⁶ were calculated by ORIGEN-S and archived primarily as the SAS2H⁷ input and ORIGEN-S⁸ output files, for each axial fuel zone of each fuel assembly. These files were processed as part of this work to extract the inventories into a format suitable for input to CSASI⁹ cross-section processing sequence and ultimately for use the criticality calculation using KENO V.a.

The mass (gram) inventories from the ORIGEN-S calculations were extracted from the output files and processed into atomic number densities using a utility code GECKO (Get Compositions for KENO from ORIGEN) written for this analysis, which automatically determined the total fuel volume for the case from the number of pins per assembly, the active fuel length, and fuel pin diameter. A listing of this utility is provided in Appendix B. The gram inventories represent the average compositions over all fuel pins, including any integrated burnable poison pins in the assembly. The gram quantities (M) were converted to atom density (ADEN) in units of atoms/(b-cm) using the equation

$$\text{ADEN} = \frac{M \times 0.60225}{\text{AWT} \times V},$$

where AWT is the atomic weight for the nuclide, and V is the total fuel volume. A limitation in obtaining the assembly inventories from the ORIGEN-S output files is that the inventories are printed to only two significant figures. This factor could potentially result in an error in composition specification of up to 0.5% for a given nuclide due to roundoff. For a fissile actinide such as ²³⁵U, this could result in an error in the neutron multiplication factor, where the calculational biases are typically at the percent level. It is recommended that either the binary ORIGEN-S composition interface, or the SAS2H card-image interface, be used in future assessments to store fuel compositions.

Since the number of nuclides in the ORIGEN-S nuclear database is much larger than that in the 44GROUPNDF5 cross-section library used with KENO V.a, automated selection criteria were applied during the processing. The criteria used by GECKO to select the actinide and fission product nuclides from the ORIGEN-S output were:

1. the nuclide must reside on the 44GROUPNDF5 cross-section library, and
2. the atomic number density must be greater than 10^{-8} atoms/(b-cm).

For the light-element tables, only gadolinium and europium (decay product) were selected. The burnable poisons are tracked by ORIGEN-S in the SAS2H depletion analysis as light elements, which allows the burnable-poison inventory to be determined separately from fission products for regions containing both burnable poison and fissionable material. This method has a particular importance to BWR-type CRC analyses in that it allows the burnable poison inventory to be determined separately from the fission product gadolinium, and distributed heterogeneously in only the gadolinium poison pins, allowing a more detailed assembly representation for the criticality calculations. To obtain the correct concentrations in the burnable poison rods the volume (V) used to derive the number densities must be adjusted to include only the poison rods.

The initial concentration of oxygen (as ^{16}O in the fuel) was not available from the ORIGEN-S output since it was omitted as a light-element input specification in the SAS2H input. The oxygen was therefore added automatically to each case by the GECKO utility at a fixed nominal atomic number density of 4.5497×10^{-2} atoms/b-cm.

The water-moderator density for each of the statepoints was based on the statepoint temperatures listed in Table 5 by interpolating on standard density tables for a system pressure of 1000 psia. The moderator densities for the SP7 – SP11 analyses were 0.9882, 0.9649, 0.9583, 0.9818, and 0.9768 g/cm³, respectively.

4.5. CROSS-SECTION PROCESSING

Neutron cross sections for the criticality analyses were obtained from the SCALE 44GROUPNDF5 library, a 44-group neutron cross-section library based on ENDF/B-V data, with ENDF/B-VI evaluations for ^{16}O , ^{154}Eu , and ^{155}Eu . The 44GROUPNDF5 library was developed specifically for criticality safety calculations involving LWR fuel.

The cross sections were processed for the KENO V.a criticality analyses using the Criticality Safety Analysis Sequence CSASI, a control sequence within the CSAS4 control module of SCALE. The CSASI sequence uses the BONAMI code to apply the Bondarenko resonance self-shielding method for nuclides with Bondarenko data; it then invokes NITAWL-II to perform Nordheim resolved resonance self-shielding corrections using the specified problem-dependent temperature. The microscopic cross sections for the nuclides in each mixture are subsequently combined in CSASI using the ICE module of SCALE to create a macroscopic cross section for each mixture. This step reduced significantly the number of cross sections handled by KENO V.a for a statepoint calculation.

For each statepoint calculation, approximately 1200 sequential CSASI runs (BONAMI/NITAWL-II/ICE) were performed to generate the macroscopic cross sections for

each assembly zone. The macroscopic cross sections incorporate the number densities and temperature for each fuel zone, and therefore no composition specifications were required in the KENO V.a case. Following each CSASI run, the WAX utility module was run to assign a unique cross-section identifier to the set based on the assembly ID (e.g., D4, J12, etc.) and axial position, and then append the cross section to a working library to build a single set of cross sections required for the criticality problem.

During the cross-section library processing, an undocumented array dimensional limit was exceeded in WAX, requiring a fix in WAX to handle up to the approximately 2400 cross-section sets needed for the heterogeneous assembly statepoint calculations. A typical CSASI input case, generated by the GECKO utility code, is listed in Appendix A. The GECKO code listing is given in Appendix B.

4.6. GE8×8NB ASSEMBLY MODEL

The GE8×8NB assemblies were assumed to have 60 pins in each axial fuel zone in the KENO V.a model. The natural enrichment uranium zones at each end of the assemblies actually contained between 48 and 60 pins. For these zones the number densities of the fuel were adjusted in order to conserve the total mass of the zone (for fuel zones with less than 60 pins). The actinide and fission product number densities within each zone were assumed to be spatially uniform over all assembly pins, and over the axial zone length.

The gadolinium poison was represented using two different assembly models, one that homogenized the poison in all of the assembly pins, and the other that explicitly represented the burnable poison pins in the assembly. In the homogeneous model, the gadolinium poison was simply distributed uniformly over all 60 pins of the fuel assembly.

In the heterogeneous model the gadolinium poison was placed in a limited number of pins as UO₂/Gd₂O₃ pins. The actual number of gadolinia pins per assembly axial zone is provided in Table 3, and ranges from 7 to 12 pins per assembly. However, the exact configuration of the pins in the assembly is proprietary information and was not available to ORNL. For the purposes of this study, the discrete pin model assumed 8 gadolinia pins per assembly in the criticality calculations. The pins were distributed symmetrically in the central ring of fuel pins, near the four corners of the assembly, as shown in Fig. 12. Although this is not the actual pin configuration, this model is assumed to be generally representative of BWR assemblies and sufficient to assess the importance of a heterogeneous poison pin representation for CRC calculations involving gadolinium poison-bearing assemblies.

The number densities of the gadolinium poison isotopes (and europium decay daughters) were calculated by GECKO using an assembly volume based on 8 poison pins per assembly for the heterogeneous assembly model.

The assembly fuel pin spacer grids were not included in the KENO V.a model since there was insufficient design information available to include them. The Zircaloy channels were modeled with a single thickness of 0.203 cm (0.08 in.), corresponding to the thickness of the Cycle 8 fuel assemblies.

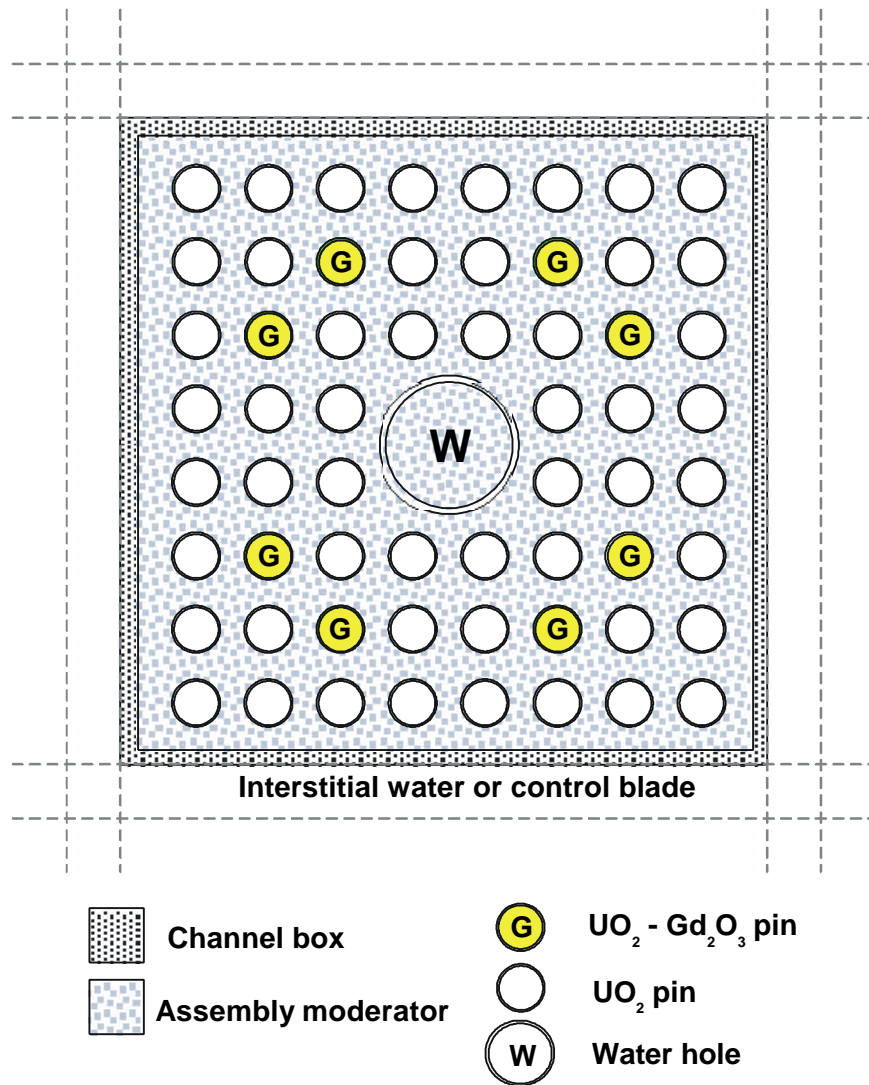


Fig. 12. KENO V.a GE8 8NB assembly model.

4.7. LASALLE UNIT 1 REACTOR MODEL

A KENO V.a full-core model of the LS1 reactor model was developed using the 10-axial-zone assembly representation adopted in the previous analyses.¹ The reactor model explicitly represented the 764 fuel assemblies in the core, plus the approximately 140 control blades inserted into the core during the critical measurements. The quasi eighth-core symmetry reduced the number of unique assembly zones (compositions) in the model to about 1200. For calculations that explicitly represented the burnable gadolinium pins in the assembly (8 pins per assembly), two mixtures per axial fuel zone were required – one for the UO₂ pins; the second, for the UO₂ / Gd₂O₃ pins.

Each assembly axial zone was modeled using 10 units in the KENO V.a model, resulting in a total of about 12,000 units to define the unique assemblies for the problem. In addition, each assembly required 6 array entries to define the fuel pin arrangements, or about 7,000 arrays for the problem. A utility code, LS1K, was written to automate the preparation of the mixture, geometry, and array data blocks for the KENO V.a input. An assembly map with the assembly locations for each statepoint is required by the LS1K utility. The LS1K utility code listing and the assembly map for Cycle 8 are provided in Appendix C.

After constructing the 10 units representing the 10 axial zones of an assembly, the units were stacked in a vertical array to form the complete assembly unit having a length of 381.0 cm. The assembly interstitial water (see Fig. 12) was modeled with units that spanned the full active length of the complete assembly (381.0 cm). The control blades were constructed with five units each, one for each blade, and one unit at the center of the cruciform. The 21 B₄C rods in each control blade were modeled explicitly in the control blade models. Two control blade models were assembled – one to represent the fully inserted control blades; the other, to represent the single critical height control blade. An assessment of the impact of approximating the B₄C rods as a homogeneous mixture (with steel tube sheath and water) within the control blades indicated that homogenization resulted in about a 1% decrease in the k_{eff} compared to explicitly modeling the B₄C rods. A cross-section illustration of the KENO V.a assembly group and control blade model is shown in Fig. 13.

After each unique assembly unit and the interstitial water units were defined, the core configuration was assembled as a 59 × 59 unit array using the assembly configurations for the respective cycles (see Figs. 5 and 6). Thirty of the 59 row (and column) positions in the array contain the assembly units, with the remaining 29 units in each assembly row (or column) representing the water units between the assemblies. Between each of the 30 rows containing the assembly units were units containing the interstitial water. The control blade units were subsequently added to the array based on the control blade patterns for each critical statepoint (see Figs. 7 through 11). An abridged KENO V.a model input listed for the Cycle 8 SP11 critical configuration is provided in Appendix D. The total size of the full-core model is about 70,000 lines (not all lines are included in listing). A section view of the reactor core for the Cycle 8 SP11 critical configuration is illustrated in Fig. 14 showing the control blade configuration at a core elevation of 100 cm. A subsection of the KENO V.a core model, obtained using the KENO3D geometry visualization program, is illustrated in Fig. 15.

The region surrounding the reactor core was not modeled in detail. Due to the large physical size of the reactor core (4.6-m diam), only about 0.5% of the neutrons leak from the system, and therefore a detailed treatment to accurately model the reflection from the out-of-core components was not warranted for this analysis. For the criticality analysis, the reactor core was surrounded by 30 cm of water to approximate the reflection conditions close to the core.

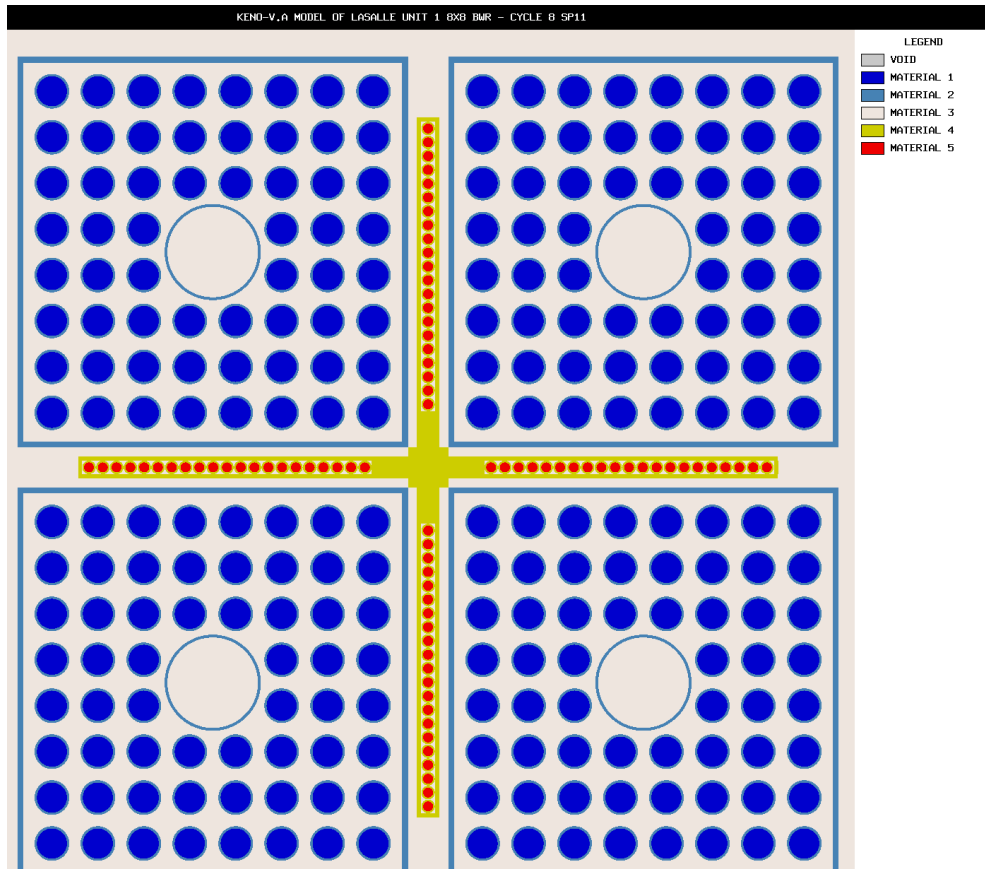


Fig. 13. KENO V.a model of LS1 assembly group and control blades.

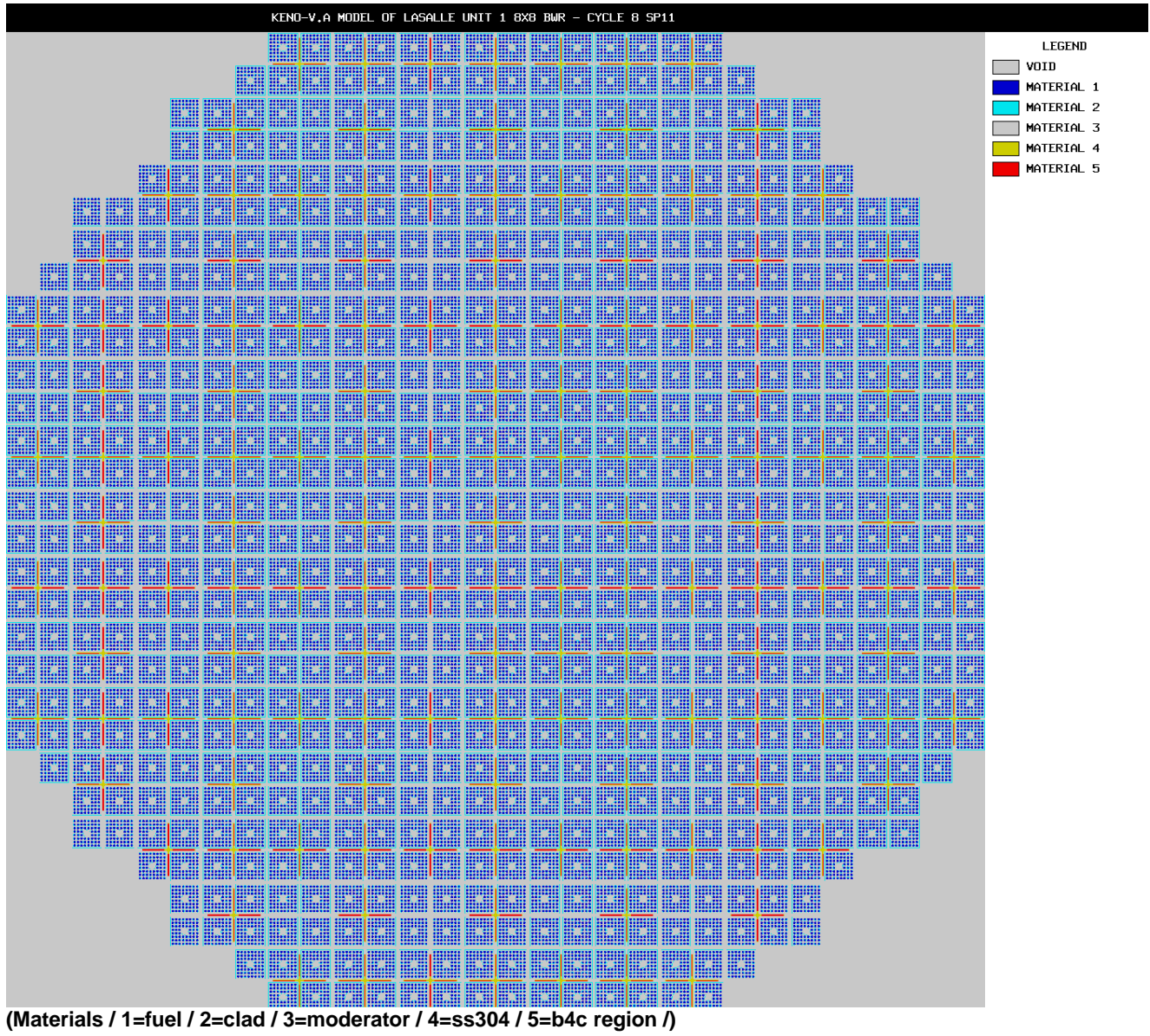


Fig. 14. KENO V.a model of the LS1 SP11 critical configuration.

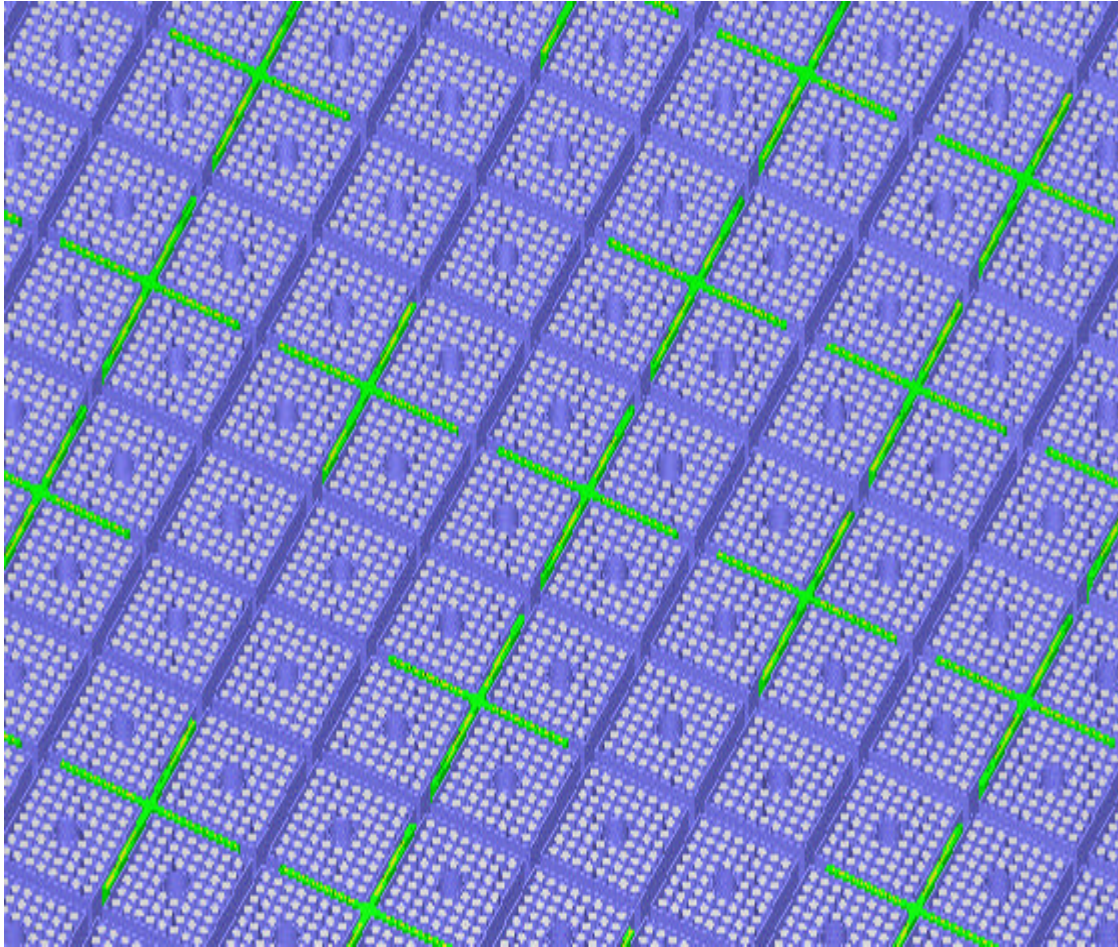


Fig. 15. KENO3D visualization of the LaSalle Unit 1 Reactor – top view.

4.8. SUMMARY OF KEY ANALYSIS APPROXIMATIONS

The key analysis assumptions and modeling approximations in the KENO V.a criticality analysis of the LS1 statepoints are summarized in this section. Since the fuel irradiated compositions were not calculated as part of this work, the approximations and uncertainties do not extend to the depletion analysis methodology. Only the assumptions in the criticality analysis are summarized here. The key modeling assumptions are the following:

1. all assemblies contain 60 pins for all axial zones (assembly mass conserved),
2. the gadolinium poison pins in the enriched uranium assemblies were approximated using a discrete symmetric 8-pin arrangement (see Fig. 12) in all assemblies, and also an homogenized (60-pin) arrangement,
3. uniform actinide and fission product concentrations in all assembly fuel zones (no correction for control blade or gadolinium poison perturbations on fuel compositions),
4. uniform oxygen (as ^{16}O) concentrations were assumed for all assemblies,
5. fuel assembly pin spacer grids and end region details were not modeled,
6. reactor core reflection was approximated by thick water reflection,
7. channel thickness for the assemblies H and J (see Table 3) were assumed to be the same as earlier cycles (assemblies A – K),
8. quarter-core (quasi eight-core) symmetry, and
9. ten axial burnup zones.

5. RESULTS AND DISCUSSION

The neutron multiplication factors (k_{eff}) calculated by KENO V.a for each of the five statepoint critical configurations are listed in Table 6. These results are compared against the known k_{eff} values.*

The KENO V.a results are based on 500 generations of 1000 particles per generation, for a total of 500,000 particle histories. The criticality analysis execution time was about 20 minutes CPU time on the DEC Alpha workstation.

The criticality calculations performed using the homogenized model for the gadolinium poison in the assemblies demonstrate that distributing the poison uniformly in all fuel pins results in a substantial underprediction in the system k_{eff} for most statepoints. The degree of underprediction is most pronounced in the Cycle 8 statepoints, which have a high initial gadolinium poison loading compared with the Cycle 7 statepoints, due to a larger number of fresh assemblies in the BOC core (248 compared to 208) and the higher gadolinium enrichment in the Cycle 8 fresh assemblies. The SP9 measurement, performed at a Cycle 7 burnup of about 8000 MWd/MTU, is accurately predicted by the homogeneous model likely due to the substantial depletion of the initial gadolinium poison loading in the core.

The criticality calculations performed using a heterogeneous symmetric 8-Gd-pin model resulted in a significant improvement in the predicted k_{eff} . For the middle-of-cycle (MOC) statepoints SP8 and SP9, the predicted k_{eff} value is within 1% $\Delta k/k$ of measurement. For the BOC and low-cycle-burnup statepoints SP7, SP10, and SP11, which will have the highest gadolinium poison concentrations, the KENO V.a results are overpredicting by between 1 and 2.3% $\Delta k/k$.

The discrete gadolinium poison pins were modeled using an 8-pin assembly approximation (Fig. 12) since the actual pin arrangement is proprietary information. The 8-pin configuration was easily implemented due to the assembly symmetry and the number of Gadolinium pins is close to the actual number of pins based on an average over the assemblies in the reactor core. If the average number of gadolinium poison pins is calculated based on the fresh assemblies in the BOC cores (where the majority of the gadolinium poison resides), then the effective average number of pins is estimated to be about 8.3 pins, based on the 208 fresh F- and G-type assemblies in Cycle 7, and about 9.1 pins per assembly based on the 248 fresh H- and J-type assemblies in Cycle 8. The use of 8 pins per assembly in the criticality analysis model, although close to the Cycle 7 average, is less than the average for the Cycle 8 statepoints, and may potentially result in an under-representation of the gadolinium worth in the assemblies.

A detailed assessment of the applicability of using an average number of poison pins to represent all assemblies in the core is beyond the scope of this report. In addition, this report has not addressed the effect of the poison pin arrangement in the assembly compared with the actual assembly arrangements because the assembly configurations are proprietary. Poison pins located

* Note that the actual k_{eff} for the statepoint is slightly greater than 1, as determined from the reactor period at the statepoint reactor configuration.

in the inner region of the assembly will have a different associated worth compared with pins located near the outer edge of the assembly. Similarly, the pin locations relative to the control blades may also be important.

An additional set of KENO V.a calculations were performed using a 9-pin gadolinium poison pin model, with the additional pin located in the outer ring of pins in the assembly. These calculations were performed for the Cycle 8 statepoints SP10 and SP11 only, because the average number of pins in the Cycle 7 assemblies was closer to 8 pins. The results are plotted in

Fig. 16 with the previous results. The two Cycle 8 statepoints are substantially improved with the 9-pin assembly model. The k_{eff} values, which showed a 2% discrepancy using the 8-pin representation, are predicted to within about 1% using the 9-pin approximation, indicating a significant degree of sensitivity to the average number of poison pins associated with the assemblies.

Table 6. Calculated k_{eff} for LS1 statepoints

State point	Cycle	Cycle burnup (MWd/MTU)	Measured k_{eff}	Calculated k_{eff} (homogeneous Gd model)	Calculated k_{eff} (8-pin Gd model)	Calculated k_{eff} (9-pin Gd model – Cycle 8 only)
SP7	7 (BOC)	0.00	1.00584	0.9740 ± 0.0010	1.0163 ± 0.0009	^a
SP8	7	4728.4	1.00519	0.9585 ± 0.0012	0.9992 ± 0.0010	^a
SP9	7	7507.28	1.00875	1.0029 ± 0.0010	1.0110 ± 0.0009	^a
SP10	8 (BOC)	0.00	1.00605	0.8972 ± 0.0010	1.0251 ± 0.0011	1.0154 ± 0.0009
SP11	8	89.8	1.00574	0.8978 ± 0.0011	1.0284 ± 0.0011	1.0175 ± 0.0009

^a Values were not reported.

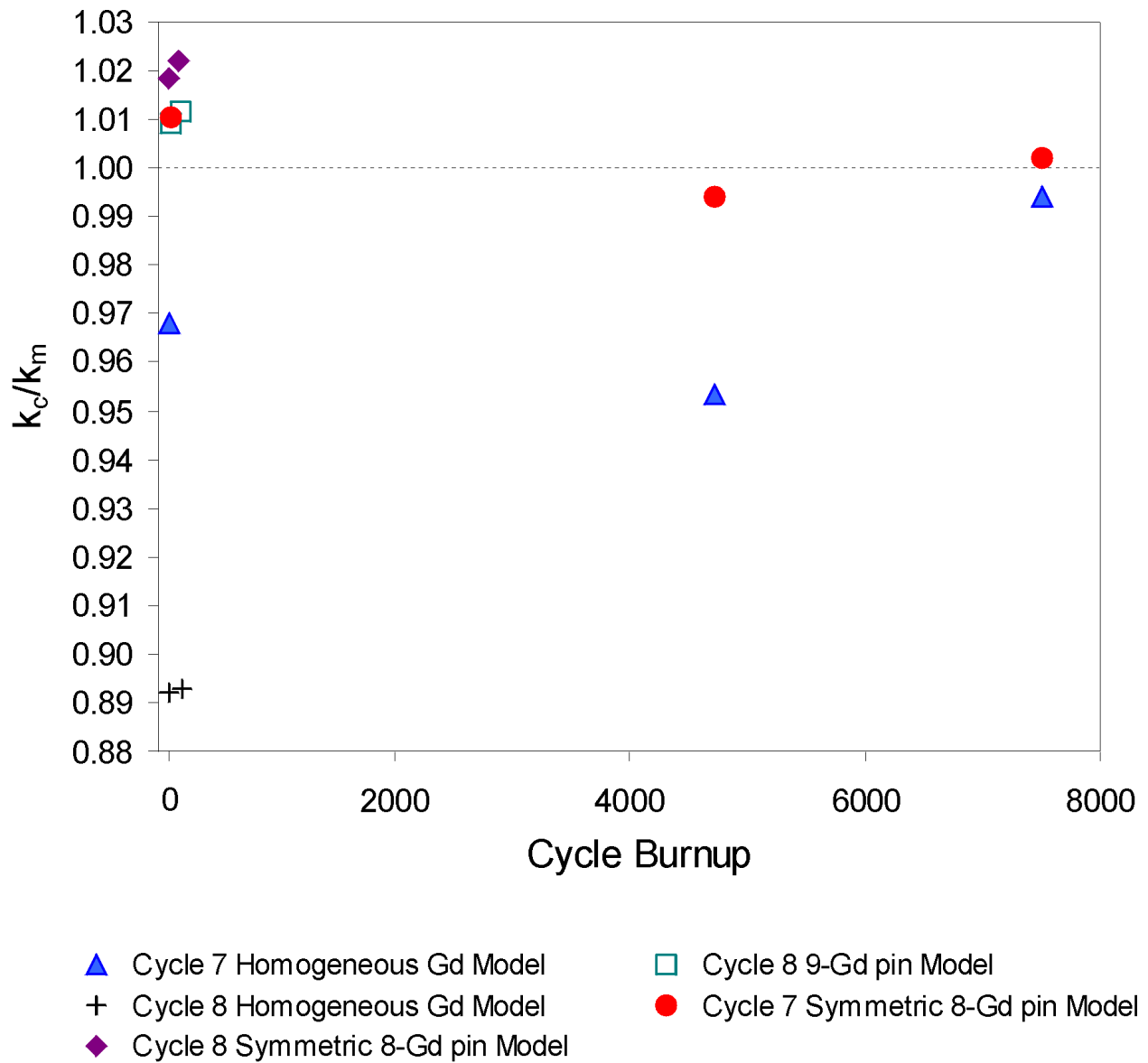


Fig. 16. Calculated (k_c)-to-measured (k_m) k_{eff} values vs cycle burnup.

6. CONCLUSIONS

The KENO V.a Monte Carlo results for five LS1 BWR critical configurations are within about 2% $\Delta k/k$ of the measured k_{eff} using a simplified assembly model that represents the gadolinium poison in a symmetric 8-pin arrangement. When the calculations for the Cycle 8 criticals are performed using a simplified 9-pin arrangement, a configuration closer to that of the fresh Cycle 8 assemblies, the results are improved to within approximately 1% for both reactor statepoints. These results suggest that the BWR CRCs can be predicted reasonably accurately without detailed information of the actual gadolinium pin distribution within the assemblies. More detailed calculations using the actual gadolinium pin distributions were not possible since the pin distributions for the assemblies in the LS1 CRCs were not available to ORNL for this work.

An homogenized representation of the gadolinium poison in the assembly generally results in a substantial underprediction in the k_{eff} . Uniformly distributing the gadolinium in all fuel pins gives the poison excessive weight in the calculations, due to the intermixing of poison in all fissile material regions and due to shelf-shielding effects. Only the SP9 configuration was well predicted with the homogeneous representation since the gadolinium poison is essentially depleted at the Cycle 7 burnup of about 8000 MWd/MTU, reducing the degree of heterogeneity in the assembly pin compositions.

Additional analyses are recommended to ensure that the approximations applied in these calculations have not significantly biased the results or produced offsetting biases. The sensitivity of the results to the average number of poison pins per assembly and the arrangement of the pins in the assemblies should be evaluated against a more detailed model that provides a closer representation of the actual assemblies (if this information is made available). It is also recommended that a sensitivity study of the key reactor state input parameters (e.g., moderator temperature and uniformity) be performed to determine the magnitude of state uncertainties on the results.

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APPENDIX A

CSASI INPUT LISTING FOR ASSEMBLY C14, ZONE 4, SP11

Appendix A

CSASI Input Listing for Assembly C14, Zone 4, SP11

```
=csasi
  C14                4 Assy-04, Node-01 {Cyc-08, .0 to Cyc-08, 3.7 EFPD}
44groupndf5 latticecell
gd-152      4 0 2.3018E-06 351. end
gd-154      4 0 2.5123E-05 351. end
gd-155      4 0 9.9843E-08 351. end
gd-156      4 0 5.3162E-04 351. end
gd-157      4 0 8.6781E-08 351. end
gd-158      4 0 6.5962E-04 351. end
gd-160      4 0 3.4941E-04 351. end
u-234       1 0 3.7129E-06 351. end
u-235       1 0 1.6175E-04 351. end
u-236       1 0 1.0197E-04 351. end
u-237       1 0 3.3743E-08 351. end
u-238       1 0 2.0949E-02 351. end
np-237      1 0 9.5084E-06 351. end
pu-238      1 0 3.6297E-06 351. end
pu-239      1 0 9.7283E-05 351. end
pu-240      1 0 5.3169E-05 351. end
pu-241      1 0 2.2941E-05 351. end
pu-242      1 0 1.2137E-05 351. end
am-241      1 0 1.8640E-06 351. end
am-242m     1 0 2.7028E-08 351. end
am-243      1 0 2.3768E-06 351. end
cm-242      1 0 1.6727E-07 351. end
cm-244      1 0 6.6359E-07 351. end
cm-245      1 0 2.1761E-08 351. end
h-3         1 0 8.5565E-08 351. end
ge-76       1 0 2.6923E-08 351. end
se-77       1 0 5.9301E-08 351. end
se-78       1 0 1.9176E-07 351. end
se-80       1 0 9.8112E-07 351. end
br-81       1 0 1.4383E-06 351. end
se-82       1 0 2.3087E-06 351. end
kr-82       1 0 4.1237E-08 351. end
kr-83       1 0 2.7656E-06 351. end
kr-84       1 0 8.1980E-06 351. end
kr-85       1 0 1.4316E-06 351. end
rb-85       1 0 6.5916E-06 351. end
kr-86       1 0 1.2542E-05 351. end
sr-86       1 0 2.3333E-08 351. end
rb-87       1 0 1.6228E-05 351. end
sr-88       1 0 2.3027E-05 351. end
sr-89       1 0 1.9940E-07 351. end
y-89        1 0 3.0229E-05 351. end
sr-90       1 0 3.4281E-05 351. end
zr-90       1 0 2.6876E-06 351. end
y-91        1 0 3.3633E-07 351. end
zr-91       1 0 3.8244E-05 351. end
zr-92       1 0 4.0779E-05 351. end
zr-93       1 0 2.9459E-05 351. end
zr-94       1 0 4.7526E-05 351. end
zr-95       1 0 5.5340E-07 351. end
nb-95       1 0 4.0531E-07 351. end
mo-95       1 0 4.5467E-05 351. end
zr-96       1 0 4.8850E-05 351. end
mo-96       1 0 2.2240E-06 351. end
mo-97       1 0 4.5293E-05 351. end
mo-98       1 0 4.8609E-05 351. end
mo-99       1 0 2.9419E-08 351. end
tc-99       1 0 4.6373E-05 351. end
mo-100      1 0 5.3807E-05 351. end
ru-100      1 0 5.7756E-06 351. end
```

ru-101	1	0	4.4232E-05	351.	end
ru-102	1	0	4.3557E-05	351.	end
ru-103	1	0	2.5880E-07	351.	end
rh-103	1	0	2.5401E-05	351.	end
ru-104	1	0	2.9429E-05	351.	end
pd-104	1	0	1.2294E-05	351.	end
pd-105	1	0	2.0545E-05	351.	end
ru-106	1	0	4.0982E-06	351.	end
pd-106	1	0	1.4553E-05	351.	end
pd-107	1	0	1.1418E-05	351.	end
pd-108	1	0	7.4504E-06	351.	end
ag-109	1	0	4.5288E-06	351.	end
pd-110	1	0	2.1832E-06	351.	end
cd-110	1	0	1.8018E-06	351.	end
cd-111	1	0	1.1074E-06	351.	end
cd-112	1	0	5.7739E-07	351.	end
cd-114	1	0	5.8891E-07	351.	end
in-115	1	0	7.4261E-08	351.	end
cd-116	1	0	2.4044E-07	351.	end
sn-116	1	0	1.0596E-07	351.	end
sn-117	1	0	2.2151E-07	351.	end
sn-118	1	0	1.7759E-07	351.	end
sn-119	1	0	1.8418E-07	351.	end
sn-120	1	0	1.8018E-07	351.	end
sb-121	1	0	1.7808E-07	351.	end
sn-122	1	0	2.3064E-07	351.	end
te-122	1	0	1.0965E-08	351.	end
sb-123	1	0	2.0669E-07	351.	end
sn-124	1	0	3.8018E-07	351.	end
sb-125	1	0	2.4485E-07	351.	end
te-125	1	0	1.9746E-07	351.	end
sn-126	1	0	8.5800E-07	351.	end
te-126	1	0	1.5103E-08	351.	end
te-127m	1	0	1.2963E-08	351.	end
i-127	1	0	1.8755E-06	351.	end
te-128	1	0	4.0108E-06	351.	end
xe-128	1	0	1.0278E-07	351.	end
i-129	1	0	7.9404E-06	351.	end
te-130	1	0	1.6062E-05	351.	end
xe-130	1	0	3.5314E-07	351.	end
i-131	1	0	4.9741E-08	351.	end
xe-131	1	0	1.8578E-05	351.	end
te-132	1	0	2.9544E-08	351.	end
xe-132	1	0	4.7494E-05	351.	end
xe-133	1	0	8.5924E-08	351.	end
cs-133	1	0	5.0292E-05	351.	end
xe-134	1	0	6.4837E-05	351.	end
cs-134	1	0	3.3155E-06	351.	end
ba-134	1	0	3.1682E-06	351.	end
cs-135	1	0	1.5614E-05	351.	end
ba-135	1	0	1.5541E-08	351.	end
xe-136	1	0	9.6732E-05	351.	end
ba-136	1	0	6.9509E-07	351.	end
cs-137	1	0	5.0625E-05	351.	end
ba-137	1	0	3.4231E-06	351.	end
ba-138	1	0	5.3836E-05	351.	end
la-139	1	0	5.0252E-05	351.	end
ba-140	1	0	1.0754E-07	351.	end
la-140	1	0	1.5144E-08	351.	end
ce-140	1	0	5.1127E-05	351.	end
ce-141	1	0	1.9956E-07	351.	end
pr-141	1	0	4.5163E-05	351.	end
ce-142	1	0	4.5888E-05	351.	end
nd-142	1	0	8.7430E-07	351.	end
pr-143	1	0	9.8729E-08	351.	end
nd-143	1	0	3.0896E-05	351.	end
ce-144	1	0	5.3135E-06	351.	end
nd-144	1	0	4.9021E-05	351.	end
nd-145	1	0	2.6895E-05	351.	end
nd-146	1	0	2.7556E-05	351.	end
nd-147	1	0	3.7611E-08	351.	end
pm-147	1	0	5.2387E-06	351.	end

```

sm-147      1 0 4.9700E-06 351. end
nd-148      1 0 1.4226E-05 351. end
pm-148m     1 0 1.4943E-08 351. end
sm-148      1 0 4.9865E-06 351. end
sm-149      1 0 5.6819E-08 351. end
nd-150      1 0 6.7629E-06 351. end
sm-150      1 0 1.0844E-05 351. end
sm-151      1 0 4.2172E-07 351. end
sm-152      1 0 5.0339E-06 351. end
eu-153      1 0 4.3395E-06 351. end
sm-154      1 0 1.3255E-06 351. end
eu-154      1 0 7.1001E-07 351. end
gd-154      1 0 1.3126E-07 351. end
eu-155      1 0 1.8950E-07 351. end
eu-156      1 0 1.7562E-08 351. end
gd-156      1 0 2.9270E-06 351. end
gd-158      1 0 5.8893E-07 351. end
tb-159      1 0 7.6841E-08 351. end
gd-160      1 0 3.4864E-08 351. end
dy-161      1 0 1.0486E-08 351. end
o-16        1 0 4.5497E-02 351. end
arbm-zirc4  6.56 5 0 0 0 8016 0.12 24000 0.10 26000 0.20 50000 1.40
            40000 98.18 2 1.0 620.0 end
arbm-modr   0.9723      2 0 0 0
            1000      11.1900
            8016      88.81000
            3 1.0 560.3 end
end comp
squarepitch 1.62560 1.0642 1 3 1.2268 2 end
more data
res=4 cylinder 0.532 dan(4)=0.020 end
end
=wax
0$$$ 41 e 1$$ 1 1t
2$$$ 40 0 2t
end
=wax
0$$$ 40 e 1$$ 2 1t
2$$$ 41 0 2t
2$$$ 2 2 2t
3$$$ 1 4
4$$$ 9031404 8031404 3t
end

```


APPENDIX B
GECKO FORTRAN UTILITY CODE LISTING

Appendix B

GECKO Fortran Utility Code Listing

```
program gecko2
c *****
c gecko2 - get compositions for keno from origen
c utility code to read the origen formatted output file from sas2h
c printed nuclide compositions are available in a standard
c composition input form suitable for inclusion in a csas
c case i.e., kenova
c *****
integer id(29)
integer id19(600),id30(600)
integer nucl(600)
dimension nucid(2000),conc(2000),iprt(2000),aden(2000)
dimension iz(2000),xa(2000)
character*4 el(2000)
character*1 sta(2000)
character*3 mwt(2000)
dimension lib(3)
character*10 scid(600),hend*4
character*4 blank*3,buf*132,dash*1,title*132,buf6*6,celparm*80
character*4 totl,buf4,keywrd(4)
data dash,blank,totl /'-',' ','tota'/
data keywrd /'modu','npin','fuel','squa'/
character*29 units
data units /'nuclide concentrations, grams'/

c
c
c read in acceptable nuclides for csas from standard composition lib
open(20,file='stdcmp',status='old')
open(5,status='unknown',form='formatted')
open(99,file='record',form='formatted',position='append')

c
isc=0
mx1=1
mx2=4
ivf=0
temp=351.
hend=' end'

c
do 12 i=1,600
read(20,end=20,fmt='(a10,i12)') scid(isc+1),nucl(isc+1)
c write(6,*) scid,nucl
isc=isc+1
12 continue
20 continue
c write(6,*) 'standard composition nuclides=',isc
c print total number of nuclides in list
c
open(83,status='old',form='unformatted',file='ft83f001')
read(83) dl,nnuc,ngn,d2,d3,ngg
if (ngn.ne.44) write(6,*) ' --- error --- ngn ne 44'
if (nnuc.gt.600) write(6,*) ' --- error --- nnuc gt dim'
ng=ngg+ngn
do 30 i=1,nnuc
read(83) id,ft30
id19(i)=id(19)
id30(i)=nint(ft30)*10
mz=id19(i)/1000
mass=(id19(i)-mz*1000)
if (mass.gt.600) id30(i)=id30(i)+1
c write(6,*) id19(i),mass,id30(i)
30 continue
c
c *** start reading composition interface
```

```

c      npois = 0
      j = 1
      k = 0
      do
      read(5,10000,end=120) buf
      if (buf(5:8).eq.keywr(1)) then
        read(5,10000,end=120) buf
        title = buf(5:100)
        goto 10
      endif
      end do
c
10 continue
      do
      read(5,10000,end=120) buf
      if (index(buf,keywr(4)).gt.0) then
        loc = index(buf,keywr(4))
        loc = loc + 24
        buf6 = buf(loc:loc+5)
c      write(6,*) 'fuelod=',buf6
        read(buf6,'(f6.3)') fd
        celparm(1:72)=buf(7:78)
        goto 18
      endif
      end do
c
18 continue
      do
      read(5,10000,end=120) buf
      if (index(buf,keywr(2)).gt.0) then
        loc1 = index(buf,keywr(2))
        loc1 = loc1 + 14
        buf4 = buf(loc1:loc1+2)
c      write(6,*) 'npin/assembly=',buf4
        read(buf4,'(i3)') npin
        loc2 = index(buf,keywr(3))
        if (loc2.eq.0) goto 100
        loc2 = loc2 + 9
        buf6 = buf(loc2:loc2+5)
c      write(6,*) 'fuelength=',buf6
        read(buf6,'(f6.3)') fuelngth
        goto 40
      endif
      end do
      write(6,*) ' --- error --- keywords not found'
      go to 100
c
40  read(5,10000,end=120) buf
      ip = index(buf,units)
      if (ip.gt.0) then
c      start of nuclide concentrations
        read(5,10000,end=120) buf
        read(5,10000,end=120) buf
42  read(5,10100,end=120) el(j),mwt(j),sta(j),xz,xa(j)
        if (el(j).eq.totl) then
c      write(6,*) 'match for total'
          k = k + 1
          lib(k) = j
          if (k.eq.3) goto 120
          go to 40
        endif
        if (el(j).eq.blank) then
          read(5,10000,end=120) buf
          read(5,10000,end=120) buf
          read(5,10000,end=120) buf
          read(5,10000,end=120) buf
          read(5,10000,end=120) buf
          go to 42
        endif
c      write(6,*) j,el(j),mwt(j),sta(j),xz,xa(j)
        read(mwt(j),'(i3)') iz(j)

```

```

        j = j + 1
        goto 42
    endif
    go to 40
c
120 continue
c
    do 122 i=1,3
122 lib(i)=lib(i) - 1
c
    iend = lib(3)
    afuel = (fd/2.)*(fd/2.)*3.141593
c
    set vol below based on npin=60 to conserve mass per assy
    apin = 60.0
    vol = afuel*apin*fuelngth
c
c
    prepare csaslx case input
    write(6,10300) title
    do 70 i=1,iend
        call noah(ia,el(i))
        idn = ia*10000+iz(i)*10
        if (sta(i).eq.'m') idn = idn + 1
c
        write(6,*) el(i),mwt(i),sta(i),idn
c
c
        check for lite element gd and eu
        ipois = 0
        if (i.gt.lib(1)) goto 48
        if (ia.eq.64) ipois=1
        if (ia.eq.63) ipois=1
        if (ipois.eq.0) go to 70
c
        above rejects all non-poison lite elements
c
48    continue
c
    check that nuclid is on master library
    do 80 j=1,nnuc
        if (idn.ne.id30(j)) goto 80
        kd19 = id19(j)
c
        set standard composition name scid
        do 50 k=1,isc
            if (kd19.eq.nucl(k)) goto 55
50        continue
c
        write(6,*) '--- no match on scid name for ',kd19
        go to 70
c
55    continue
    vf = 1.
    if (ipois.eq.1) vf=8.0/apin
c
    scale factor for number densities of poison pins (8)
    aden(i)=xa(i)*0.60225/iz(i)/vol/vf
    if (aden(i).lt.1.0e-8) goto 70
    if (ipois.eq.1) then
        write(6,85) scid(k),mx2,ivf,aden(i),temp,hend
        npois = npois + 1
    else
        write(6,85) scid(k),mx1,ivf,aden(i),temp,hend
    endif
c
    above, allows simulation of lite element poisons if required
    goto 70
80    continue
c
    write(6,*) '--- following nuclide rejected ',idn
70    continue
c
    aden2 = 4.5497e-2
    write(6,85) scid(195),mx1,ivf,aden2,temp,hend
c
    above, write stdcmp for oxygen in fuel
c
c
    always write trace amount of gd to ensure mix 4 is present
    if (npois.eq.0) write(6,85) 'gd-156      ',mx2,ivf,1e-20,temp,hend
c
    write(6,10600)
    write(6,10700)
    write(6,10400)

```

```

        write(6,10200) celparm
        write(6,10800) mx2,fd/2.0,mx2
        write(6,10500)
c       write(6,*) title
c       write(6,*) 'litel=',lib(1),'act=',lib(2),'fp=',lib(3)
c       write(6,*) 'fuelod=',fd
c       write(6,*) 'npin/assembly=',npin
c       write(6,*) 'fuelength=',fuelngth
c       write(6,*) 'fuel volume=',vol
c
        call wax(title,ice)
        write(99,12000) title(1:10),ice,npin,fd,fuelngth
c
      85  format(a10,2i2,1pe12.4,0pf5.0,a4)
      86  format(2i6,i10,3x,a10,1pe12.4)
        close (83)
        close (20)
      100 stop
10000 format(a132)
10100 format(3x,a4,a3,a1,1x,e9.2,50x,1x,e9.2)
10200 format(a72)
10300 format(7h=csasi ,/,a80,/,24h44groupndf5  latticecell)
10400 format(8hend comp)
10500 format(3hend)
10600 format(67harbm-zirc4 6.56 5 0 0 0 8016 0.12 24000 0.10
& 26000 0.20 50000 1.40 ,/,11x,27h40000 98.18 2 1.0 620.0 end )
10700 format(43harbm-modr 0.9723          2 0 0 0 /
& 11x,19h1000      11.1900 /
& 11x,19h8016      88.81000 /
& 11x,19h3 1.0 560.3 end )
10800 format(10hmore data /
& 4hres=,i1,10h cylinder ,f6.3,5h dan(,i1,12h)=0.020 end )
12000 format(6h asby,a10,5h ice=,i7,6h npin=,i2,4h fd=,
& f6.3,4h fl=,f6.3)
        end
c
        subroutine noah(i,name)
        character name*4,nel*2
        character*2 ele(99),sta(2)
c
        data ele/ ' h','he','li','be',' b',' c',' n',' o',' f','ne',
* 'na','mg','al','si',' p',' s','cl','ar',' k','ca','sc','ti',' v',
* 'cr','mn','fe','co','ni','cu','zn','ga','ge','as','se','br','kr',
* 'rb','sr',' y','zr','nb','mo','tc','ru','rh','pd','ag','cd','in',
* 'sn','sb','te',' i','xe','cs','ba','la','ce','pr','nd','pm','sm',
* 'eu','gd','tb','dy','ho','er','tm','yb','lu','hf','ta',' w','re',
* 'os','ir','pt','au','hg','tl','pb','bi','po','at','rn','fr','ra',
* 'ac','th','pa',' u','np','pu','am','cm','bk','cf','es'/
        data sta/ ' ','m' /
c
        nel = name(3:4)
        do 20 i=1,99
        if (nel.eq.ele(i)) return
20  continue
        write(6,*) 'no match for nuclide',name
        stop
        end
c
        subroutine wax(title,id)
        character*132 title
        character*1 buf,dash,blank,name(10)
        data name / 'A','B','C','D','E','F','G','H','I','J' /
        data blank,dash / ' ','-' /
c
        buf = blank
        i = 0
        do while(buf.eq.blank)
            i = i + 1
            buf = title(i:i)
        end do
        do 20 j=1,10
            if (buf.eq.name(j)) goto 40

```

```

20 continue
   write(6,*) ' --- error --- invalid name ',buf
   stop
40 id = j*10000
   i = i + 1
   read(title(i:i),'(i1)') n1
   i = i + 1
   buf = title(i:i)
   if (buf.eq.dash) then
     nas = n1
   else if (buf.eq.blank) then
     nas = n1
   else
     read(buf,'(i1)') n2
     nas = n1*10 + n2
   endif
   i = i + 10
   buf = blank
   do while(buf.eq.blank)
     i = i + 1
     buf = title(i:i)
   end do
   read(title(i:i+1),'(i2)') node
   id = id + nas*100 + node
   id1 = id + 9000000
   id2 = id + 8000000
c
   write(6,'(4h=wax)')
   write(6,'(20h0$$ 41 e 1$$ 1 1t  )')
   write(6,'(20h2$$ 40 0 2t      )')
   write(6,'(3hend)')
   write(6,'(4h=wax)')
   write(6,'(20h0$$ 40 e 1$$ 2 1t  )')
   write(6,'(20h2$$ 41 0 2t      )')
   write(6,'(20h2$$  2 2 2t      )')
   write(6,'(10h3$$  1  4  )')
   write(6,'(4h4$$ ,2(i8), 4h  3t  )') id1,id2
   write(6,'(3hend)')
   return
end

```


APPENDIX C
LS1K FORTRAN UTILITY CODE LISTING
AND ASSEMBLY MAP

Appendix C

LS1K Fortran Utility Code Listing and Assembly Map

```
program ls1k
c *****
c builds kenova material, geometry, and array data blocks, and
c script files to generate material cross sections for the
c lasalle unit 1 crc calculations
c *****
character*1 blank,buf*20
character*5 map(15,15)
dimension imap(15,15),imap2(30,30)
dimension imapf(59,59)
dimension hz(10)
data hz /15.24,45.72,60.96,5*45.72,2*15.24/
c above, sets node heights
common /message/ iboc,ncyc
node = 10
imax = 15
jmax = 15
c
read(5,'(a20)') buf
write(6,*) 'preparing kenova data for ',buf(2:20)
read(5,'(15a5)') ((map(i,j),i=1,imax),j=1,jmax)
open(10,file='mixt',status='unknown',form='formatted')
open(11,file='geom',status='unknown',form='formatted')
open(12,file='array',status='unknown',form='formatted')
write(10,'(10hread mixt  )')
write(11,'(10hread geom  )')
write(12,'(10hread array )')
icnt = 0
nu = 0
iarr = 0
c --- reserve initial 9 mixes for structural and non-fuel matls
mix = 8
c --- set special mixt assignments for boc statepoints
iboc = 0
if (index(buf,'boc').gt.0) then
  iboc = 1
  j = index(buf,'cycle')
  if (j.eq.0) stop
  j = j + 5
  blank = buf(j:j)
  read(blank,'(il)') ncyc
endif
c
aden = 1.
c above, aden set for macroscopic xsc
do 20 j=1,jmax
do 40 i=1,imax
do 60 n=1,node
c   write(6,'(2x,a5)') map(i,j)(3:4)
c   if (index(map(i,j),'X').gt.0) goto 40
c above, skip symmetric sites
icnt = icnt + 1
nu = nu + 1
c   two mixtures per zone
mix = mix + 2
c   determine xsec id from assembly name
call label(map(i,j),idxs)
write(6,*) idxs
idxs = idxs + n
c   identifiers for u and u/gd pins
idx1 = idxs + 9000000
idx2 = idxs + 8000000
c --- write mixt file entry for mix/xsc map
```

```

        write(10,10000) mix,idx1,aden
        write(10,10400) mix+1,idx1,aden,idx2,aden
c
c --- write geometry data for each unit (nu)
        hzn = hz(n)
        write(11,10300) map(i,j),n,i+15,j+15,idxs
        write(11,10200) nu
        write(11,10500) mix,hzn,hzn,hzn
        nul = nu
c --- u pin complete
        nu = nu + 1
        write(11,10200) nu
        write(11,10500) mix+1,hzn,hzn,hzn
        nulp = nu
c --- u+gd pin complete
        nu = nu + 1
        write(11,10200) nu
        write(11,10510) mix,hzn,hzn
        nu2 = nu
c --- u "hole" inner pin complete
        nu = nu + 1
        write(11,10200) nu
        write(11,10520) hzn,hzn,hzn,(nu2,k=1,12)
        nu3 = nu
c --- water rod plus inner u pins complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13000) iarr,(nul,k=1,4)
        nu4 = nu
c --- assembly corners (4x4) complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13010) iarr,nul,nulp,(nul,k=1,4),nul,nulp
        nu5 = nu
c --- assembly left side complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13010) iarr,nulp,(nul,k=1,5),nulp,nul
        nu6 = nu
c --- assembly right side complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13012) iarr,nulp,nul,nul,nulp,(nul,k=1,4)
        nu7 = nu
c --- assembly bottom side complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13012) iarr,(nul,k=1,4),nulp,nul,nul,nulp
        nu8 = nu
c --- assembly top side complete
c
c --- now, define general assembly
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10540) iarr,hzn,hzn
        write(12,13020) iarr,nu4,nu8,nu4,nu5,nu3,nu6,nu4,nu7,nu4
c
        60 continue
c --- all nodes complete, add assembly array (10 units per node)
        iarr = iarr + 1
        ilast = nu

```

```

        write(12,13040) iarr,(ilast-10*(k-1),k=10,1,-1)
        nu = nu + 1
        write(11,10200) nu
        write(11,10530) iarr
c --- store assembly node unit number in array imap to build core array
        imap(i,j) = nu
c
        40 continue
        20 continue
c --- fill symetric assembly sites (set as zero in imap)
        do 80 j=1,jmax
        do 90 i=1,imax
            if (imap(i,j).eq.0) imap(i,j)=imap(j,i)
            if (imap(i,j).eq.0) imap(i,j)=13000
        90 continue
        80 continue
c
        icnt = icnt/node
        write(6,*) icnt,' assemblies completed'
        write(6,*) 'core map  imap(i,j)'
        write(6,'(15a5)') ((map(i,j),i=1,15),j=1,15)
        write(6,'(15i5)') ((imap(i,j),i=1,15),j=1,15)
c
c --- generate core layout using array imap
        write(12,13100)
        nu = 9000
        write(12,13120) nu
c
c
c --- fill interstitial assembly locations with water units
        do 120 j=1,jmax*2
        do 140 i=1,imax*2
            ix = 0
            iy = 0
c
            test for x,y even,odd
            if (mod(i,2).eq.0) ix = 1
            if (mod(j,2).eq.0) iy = 1
            if (ix.eq.0) then
                if (iy.eq.0) imap2(i,j) = 13003
                if (iy.eq.1) imap2(i,j) = 13001
            else
                if (iy.eq.0) imap2(i,j) = 13002
                if (iy.eq.1) imap2(i,j) = imap(i/2,j/2)
            endif
c
c
            even/even locations are assemblies
c
        140 continue
        120 continue
c
c
        set locations of inserted cruxiform centres on map
c
        row 1 - alternate full insertion - imap2 id=90003
        j = 1
        do 200 i=1,30,8
        200 imap2(i,j) = 90003
c
        add (42,31) blade site for cycle 7 only
        imap2(13,j) = 90003
c
c
        row 5 - full insertion all sites
        j = 5
        do 220 i=1,30,4
        220 imap2(i,j) = 90003
c
c
        row 9 - alternate full insertion
        j = 9
        do 240 i=1,30,8
        240 imap2(i,j) = 90003
            imap2(5,j) = 90003
c
        add (50,23) blade site for cycle 7 only
        imap2(21,9) = 90003
c
c
        row 13 - full insertion all sites

```

```

        j = 13
        do 260 i=1,30,4
260  imap2(i,j) = 90003
c
c   row 17 - alternate full insertion
        j = 17
        do 280 i=1,26,8
280  imap2(i,j) = 90003
c   add (42,15) blade site for cycle 7 only
        imap2(13,j) = 90003
c
c   row 21 - full insertion all sites
        j = 21
        do 290 i=1,22,4
290  imap2(i,j) = 90003
c
c   row 25 - alternate full insertion
        j = 25
        do 300 i=1,18,8
300  imap2(i,j) = 90003
c
c   row 29 - full insertion all sites
        j = 29
        do 310 i=1,15,4
310  imap2(i,j) = 90003
c
c *** map image 1/4 core imap2 to full core image imapf
c
        do 400 i=30,59
        do 400 j=30,59
400  imapf(i,j) = imap2(i-29,j-29)
c
c   reflect to lower left quadrant
        do 420 i=1,29
        do 420 j=30,59
420  imapf(i,j) = imapf(60-i,j)
c
c   now reflect to upper half core from lower half
        do 440 i=1,59
        do 440 j=1,29
440  imapf(i,j) = imapf(i,60-j)
c
c *** add/modify locations for any non-symmetric blade sites
        isp = 7
        if (isp.eq.10 .or. isp.eq.11) then
c   withdraw control rod at blade site (26,39)
            imapf(26,22) = 13003
c   set critical control absorber height (26,23)
            imapf(26,38) = 100001
        else if (isp.eq.9) then
c   set critical control absorber at site (34,7)
            imapf(34,54) = 100001
        else if (isp.eq.8) then
c   set critical control absorber at site (18,47) cycle 7 sp8 only
            imapf(18,14) = 100001
        else if (isp.eq.7) then
c   set critical control absorber at site (18,47) cycle 7 sp7 only
            imapf(34,6) = 100001
c   add control rod at blade site (34,7)
            imapf(34,54) = 90003
        else
            write(6,*) '--- error --- invalid statepoint ',isp
        endif
c
c *** now complete mapping of control blades
        lim = 59
        do 160 j=1,lim
        do 180 i=1,lim
            if (imapf(i,j).lt.90000) go to 180
c
            if (imapf(i,j).eq.90003) then
c --- control rod 9C

```

```

        if (i.gt.1) imapf(i-1,j) = 13011
        if (i.lt.lim) imapf(i+1,j) = 13012
        if (j.gt.1) imapf(i,j-1) = 13009
        if (j.lt.lim) imapf(i,j+1) = 13010
        imapf(i,j) = 13013
    elseif (imapf(i,j).eq.100001) then
c --- control rod 10A
        if (i.gt.1) imapf(i-1,j) = 13024
        if (i.lt.lim) imapf(i+1,j) = 13025
        if (j.gt.1) imapf(i,j-1) = 13022
        if (j.lt.lim) imapf(i,j+1) = 13023
        imapf(i,j) = 13026
    else
        write(6,*) 'invalid control rod id',imapf(i,j)
        stop
    endif
c
    180 continue
    160 continue
c
    800 continue
c --- print array data for complete core
    write(12,'(10i6)') ((imapf(i,j),i=1,59),j=1,59)
    write(12,'(10h end fill  )')
    write(14,'(59i6)') ((imapf(i,j),i=1,59),j=1,59)
    close(10)
    close(11)
    close(12)
    stop
10000 format(4hmix= ,i4,4h      ,i8,f5.1)
10100 format(10hread geom  )
10110 format(10hend geom  )
10200 format(4hunit,i6  )
10300 format(1h'/ 17h'--- uo2-gd pin  , a5,6h node=i2,
    1 9h (site i= ,i2,4h, j=,i2,7h) xsc=,i7 )
10400 format(4hmix= ,i4,4h      ,2(i8,f5.1))
10500 format(
    1 lx,'cylinder ',i4,' 1 0.5321 ',f5.2,' 0.0'/
    2 lx,'cylinder  2 1  0.6134 ',f5.2,' 0.0'/
    3 lx,'cuboid   3 1  4p0.8128 ',f5.2,' 0.0' )
10510 format(
    1 lx,'cylinder ',i4,' 1 0.5321 ',f5.2,' 0.0'/
    2 lx,'cylinder  2 1  0.6134 ',f5.2,' 0.0' )
10520 format(
    1 lx,'cylinder  3 1  1.6002 ',f5.2,' 0.0'/
    2 lx,'cylinder  2 1  1.7018 ',f5.2,' 0.0'/
    3 lx,'cuboid   3 1  4p3.2512 ',f5.2,' 0.0'/
    4 lx,'hole ',i5,'  2.4384 2.4384 0.0'/
    5 lx,'hole ',i5,'  2.4384 0.8128 0.0'/
    6 lx,'hole ',i5,'  2.4384 -0.8128 0.0'/
    7 lx,'hole ',i5,'  2.4384 -2.4384 0.0'/
    8 lx,'hole ',i5,'  0.8128 -2.4384 0.0'/
    9 lx,'hole ',i5,' -0.8128 -2.4384 0.0'/
    a lx,'hole ',i5,' -2.4384 -2.4384 0.0'/
    b lx,'hole ',i5,' -2.4384 -0.8128 0.0'/
    c lx,'hole ',i5,' -2.4384 0.8128 0.0'/
    d lx,'hole ',i5,' -2.4384 2.4384 0.0'/
    e lx,'hole ',i5,' -0.8128 2.4384 0.0'/
    f lx,'hole ',i5,'  0.8128 2.4384 0.0' )
10530 format(
    1 lx,'array ',i4,'  3*0' )
10540 format(
    1 lx,'array ',i4,'  -6.5024 -6.5024 0.0'/
    2 lx,'cuboid  3 1  4p6.7031 ',f5.2,' 0.0'/
    3 lx,'cuboid  2 1  4p6.9061 ',f5.2,' 0.0' )
13000 format(
    1 4hara= ,i4,27h nux=2 nuy=2 nuz=1 fill /
    2 4i6,12h end fill )
13010 format(
    1 4hara= ,i4,27h nux=2 nuy=4 nuz=1 fill /
    2 8i6,12h end fill )
13012 format(

```

```

1 4hara= ,i4,27h nux=4 nuy=2 nuz=1 fill /
2 8i6,12h end fill )
13020 format(
1 4hara= ,i4,27h nux=3 nuy=3 nuz=1 fill /
2 3i6/ 3i6/ 3i6 ,12h end fill )
13040 format(
1 4hara= ,i4,27h nux=1 nuy=1 nuz=10 fill /
2 5i6/ 5i6 ,12h end fill )
13100 format(
1 37h'--- reactor core array - layout map )
13120 format(
1 4hara= ,i4,27h nux=59 nuy=59 nuz=1 fill )
end
c
subroutine label(asmby,idxs)
character*5 asmby
character*1 buf,blank,dash,name(10)
data name /'A','B','C','D','E','F','G','H','I','J'/
data blank,dash /' ','-'/
common /message/ iboc,ncyc
buf = blank
i = 0
do while(buf.eq.blank)
i = i + 1
buf = asmby(i:i)
end do
do 20 j=1,10
if (buf.eq.name(j)) goto 40
20 continue
write(6,*) ' --- error --- invalid name ',buf
stop
40 idxs = j*10000
c --- if boc sp -
if (iboc.eq.1) then
if (ncyc.eq.7) then
if (j.eq.6) return
if (j.eq.7) return
else if (ncyc.eq.8) then
if (j.eq.8) return
if (j.eq.10) return
endif
endif
c
i = i + 1
read(asmby(i:i),'(i1)') n1
i = i + 1
buf = asmby(i:i)
if (buf.eq.dash) then
m = n1
else if (buf.eq.blank) then
m = n1
else
read(buf,'(i1)') n2
m = n1*10 + n2
endif
idxs = idxs + m*100
return
end

```


Cycle 8 Assembly Map

```

=cycle8
  D4 H18 F3 D13 E6 J5 F17 E9 D15 J11 F6 F2 D10 E5 C4
  X D16 J6 G7 J12 F7 J4 F1 H10 E7 J10 H6 H7 E1 C5
F10  X F4 H9 G12 J8 F14 J9 G14 H16 F16 H12 F15 D7 C2
  X G11 X D12 D2 G15 J2 D3 E2 G5 H15 G9 D19 D21 C19
  X X X D14 G1 J13 G6 D11 G3 J7 H1 D20 D6 D9 C29
  X X X X X G10 H5 G4 J1 H2 C14 H11 F9 E8 C25
  X X X X X X D8 J3 H13 G2 H17 H3 G16 E3 C1
  X F18 X D5 X G8 X D18 D17 H8 H14 H4 E12 C26 X
  X X X E4 X X X X D1 F11 G13 F5 C3 X X
  X E11 X X X X X X F13 C21 C27 C22 X X
  X X X X X X X X X X C9 X X X X
F12  X X X X X X X X F8 X X X X X X
  X X X X X X X X C12 C28 X X X X X X
E10  X X X X X X X X X X X X X X
  C8  X X C17 X X X X X X X X X X
end

```


APPENDIX D
ABRIDGED KENO V.A INPUT LISTING
FOR LS1 STATEPOINT CONFIGURATIONS

Appendix D

Abbreviated KENO V.a Input Listing for LS1 Statepoint Configurations

```
=kenova
keno-v.a model of lasalle unit 1 8x8 BWR - cycle 8 SP11
read parm
npg=1000 gen=503 nsk=5 nub=no fdn=no tme=120
xsc=14 lib=40
lng=2000000 nb8=9000
run=yes plt=no
end parm
read mixt
mix=2 2 1.
mix=3 3 1.
mix=4 4 1.
mix=5 5 1.
' start fuel mixt
mix= 10 9040401 1.0
mix= 11 9040401 1.0 8040401 1.0
mix= 12 9040402 1.0
mix= 13 9040402 1.0 8040402 1.0
mix= 14 9040403 1.0
mix= 15 9040403 1.0 8040403 1.0
mix= 16 9040404 1.0
mix= 17 9040404 1.0 8040404 1.0
mix= 18 9040405 1.0
mix= 19 9040405 1.0 8040405 1.0
mix= 20 9040406 1.0
mix= 21 9040406 1.0 8040406 1.0
.
.
.

(2309 lines deleted)

.
.
.
mix=2329 9031710 1.0 8031710 1.0
end mixt
'
read geom
'
'--- uo2-gd pin D4 node= 1 (site i=16, j=16) xsc= 40401
unit 1
cylinder 10 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 2
cylinder 11 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 3
cylinder 10 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
unit 4
cylinder 3 1 1.6002 15.24 0.0
cylinder 2 1 1.7018 15.24 0.0
cuboid 3 1 4p3.2512 15.24 0.0
hole 3 2.4384 2.4384 0.0
hole 3 2.4384 0.8128 0.0
hole 3 2.4384 -0.8128 0.0
```

```

hole      3      2.4384 -2.4384  0.0
hole      3      0.8128 -2.4384  0.0
hole      3     -0.8128 -2.4384  0.0
hole      3     -2.4384 -2.4384  0.0
hole      3     -2.4384 -0.8128  0.0
hole      3     -2.4384  0.8128  0.0
hole      3     -2.4384  2.4384  0.0
hole      3     -0.8128  2.4384  0.0
hole      3      0.8128  2.4384  0.0
unit      5
  array   1      3*0
unit      6
  array   2      3*0
unit      7
  array   3      3*0
unit      8
  array   4      3*0
unit      9
  array   5      3*0
unit     10
  array   6     -6.5024 -6.5024  0.0
  cuboid  3 1  4p6.7031  15.24  0.0
  cuboid  2 1  4p6.9061  15.24  0.0
,
'--- uo2-gd pin      D4  node= 2 (site i=16, j=16)  xsc=  40402
unit     11
  cylinder 12 1  0.5321  45.72  0.0
  cylinder  2 1  0.6134  45.72  0.0
  cuboid   3 1  4p0.8128  45.72  0.0
unit     12
  cylinder 13 1  0.5321  45.72  0.0
  cylinder  2 1  0.6134  45.72  0.0
  cuboid   3 1  4p0.8128  45.72  0.0
unit     13
  cylinder 12 1  0.5321  45.72  0.0
  cylinder  2 1  0.6134  45.72  0.0
unit     14
  cylinder  3 1  1.6002   45.72  0.0
  cylinder  2 1  1.7018   45.72  0.0
  cuboid   3 1  4p3.2512  45.72  0.0
hole     13      2.4384  2.4384  0.0
hole     13      2.4384  0.8128  0.0
hole     13      2.4384 -0.8128  0.0
hole     13      2.4384 -2.4384  0.0
hole     13      0.8128 -2.4384  0.0
hole     13     -0.8128 -2.4384  0.0
hole     13     -2.4384 -2.4384  0.0
hole     13     -2.4384 -0.8128  0.0
hole     13     -2.4384  0.8128  0.0
hole     13     -2.4384  2.4384  0.0
hole     13     -0.8128  2.4384  0.0
hole     13      0.8128  2.4384  0.0
unit     15
  array    7      3*0
unit     16
  array    8      3*0
unit     17
  array    9      3*0
unit     18
  array   10      3*0
unit     19
  array   11      3*0
unit     20
  array   12     -6.5024 -6.5024  0.0
  cuboid  3 1  4p6.7031  45.72  0.0
  cuboid  2 1  4p6.9061  45.72  0.0
,
'--- uo2-gd pin      D4  node= 3 (site i=16, j=16)  xsc=  40403
unit     21
  cylinder 14 1  0.5321  60.96  0.0
  cylinder  2 1  0.6134  60.96  0.0
  cuboid   3 1  4p0.8128  60.96  0.0

```

```

unit 22
  cylinder 15 1 0.5321 60.96 0.0
  cylinder 2 1 0.6134 60.96 0.0
  cuboid 3 1 4p0.8128 60.96 0.0
unit 23
  cylinder 14 1 0.5321 60.96 0.0
  cylinder 2 1 0.6134 60.96 0.0
unit 24
  cylinder 3 1 1.6002 60.96 0.0
  cylinder 2 1 1.7018 60.96 0.0
  cuboid 3 1 4p3.2512 60.96 0.0
  hole 23 2.4384 2.4384 0.0
  hole 23 2.4384 0.8128 0.0
  hole 23 2.4384 -0.8128 0.0
  hole 23 2.4384 -2.4384 0.0
  hole 23 0.8128 -2.4384 0.0
  hole 23 -0.8128 -2.4384 0.0
  hole 23 -2.4384 -2.4384 0.0
  hole 23 -2.4384 -0.8128 0.0
  hole 23 -2.4384 0.8128 0.0
  hole 23 -2.4384 2.4384 0.0
  hole 23 -0.8128 2.4384 0.0
  hole 23 0.8128 2.4384 0.0
unit 25
  array 13 3*0
unit 26
  array 14 3*0
unit 27
  array 15 3*0
unit 28
  array 16 3*0
unit 29
  array 17 3*0
unit 30
  array 18 -6.5024 -6.5024 0.0
  cuboid 3 1 4p6.7031 60.96 0.0
  cuboid 2 1 4p6.9061 60.96 0.0
,
'--- uo2-gd pin D4 node= 4 (site i=16, j=16) xsc= 40404
unit 31
  cylinder 16 1 0.5321 45.72 0.0
  cylinder 2 1 0.6134 45.72 0.0
  cuboid 3 1 4p0.8128 45.72 0.0
unit 32
  cylinder 17 1 0.5321 45.72 0.0
  cylinder 2 1 0.6134 45.72 0.0
  cuboid 3 1 4p0.8128 45.72 0.0
unit 33
  cylinder 16 1 0.5321 45.72 0.0
  cylinder 2 1 0.6134 45.72 0.0
unit 34
  cylinder 3 1 1.6002 45.72 0.0
  cylinder 2 1 1.7018 45.72 0.0
  cuboid 3 1 4p3.2512 45.72 0.0
  hole 33 2.4384 2.4384 0.0
  hole 33 2.4384 0.8128 0.0
  hole 33 2.4384 -0.8128 0.0
  hole 33 2.4384 -2.4384 0.0
  hole 33 0.8128 -2.4384 0.0
  hole 33 -0.8128 -2.4384 0.0
  hole 33 -2.4384 -2.4384 0.0
  hole 33 -2.4384 -0.8128 0.0
  hole 33 -2.4384 0.8128 0.0
  hole 33 -2.4384 2.4384 0.0
  hole 33 -0.8128 2.4384 0.0
  hole 33 0.8128 2.4384 0.0
unit 35
  array 19 3*0
unit 36
  array 20 3*0
unit 37
  array 21 3*0

```

```

unit      38
  array   22   3*0
unit      39
  array   23   3*0
unit      40
  array   24   -6.5024 -6.5024  0.0
  cuboid  3 1  4p6.7031  45.72  0.0
  cuboid  2 1  4p6.9061  45.72  0.0
,
'--- uo2-gd pin    D4  node= 5 (site i=16, j=16)  xsc=  40405
unit      41
  cylinder 18 1  0.5321  45.72  0.0
  cylinder 2 1  0.6134  45.72  0.0
  cuboid   3 1  4p0.8128  45.72  0.0
unit      42
  cylinder 19 1  0.5321  45.72  0.0
  cylinder 2 1  0.6134  45.72  0.0
  cuboid   3 1  4p0.8128  45.72  0.0
unit      43
  cylinder 18 1  0.5321  45.72  0.0
  cylinder 2 1  0.6134  45.72  0.0
unit      44
  cylinder 3 1  1.6002   45.72  0.0
  cylinder 2 1  1.7018   45.72  0.0
  cuboid   3 1  4p3.2512  45.72  0.0
  hole     43  2.4384  2.4384  0.0
  hole     43  2.4384  0.8128  0.0
  hole     43  2.4384 -0.8128  0.0
  hole     43  2.4384 -2.4384  0.0
  hole     43  0.8128 -2.4384  0.0
  hole     43 -0.8128 -2.4384  0.0
  hole     43 -2.4384 -2.4384  0.0
  hole     43 -2.4384 -0.8128  0.0
  hole     43 -2.4384  0.8128  0.0
  hole     43 -2.4384  2.4384  0.0
  hole     43 -0.8128  2.4384  0.0
  hole     43  0.8128  2.4384  0.0
unit      45
  array   25   3*0
unit      46
  array   26   3*0
unit      47
  array   27   3*0
unit      48
  array   28   3*0
unit      49
  array   29   3*0
unit      50
  array   30   -6.5024 -6.5024  0.0
  cuboid  3 1  4p6.7031  45.72  0.0
  cuboid  2 1  4p6.9061  45.72  0.0
,
'--- uo2-gd pin    D4  node= 6 (site i=16, j=16)  xsc=  40406
unit      51
  cylinder 20 1  0.5321  45.72  0.0
  cylinder 2 1  0.6134  45.72  0.0
  cuboid   3 1  4p0.8128  45.72  0.0
unit      52
  cylinder 21 1  0.5321  45.72  0.0
  cylinder 2 1  0.6134  45.72  0.0
  cuboid   3 1  4p0.8128  45.72  0.0
unit      53
  cylinder 20 1  0.5321  45.72  0.0
  cylinder 2 1  0.6134  45.72  0.0
unit      54
  cylinder 3 1  1.6002   45.72  0.0
  cylinder 2 1  1.7018   45.72  0.0
  cuboid   3 1  4p3.2512  45.72  0.0
  hole     53  2.4384  2.4384  0.0
  hole     53  2.4384  0.8128  0.0
  hole     53  2.4384 -0.8128  0.0
  hole     53  2.4384 -2.4384  0.0

```



```

hole    53    0.8128 -2.4384  0.0
hole    53   -0.8128 -2.4384  0.0
hole    53   -2.4384 -2.4384  0.0
hole    53   -2.4384 -0.8128  0.0
hole    53   -2.4384  0.8128  0.0
hole    53   -2.4384  2.4384  0.0
hole    53   -0.8128  2.4384  0.0
hole    53    0.8128  2.4384  0.0
unit    55
array   31    3*0
unit    56
array   32    3*0
unit    57
array   33    3*0
unit    58
array   34    3*0
unit    59
array   35    3*0
unit    60
array   36   -6.5024 -6.5024  0.0
cuboid  3 1  4p6.7031  45.72  0.0
cuboid  2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4 node= 7 (site i=16, j=16) xsc= 40407
unit    61
cylinder 22 1  0.5321  45.72  0.0
cylinder 2 1   0.6134  45.72  0.0
cuboid   3 1  4p0.8128  45.72  0.0
unit    62
cylinder 23 1  0.5321  45.72  0.0
cylinder 2 1   0.6134  45.72  0.0
cuboid   3 1  4p0.8128  45.72  0.0
unit    63
cylinder 22 1  0.5321  45.72  0.0
cylinder 2 1   0.6134  45.72  0.0
unit    64
cylinder 3 1  1.6002   45.72  0.0
cylinder 2 1  1.7018   45.72  0.0
cuboid   3 1  4p3.2512  45.72  0.0
hole    63    2.4384  2.4384  0.0
hole    63    2.4384  0.8128  0.0
hole    63    2.4384 -0.8128  0.0
hole    63    2.4384 -2.4384  0.0
hole    63    0.8128 -2.4384  0.0
hole    63   -0.8128 -2.4384  0.0
hole    63   -2.4384 -2.4384  0.0
hole    63   -2.4384 -0.8128  0.0
hole    63   -2.4384  0.8128  0.0
hole    63   -2.4384  2.4384  0.0
hole    63   -0.8128  2.4384  0.0
hole    63    0.8128  2.4384  0.0
unit    65
array   37    3*0
unit    66
array   38    3*0
unit    67
array   39    3*0
unit    68
array   40    3*0
unit    69
array   41    3*0
unit    70
array   42   -6.5024 -6.5024  0.0
cuboid  3 1  4p6.7031  45.72  0.0
cuboid  2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4 node= 8 (site i=16, j=16) xsc= 40408
unit    71
cylinder 24 1  0.5321  45.72  0.0
cylinder 2 1   0.6134  45.72  0.0
cuboid   3 1  4p0.8128  45.72  0.0
unit    72

```

```

cylinder 25 1 0.5321 45.72 0.0
cylinder 2 1 0.6134 45.72 0.0
cuboid 3 1 4p0.8128 45.72 0.0
unit 73
cylinder 24 1 0.5321 45.72 0.0
cylinder 2 1 0.6134 45.72 0.0
unit 74
cylinder 3 1 1.6002 45.72 0.0
cylinder 2 1 1.7018 45.72 0.0
cuboid 3 1 4p3.2512 45.72 0.0
hole 73 2.4384 2.4384 0.0
hole 73 2.4384 0.8128 0.0
hole 73 2.4384 -0.8128 0.0
hole 73 2.4384 -2.4384 0.0
hole 73 0.8128 -2.4384 0.0
hole 73 -0.8128 -2.4384 0.0
hole 73 -2.4384 -2.4384 0.0
hole 73 -2.4384 -0.8128 0.0
hole 73 -2.4384 0.8128 0.0
hole 73 -2.4384 2.4384 0.0
hole 73 -0.8128 2.4384 0.0
hole 73 0.8128 2.4384 0.0
unit 75
array 43 3*0
unit 76
array 44 3*0
unit 77
array 45 3*0
unit 78
array 46 3*0
unit 79
array 47 3*0
unit 80
array 48 -6.5024 -6.5024 0.0
cuboid 3 1 4p6.7031 45.72 0.0
cuboid 2 1 4p6.9061 45.72 0.0
'
'--- uo2-gd pin D4 node= 9 (site i=16, j=16) xsc= 40409
unit 81
cylinder 26 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 82
cylinder 27 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 83
cylinder 26 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
unit 84
cylinder 3 1 1.6002 15.24 0.0
cylinder 2 1 1.7018 15.24 0.0
cuboid 3 1 4p3.2512 15.24 0.0
hole 83 2.4384 2.4384 0.0
hole 83 2.4384 0.8128 0.0
hole 83 2.4384 -0.8128 0.0
hole 83 2.4384 -2.4384 0.0
hole 83 0.8128 -2.4384 0.0
hole 83 -0.8128 -2.4384 0.0
hole 83 -2.4384 -2.4384 0.0
hole 83 -2.4384 -0.8128 0.0
hole 83 -2.4384 0.8128 0.0
hole 83 -2.4384 2.4384 0.0
hole 83 -0.8128 2.4384 0.0
hole 83 0.8128 2.4384 0.0
unit 85
array 49 3*0
unit 86
array 50 3*0
unit 87
array 51 3*0
unit 88

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array 52 3*0
unit 89
array 53 3*0
unit 90
array 54 -6.5024 -6.5024 0.0
cuboid 3 1 4p6.7031 15.24 0.0
cuboid 2 1 4p6.9061 15.24 0.0
'
'--- uo2-gd pin D4 node=10 (site i=16, j=16) xsc= 40410
unit 91
cylinder 28 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 92
cylinder 29 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 93
cylinder 28 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
unit 94
cylinder 3 1 1.6002 15.24 0.0
cylinder 2 1 1.7018 15.24 0.0
cuboid 3 1 4p3.2512 15.24 0.0
hole 93 2.4384 2.4384 0.0
hole 93 2.4384 0.8128 0.0
hole 93 2.4384 -0.8128 0.0
hole 93 2.4384 -2.4384 0.0
hole 93 0.8128 -2.4384 0.0
hole 93 -0.8128 -2.4384 0.0
hole 93 -2.4384 -2.4384 0.0
hole 93 -2.4384 -0.8128 0.0
hole 93 -2.4384 0.8128 0.0
hole 93 -2.4384 2.4384 0.0
hole 93 -0.8128 2.4384 0.0
hole 93 0.8128 2.4384 0.0
unit 95
array 55 3*0
unit 96
array 56 3*0
unit 97
array 57 3*0
unit 98
array 58 3*0
unit 99
array 59 3*0
unit 100
array 60 -6.5024 -6.5024 0.0
cuboid 3 1 4p6.7031 15.24 0.0
cuboid 2 1 4p6.9061 15.24 0.0
unit 101
array 61 3*0
'
'--- uo2-gd pin H18 node= 1 (site i=17, j=16) xsc= 81801
unit 102
cylinder 30 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 103
cylinder 31 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
cuboid 3 1 4p0.8128 15.24 0.0
unit 104
cylinder 30 1 0.5321 15.24 0.0
cylinder 2 1 0.6134 15.24 0.0
unit 105
cylinder 3 1 1.6002 15.24 0.0
cylinder 2 1 1.7018 15.24 0.0
cuboid 3 1 4p3.2512 15.24 0.0
hole 104 2.4384 2.4384 0.0
hole 104 2.4384 0.8128 0.0
hole 104 2.4384 -0.8128 0.0

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```

hole 104 2.4384 -2.4384 0.0
hole 104 0.8128 -2.4384 0.0
hole 104 -0.8128 -2.4384 0.0
hole 104 -2.4384 -2.4384 0.0
hole 104 -2.4384 -0.8128 0.0
hole 104 -2.4384 0.8128 0.0
hole 104 -2.4384 2.4384 0.0
hole 104 -0.8128 2.4384 0.0
hole 104 0.8128 2.4384 0.0
unit 106
array 62 3*0
unit 107
array 63 3*0
unit 108
array 64 3*0
unit 109
array 65 3*0
unit 110
array 66 3*0
unit 111
array 67 -6.5024 -6.5024 0.0
cuboid 3 1 4p6.7031 15.24 0.0
cuboid 2 1 4p6.9061 15.24 0.0
,
.
.
.

(49,636 lines deleted)

.
.
.
.
-----
unit 12000
'--- non-fuelled lattice sites
cuboid 3 1 4p6.9061 381.0 0.0
,
-----inter-assembly water-----
unit 12001
'--- assembly interstitial water (top/bottom)
cuboid 3 1 2p0.7139 2p6.9061 381.0 0.0
,
unit 12002
'--- assembly interstitial water (left/right)
cuboid 3 1 2p6.9061 2p0.7139 381.0 0.0
,
unit 12003
'--- assembly interstitial water (intersection)
cuboid 3 1 4p0.7139 381.0 0.0
,
-----
unit 12004
'--- b4c rod unit --- inserted control rod
cylinder 5 1 0.1753 365.8 0.0
cylinder 4 1 0.2388 365.8 0.0
cuboid 3 1 4p0.244 365.8 0.0
,
unit 12005
'--- b4c rod unit --- critical control blade (20 notches)
cylinder 5 1 0.1753 213.4 0.0
cylinder 4 1 0.2388 213.4 0.0
cuboid 3 1 4p0.244 213.4 0.0
,
-----inserted control blade-----
unit 12009
'--- control blade (top)

```

```

array 8002      -0.244  -4.6203  0.0
cuboid 4 1 2p0.3962  6.9060 -4.7625  365.8 0.0
cuboid 3 1 2p0.7139  2p6.9061  381.0 0.0
,
unit 12010
'--- control blade (bottom)
array 8002      -0.244  -5.6350  0.0
cuboid 4 1 2p0.3962  4.7625 -6.9060  365.8 0.0
cuboid 3 1 2p0.7139  2p6.9061  381.0 0.0
,
unit 12011
'--- control blade (left)
array 8001      -4.6203 -0.244    0.0
cuboid 4 1 6.9060 -4.7625 2p0.3962  365.8 0.0
cuboid 3 1 2p6.9061  2p0.7139  381.0 0.0
,
unit 12012
'--- control blade (right)
array 8001      -5.6350 -0.244    0.0
cuboid 4 1 4.7625 -6.9061 2p0.3962  365.8 0.0
cuboid 3 1 2p6.9061  2p0.7139  381.0 0.0
,
unit 12013
'--- control blade (intersection)
cuboid 4 1 4p0.7139  365.8 0.0
cuboid 3 1 4p0.7139  381.0 0.0
,
'-----critical control blade-----
unit 12022
'--- control blade (top)
array 8004      -0.244  -4.6203  0.0
cuboid 4 1 2p0.3962  6.9060 -4.7625  213.4 0.0
cuboid 3 1 2p0.7139  2p6.9061  381.0 0.0
,
unit 12023
'--- control blade (bottom)
array 8004      -0.244  -5.6350  0.0
cuboid 4 1 2p0.3962  4.7625 -6.9060  213.4 0.0
cuboid 3 1 2p0.7139  2p6.9061  381.0 0.0
,
unit 12024
'--- control blade (left)
array 8003      -4.6203 -0.244    0.0
cuboid 4 1 6.9060 -4.7625 2p0.3962  213.4 0.0
cuboid 3 1 2p6.9061  2p0.7139  381.0 0.0
,
unit 12025
'--- control blade (right)
array 8003      -5.6350 -0.244    0.0
cuboid 4 1 4.7625 -6.9061 2p0.3962  213.4 0.0
cuboid 3 1 2p6.9061  2p0.7139  381.0 0.0
,
unit 12026
'--- control blade (intersection)
cuboid 4 1 4p0.7139  213.4 0.0
cuboid 3 1 4p0.7139  381.0 0.0
,
,
global unit 13000
'--- reactor core
array 9000 3*0.0
reflector 3 1 6r30. 1
,
end geom
read array
ara=  1  nux=2  nuy=2  nuz=1 fill
      1    1    1    1  end fill
ara=  2  nux=2  nuy=4  nuz=1 fill
      1    2    1    1    1    1    1    2  end fill
ara=  3  nux=2  nuy=4  nuz=1 fill
      2    1    1    1    1    1    2    1  end fill

```

```

ara=  4  nux=4  nuy=2  nuz=1  fill
   2    1    1    2    1    1    1    1  end fill
ara=  5  nux=4  nuy=2  nuz=1  fill
   1    1    1    1    2    1    1    2  end fill
ara=  6  nux=3  nuy=3  nuz=1  fill
   5    9    5
   6    4    7
   5    8    5  end fill
ara=  7  nux=2  nuy=2  nuz=1  fill
  11   11   11   11  end fill
ara=  8  nux=2  nuy=4  nuz=1  fill
  11   12   11   11   11   11   11  12  end fill
ara=  9  nux=2  nuy=4  nuz=1  fill
  12   11   11   11   11   11   12   11  end fill
ara= 10  nux=4  nuy=2  nuz=1  fill
  12   11   11   12   11   11   11   11  end fill
ara= 11  nux=4  nuy=2  nuz=1  fill
  11   11   11   11   12   11   11   12  end fill
ara= 12  nux=3  nuy=3  nuz=1  fill
  15   19   15
  16   14   17
  15   18   15  end fill
ara= 13  nux=2  nuy=2  nuz=1  fill
  21   21   21   21  end fill
ara= 14  nux=2  nuy=4  nuz=1  fill
  21   22   21   21   21   21   21  22  end fill
ara= 15  nux=2  nuy=4  nuz=1  fill
  22   21   21   21   21   21   22   21  end fill
ara= 16  nux=4  nuy=2  nuz=1  fill
  22   21   21   22   21   21   21   21  end fill
ara= 17  nux=4  nuy=2  nuz=1  fill
  21   21   21   21   22   21   21   22  end fill
ara= 18  nux=3  nuy=3  nuz=1  fill
  25   29   25
  26   24   27
  25   28   25  end fill
ara= 19  nux=2  nuy=2  nuz=1  fill
  31   31   31   31  end fill
ara= 20  nux=2  nuy=4  nuz=1  fill
  31   32   31   31   31   31   31  32  end fill
ara= 21  nux=2  nuy=4  nuz=1  fill
  32   31   31   31   31   31   32   31  end fill
ara= 22  nux=4  nuy=2  nuz=1  fill
  32   31   31   32   31   31   31   31  end fill
ara= 23  nux=4  nuy=2  nuz=1  fill
  31   31   31   31   32   31   31   32  end fill
ara= 24  nux=3  nuy=3  nuz=1  fill
  35   39   35
  36   34   37
  35   38   35  end fill
ara= 25  nux=2  nuy=2  nuz=1  fill
  41   41   41   41  end fill
ara= 26  nux=2  nuy=4  nuz=1  fill
  41   42   41   41   41   41   41  42  end fill
ara= 27  nux=2  nuy=4  nuz=1  fill
  42   41   41   41   41   41   42   41  end fill
ara= 28  nux=4  nuy=2  nuz=1  fill
  42   41   41   42   41   41   41   41  end fill
ara= 29  nux=4  nuy=2  nuz=1  fill
  41   41   41   41   42   41   41   42  end fill
ara= 30  nux=3  nuy=3  nuz=1  fill
  45   49   45
  46   44   47
  45   48   45  end fill
ara= 31  nux=2  nuy=2  nuz=1  fill
  51   51   51   51  end fill
ara= 32  nux=2  nuy=4  nuz=1  fill
  51   52   51   51   51   51   51  52  end fill
ara= 33  nux=2  nuy=4  nuz=1  fill
  52   51   51   51   51   51   52   51  end fill
ara= 34  nux=4  nuy=2  nuz=1  fill
  52   51   51   52   51   51   51   51  end fill

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```

ara= 35 nux=4 nuy=2 nuz=1 fill
51 51 51 51 52 51 51 52 end fill
ara= 36 nux=3 nuy=3 nuz=1 fill
55 59 55
56 54 57
55 58 55 end fill
ara= 37 nux=2 nuy=2 nuz=1 fill
61 61 61 61 end fill
ara= 38 nux=2 nuy=4 nuz=1 fill
61 62 61 61 61 61 61 62 end fill
ara= 39 nux=2 nuy=4 nuz=1 fill
62 61 61 61 61 61 62 61 end fill
ara= 40 nux=4 nuy=2 nuz=1 fill
62 61 61 62 61 61 61 61 end fill
ara= 41 nux=4 nuy=2 nuz=1 fill
61 61 61 61 62 61 61 62 end fill
ara= 42 nux=3 nuy=3 nuz=1 fill
65 69 65
66 64 67
65 68 65 end fill
ara= 43 nux=2 nuy=2 nuz=1 fill
71 71 71 71 end fill
ara= 44 nux=2 nuy=4 nuz=1 fill
71 72 71 71 71 71 71 72 end fill
ara= 45 nux=2 nuy=4 nuz=1 fill
72 71 71 71 71 71 72 71 end fill
ara= 46 nux=4 nuy=2 nuz=1 fill
72 71 71 72 71 71 71 71 end fill
ara= 47 nux=4 nuy=2 nuz=1 fill
71 71 71 71 72 71 71 72 end fill
ara= 48 nux=3 nuy=3 nuz=1 fill
75 79 75
76 74 77
75 78 75 end fill
ara= 49 nux=2 nuy=2 nuz=1 fill
81 81 81 81 end fill
ara= 50 nux=2 nuy=4 nuz=1 fill
81 82 81 81 81 81 81 82 end fill
ara= 51 nux=2 nuy=4 nuz=1 fill
82 81 81 81 81 81 82 81 end fill
ara= 52 nux=4 nuy=2 nuz=1 fill
82 81 81 82 81 81 81 81 end fill
ara= 53 nux=4 nuy=2 nuz=1 fill
81 81 81 81 82 81 81 82 end fill
ara= 54 nux=3 nuy=3 nuz=1 fill
85 89 85
86 84 87
85 88 85 end fill
ara= 55 nux=2 nuy=2 nuz=1 fill
91 91 91 91 end fill
ara= 56 nux=2 nuy=4 nuz=1 fill
91 92 91 91 91 91 91 92 end fill
ara= 57 nux=2 nuy=4 nuz=1 fill
92 91 91 91 91 91 92 91 end fill
ara= 58 nux=4 nuy=2 nuz=1 fill
92 91 91 92 91 91 91 91 end fill
ara= 59 nux=4 nuy=2 nuz=1 fill
91 91 91 91 92 91 91 92 end fill
ara= 60 nux=3 nuy=3 nuz=1 fill
95 99 95
96 94 97
95 98 95 end fill
ara= 61 nux=1 nuy=1 nuz=10 fill
10 20 30 40 50
60 70 80 90 100 end fill
ara= 62 nux=2 nuy=2 nuz=1 fill
102 102 102 102 end fill
ara= 63 nux=2 nuy=4 nuz=1 fill
102 103 102 102 102 102 102 103 end fill
ara= 64 nux=2 nuy=4 nuz=1 fill
103 102 102 102 102 102 103 102 end fill
ara= 65 nux=4 nuy=2 nuz=1 fill

```

```

    103  102  102  103  102  102  102  102  end fill
ara= 66  nux=4  nuy=2  nuz=1 fill
    102  102  102  102  103  102  102  103  end fill
ara= 67  nux=3  nuy=3  nuz=1 fill
    106  110  106
    107  105  108
    106  109  106  end fill
.
.
.

```

(16,431 lines deleted)

```

.
.
.
'
'--- control rod b4c arrays
' fully inserted
ara=8001 nux=21 nuy=1 nuz=1 fill 21r12004 end fill
ara=8002 nux=1 nuy=21 nuz=1 fill 21r12004 end fill
' critical height rod
ara=8003 nux=21 nuy=1 nuz=1 fill 21r12005 end fill
ara=8004 nux=1 nuy=21 nuz=1 fill 21r12005 end fill
'
'--- reactor core array - layout map
ara=9000 nux=59 nuy=59 nuz=1 fill
12000 12001 12000 12001 12000 12001 12000 12001 12000 12001
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12000
end fill
'
' end lattice description
end array
read bounds xyf=void zfc=void end bounds
read plot pic=mat
xul=0 yul=456.0 zul=200.0 xlr=456.0 ylr=0 zlr=200.0
uax=1 vdn=-1 nax=300 end plot
end data
end

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