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Analysis of Fresh Fuel Critical Experiments Appropriate for Burnup Credit Validation

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Computational Physics and Engineering Division

**ANALYSIS OF FRESH FUEL CRITICAL EXPERIMENTS
APPROPRIATE FOR BURNUP CREDIT VALIDATION**

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Manuscript Completed: March 1994

Date Published: October 1995

Prepared for
Sandia National Laboratories
under subcontract AD-4072 with Oak Ridge National Laboratory

Prepared by the
OAK RIDGE NATIONAL LABORATORY
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

	<u>Page</u>
LIST OF FIGURES	iv
LIST OF TABLES	v
ABSTRACT	vii
ACKNOWLEDGMENTS	ix
1. INTRODUCTION	1
2. DESCRIPTION OF FRESH FUEL CRITICAL EXPERIMENTS	3
2.1 UO ₂ CRITICAL EXPERIMENTS FOR LWR FUEL IN CASK GEOMETRIES	3
2.2 GADOLINIUM CRITICAL EXPERIMENTS	4
2.3 LWR MOX FUEL CRITICAL EXPERIMENTS	4
3. CRITICALITY CALCULATIONS BASED ON FRESH FUEL EXPERIMENTS	8
3.1 CRITICALITY SEQUENCES OF THE SCALE-4 CODE SYSTEM	8
3.2 RESULTS OF CRITICALITY CALCULATIONS USING SCALE-4	9
3.2.1 Criticality Calculations Based on LWR-Type UO ₂ Experiments	9
3.2.2 Criticality Calculations Based on LWR-Type UO ₂ Experiments Containing Gadolinium	9
3.2.3 Criticality Calculations Based on LWR-Type Mixed-Oxide Experiments	12
3.2.4 Combined Results for all Critical Experiments	15
4 BIAS AND UNCERTAINTY FROM CRITICAL EXPERIMENTS	17
4.1 ESTABLISHMENT OF AN UPPER SAFETY LIMIT FOR SUBCRITICALITY	17
4.2 METHODS FOR DETERMINATION OF AN UPPER SAFETY LIMIT	19
4.2.1 USL Method 1: Confidence Band with Administrative Margin	19
4.2.2 USL Method 2: Single-Sided Uniform Width Closed Interval Approach	21
4.2.3 USL Method 3: Worst Case with Administrative Margin	22
4.2.4 Application of Upper Safety Limit Methods	23
4.3 CALCULATION OF UPPER SAFETY LIMITS	23
5. CONCLUSIONS	29
6. REFERENCES	30
APPENDIX A. PHYSICAL DESCRIPTION OF CRITICAL EXPERIMENTS	33
APPENDIX B. SCALE-4 INPUT LISTINGS FOR THE 34 FRESH FUEL CRITICALS ..	79
APPENDIX C. RESULTS OF ADDITIONAL CRITICAL CALCULATIONS	159

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1	k_{eff} vs AEG for MOX critical experiments 14
2	k_{eff} vs AEG for combined fresh fuel criticals 16
3	Confidence band and safety margin applied to a set of criticality calculations 20
4	USLs computed by Methods 1, 2, and 3 for the 34 fresh fuel criticals 25
5	Method 1 USL as a function of combinations of critical calculations 28
A.1	Description of 4.31 wt % ^{235}U enriched UO_2 fuel rods used in experiments ft214r . . . 34
A.2	Experiment ft214r 35
A.3	Experiment 214v3 36
A.4	Experimental assembly elevations for ft214r and ft214v3 37
A.5	Description of 2.35 wt % ^{235}U enriched UO_2 fuel rods used in absorber plate experiments 39
A.6	Experimental setup of the absorber plate experiments and the shielding wall experiments 40
A.7	Assembled depleted uranium wall for depleted uranium shielding wall experiment . . . 42
A.8	Assembled lead wall for lead shielding wall experiment 43
A.9	Assembled steel wall for steel shielding wall experiment 44
A.10	Experimental setup for soluble boron experiments 46
A.11	Dimensions of 2.46% enriched UO_2 fuel rod in experiment baw1484a 48
A.12	Experiment baw1484a loading diagram 49
A.13	Experiment baw1484a vertical dimensions 50
A.14	Experiment bnw1810a core loading diagram 51
A.15	Axial core structure dimensions for EPRI-196 UO_2 experiments 54
A.16	Dimensions of "eggcrate" lattice grids for EPRI-196 UO_2 and MOX experiments 55
A.17	EPRI 0.615-in.-pitch UO_2 core 56
A.18	EPRI 0.870-in.-pitch UO_2 core 57
A.19	Axial view of Saxton experimental setup 59
A.20	Gadolinium experiment bnw1810b quarter-core (symmetric) loading diagram 62
A.21	Gadolinium experiment bnw1810c quarter-core (symmetric) loading diagram 63
A.22	Description of MOX fuel rods for EPRI experiments 65
A.23	UO_2 -2 wt % PuO_2 "eggcrate" core structure dimensions for EPRI experiments 67
A.24	Unborated EPRI 0.70-in. UO_2 -2 wt % PuO_2 core 68
A.25	Borated EPRI 0.70-in. UO_2 -2 wt % PuO_2 core 69
A.26	Unborated EPRI 0.87-in. UO_2 -2 wt % PuO_2 core 70
A.27	Borated EPRI 0.87-in. UO_2 -2 wt % PuO_2 core 71
A.28	Unborated EPRI 0.99-in. UO_2 -2 wt % PuO_2 core 72
A.29	Borated EPRI 0.99-in. UO_2 -2 wt % PuO_2 core 73
A.30	Fuel loading for experiment pnl4976 76
A.31	Assembly elevations for experiment pnl4976 77

LIST OF TABLES

Table		Page
1	UO ₂ critical experiments for LWR fuel in cask geometries	4
2	Critical experiments with UO ₂ and gadolinium	6
3	Critical experiments with MOX LWR fuel	6
4	Criticality calculations for validation of UO ₂ in LWR fuel cask geometries	10
5	Thermal range energy structure for the SCALE-4 27-group burnup library	11
6	Criticality calculations for B&W-1810 gadolinium experiments	11
7	Criticality calculations for validation of LWR-type MOX experiments	13
8	Summary for results for sets of criticality calculations	16
9	Parameters used in USL calculation for fresh fuel criticals	24
10	Summary of USL calculations for various sets of data	27
A.1	Description of neutron flux trap plates in experiments ft214r and ft214v3	33
A.2	Boral™ composition in experiment p2438x17	41
A.3	Critical separation between assemblies for shielding wall experiments	45
A.4	Critical array dimensions of soluble boron experiments	47
A.5	Properties of 2.46% enriched UO ₂ fuel rods in experiment baw1484a	47
A.6	Certified chemical analysis of B ₄ C for experiment baw14894a	49
A.7	Physical properties of 4.02 wt % enriched UO ₂ fuel rods in B&W-1810 experiments .	53
A.8	Experiment description for bnw1810a	53
A.9	EPRI-196 UO ₂ critical experiment descriptions	58
A.10	Saxton UO ₂ fuel rod specifications	58
A.11	Saxton UO ₂ critical experiment descriptions	58
A.12	Gadolinium experiment descriptions	61
A.13	Physical properties of 1.944 wt % enriched UO ₂ -Gd ₂ O ₃ fuel rods for gadolinium experiments	64
A.14	MOX fuel compositions in EPRI experiments	66
A.15	Saxton MOX critical experiment descriptions	74
A.16	Saxton MOX fuel rod specifications	74
A.17	Plutonium composition for experiment pnl4976	75
C.1	Results of reactor critical calculations	157
C.2	Results of additional fresh fuel calculations	158

ACKNOWLEDGMENTS

The authors wish to express their appreciation to several individuals who contributed their ideas and efforts in the analyses described herein. Particular thanks go to M. C. Brady of Sandia National Laboratories, who participated in the early selection of fresh fuel experiments and who provided technical oversight for most of the duration of this work; C. V. Parks of Oak Ridge National Laboratory, who provided guidance and reviewed and commented on the draft report; H. Taniuchi of Kobe Steel, Ltd., Kobe, Japan, and S. K. Martin of Oak Ridge National Laboratory, who helped perform many of the calculations; and S. R. Bierman of Pacific Northwest Laboratories, who suggested many of the fresh fuel critical experiments that were analyzed. The authors also wish to acknowledge L. F. Norris for her continuing efforts in the text editing, formatting, and release of this report.

This work was sponsored as part of the Cask System Development Program within the U.S. Department of Energy's Office of Civilian Radioactive Waste Management.

This report was prepared by the Oak Ridge National Laboratory for Sandia National Laboratories in accordance with the technical and quality assurance requirements specified in Sandia subcontract AD-4072. All work described in the subcontract Statement of Work was conducted under the Sandia Burnup Credit QA Program and implementing procedures.

ABSTRACT

The ANS/ANS-8.1 standard requires that calculational methods used in determining criticality safety limits for applications outside reactors be validated by comparison with appropriate critical experiments. This report provides a detailed description of 34 fresh fuel critical experiments and their analyses using the SCALE-4.2 code system and the 27-group ENDF/B-IV cross-section library. The 34 critical experiments were selected based on geometry, material, and neutron interaction characteristics that are applicable to a transportation cask loaded with pressurized-water-reactor spent fuel. These 34 experiments are a representative subset of a much larger data base of low-enriched uranium and mixed-oxide critical experiments. A statistical approach is described and used to obtain an estimate of the bias and uncertainty in the calculational methods and to predict a confidence limit for a calculated neutron multiplication factor. The SCALE-4.2 results for a superset of approximately 100 criticals are included in uncertainty analyses, but descriptions of the individual criticals are not included.

1. INTRODUCTION

The ANSI/ANS-8.1 standard, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors,"¹ requires that a calculational method used in determining criticality safety limits for a system be validated by comparison with critical experiments that are applicable to the system. The Standard does not define nor discuss what constitutes an "area of applicability," but it does provide for extension beyond the area of applicability if trends in the bias are considered. In identifying the area of applicability for a validation, the following issues should be addressed:

Code Similarity – The computer codes selected, the modeling options employed in the codes, and the cross-section data and processing techniques that are used must be consistent in both the validation analyses and the problem analyses.

Physical System Similarity – The fissile material, the geometry, the moderator, the material compositions, and the neutron absorbers in the critical experiments used for the validation determine the area of applicability for other physical systems to be analyzed.

Similar Particle Interaction Characteristics – Justification that the particle interaction characteristics are similar between the validation analyses and the problem of interest can be difficult to demonstrate. The average energy causing fission, the ratio of thermal fissions and absorptions to total fissions and absorptions, and the ratio of moderator to fissile material (i.e., H/X) are examples of quantities used to establish similarity and justify inclusion in the area of applicability.

The purpose of this report is to describe and analyze a set of 34 fresh fuel critical experiments that represent geometry, material, and neutron interaction characteristics applicable to a transportation cask loaded with pressurized-water-reactor (PWR) spent fuel. These 34 experiments are only a representative subset of a much larger data base of low-enriched uranium and mixed-oxide (MOX) critical experiments. The 19 UO₂ critical experiments included in the set of 34 were selected to span the range of enrichment, materials, and geometry typical of transport configurations. Thirteen MOX critical experiments were selected to provide a basis for demonstrating that the calculational method is capable of analyzing pin-lattice configurations with mixtures of uranium and plutonium oxide. Because gadolinium is an important fission product in spent fuel after several years of cooling, two experiments with gadolinium included in the pin-lattice were selected to demonstrate adequate cross-section data.

The 34 criticals were analyzed using the SCALE-4.2 code system² and the 27-group ENDF/B-IV cross-section library. SCALE is a well-established code system that is widely used in away-from-reactor (AFR) applications and has served as the primary computational tool used by the U.S. Department of Energy (DOE) in technical studies related to burnup credit.³ Although the SCALE models and results for the 34 critical experiments are emphasized in the report, the description of the 34 criticals should be sufficient for analysis by any computational tool that is appropriate for criticality safety analyses.

Another purpose of this report is to describe and to demonstrate the application of a statistical approach to obtain an estimate of the bias and uncertainty in the calculational method based on the performance of the computational tool in predicting the neutron multiplication factor, k_{eff} . A method that uses the bias and uncertainty information to estimate a confidence limit for subsequent calculations of k_{eff} is also described. Trends in k_{eff} and an estimation of the bias, uncertainty, and confidence limit are done with the subset of 34 critical experiments and a much larger set of 100 fresh

fuel critical experiments. These additional 66 critical measurements were analyzed with SCALE-4.2 and used in the statistical studies, but detailed descriptions of each critical are not provided.

Note that even with the 100 fresh fuel criticals, the fission products typically present in spent fuel are not included in any measured critical analyzed in this report. Thus in terms of its applicability to burnup credit, validation results with fresh fuel critical experiments must be used in conjunction with other work that will account for aspects of spent fuel criticality analysis not specifically addressed here.

Section 2 of this report describes the 34 fresh fuel critical experiments used in the validation process. Section 3 describes the SCALE system used in the analyses of these experiments and the results obtained based on the SCALE-4.2 models. Trends in the calculated results and correlations between key parameters are also discussed. In Sect. 4, a statistical approach is described for the determination of bias and uncertainty, and for the combination of these parameters for the determination of an upper safety limit that ensures subcriticality with a given confidence level for future calculations.

2. DESCRIPTION OF FRESH FUEL CRITICAL EXPERIMENTS

This section provides a description of a select set of 34 water-moderated, lattice-type critical experiments performed with low-enriched uranium and MOX fuel rods. This set of fresh fuel critical experiments was selected from a literature survey that sought to identify a representative sampling of experiments that represent the material, geometric, and neutronic characteristics in spent fuel casks.⁴ The presence of plutonium and gadolinium (as a fission product) in spent fuel led to the decision to add criticals with gadolinium in the fuel and criticals with MOX (UO₂-PuO₂) fuel rods. The following subsections describe these critical experiments, grouped in terms of the following sets:

1. UO₂ critical experiments with geometric features of spent fuel transportation and storage casks (19);
2. UO₂ critical experiments with gadolinium in the fuel (2); and
3. MOX critical experiments containing low-enriched UO₂-PuO₂ fuel rods (13).

Section 3 will describe the assumptions made and the results obtained for calculational models based on these experiments

2.1 UO₂ CRITICAL EXPERIMENTS FOR LWR FUEL IN CASK GEOMETRIES

Nineteen LWR-type fuel lattice experiments⁵⁻¹³ were selected as the most representative of typical low-enrichment UO₂ LWR assemblies. These experiments cover a wide range of conditions and allow for the study of six different aspects of criticality related to fuel storage in transportation and storage casks and the application of burnup credit:

1. neutron interaction among LWR-type fuel assemblies;
2. effect of neutron absorber materials between fuel assemblies;
3. effect of commonly used cask shielding materials;
4. neutron spectra shift or relative neutron moderation caused by dissolved boron;
5. effect of neutron flux traps between fuel assemblies; and
6. effect of voiding on the performance of neutron flux traps.

(Although currently no burnup credit cask designs use flux traps, such experiments provide relevant information on neutron interaction among fuel assemblies separated by water.) These experiments contain enrichments ranging from 2.35 to 5.74 wt % ²³⁵U; absorbers such as boron, Boral, and stainless steel; and reflectors of uranium, lead, and steel. Fuel pin pitches ranging from 1.42 to 2.21 cm are represented, with moderator-to-fuel volume ratios ranging from 1.09 to 5.067. Table 1 provides a summary of the key aspects of each experiment. The case designation is the name assigned to the criticality model for each experiment, and is used as a convenient reference name for each experiment. The specific designs of the experiments are described in detail in Appendix A.

Table 1. UO₂ critical experiments for LWR fuel in cask geometries

Case No.	Case designation	Enrichment (wt % ²³⁵ U)	Description	Lattice pitch (cm)	Lattice water/fuel volume ratio	Ref.
1	ft214r	4.31	Flux traps, no voids	1.89	1.60	5
2	ft214v3	4.31	Flux traps with voids	1.89	1.60	5
3	p2438x05	2.35	No absorber plates	2.03	2.92	6
4	p2438x17	2.35	Boral absorber plates	2.03	2.92	6
5	p2438x24	2.35	Aluminum absorber plates	2.03	2.92	6
6	p2438x28	2.35	Stainless steel absorber plates	2.03	2.92	6
7	p392614a	4.31	Lead reflector	1.89	1.60	7
8	p3926u4a	4.31	Uranium reflector	1.89	1.60	7
9	p3602s4	4.31	Steel reflector, borated steel absorber plates	1.89	1.60	8
10	p4267a	4.31	No soluble boron	1.89	1.59	9
11	p4267b	4.31	2550 ppm soluble boron	1.89	1.59	9
12	p4267c	4.31	No soluble boron	1.72	1.09	9
13	p4267d	4.31	2550 ppm soluble boron	1.72	1.09	9
14	baw1484a	2.46	Core IV - 84 B4C pins	1.64	1.84	10
15	bnw1810a	4.02, 2.46	UO ₂ exp. for comparison with UO ₂ + Gd exps.	1.64	1.62	11
16	e196u6n	2.35	UO ₂ exp. for comparison with EPRI MOX exps.	1.56	1.20	12
17	e196u87c	2.35	UO ₂ exp. for comparison with EPRI MOX exps.	2.21	3.69	12
18	saxu56	5.74	UO ₂ exp. for comparison with Saxton MOX exps.	1.42	1.93	13
19	saxu792	5.74	UO ₂ exp. for comparison with Saxton MOX exps.	2.01	5.07	13

2.2 GADOLINIUM CRITICAL EXPERIMENTS

Gadolinium is a strong neutron absorber and a significant isotope with respect to reactivity in spent LWR fuel that has undergone several years of cooling; it is produced by the radioactive decay of fission product ^{155}Eu , which has a 4.7-year half-life. Two $\text{UO}_2\text{-Gd}_2\text{O}_3$ experiments¹¹ were modeled to examine the ability of SCALE-4 and the 27-group ENDF/B-IV burnup library to represent gadolinium absorption in LWR fuel. In addition, **bnw1810a** (case No. 15), which was based on the same lattice configuration but contained no gadolinium, was used as a reference for comparison with the remaining gadolinium-bearing experiments; this experiment is included in the set of fresh fuel UO_2 experiments (see Table 1). The two gadolinium-bearing experiments included a small number of $\text{UO}_2\text{-Gd}_2\text{O}_3$ fuel rods in selected patterns among fresh UO_2 fuel rods. Criticality was achieved by adjusting the soluble boron concentration. Table 2 provides a summary of the key aspects of each $\text{UO}_2\text{-Gd}_2\text{O}_3$ experiment. As with the UO_2 -only experiments, the specific designs of the gadolinium experiments are described in Appendix A.

2.3 LWR MOX FUEL CRITICAL EXPERIMENTS

Spent fuel contains many actinides and fission products not present in fresh fuel. From a criticality safety perspective, the most significant actinide other than uranium present in spent fuel is plutonium, which has fissile isotopes (^{239}Pu and ^{241}Pu) as well as one major neutron-absorbing isotope (^{240}Pu). Therefore, 13 MOX critical experiments¹²⁻¹⁴ were selected for validating a methodology for spent fuel containing PuO_2 and UO_2 . These LWR-type MOX fuel lattice experiments, summarized in Table 3, were included to demonstrate the capability of the SCALE-4 27-group burnup library to treat the mixture of uranium and plutonium isotopes in a fuel lattice, as would be found in spent fuel assemblies. The experiments contained varying amounts of soluble boron, triangular and square-lattice arrangements, with varying pitches. One experiment had a lattice comprised of a pattern of alternating UO_2 and MOX rods, in an attempt to simulate the overall plutonium content of a highly burned LWR reactor core (as opposed to a highly burned assembly, which would possess a higher relative plutonium content). All MOX rods consisted of natural uranium in oxide form, mixed with ~90% ^{239}Pu -enriched plutonium oxide, in PuO_2 fractions of 2 or 6.6 wt %. Four UO_2 experiments listed in Table 1 (cases 16-19) were performed in conjunction with corresponding sets of MOX experiments to provide similar geometric configurations for better resolution of plutonium effects. Table 3 provides a summary of the key aspects of each MOX experiment. The specific designs of the MOX experiments are described in Appendix A.

2.4 QUALIFICATION OF CRITICAL EXPERIMENTS

The 34 critical experiments described in this report are recognized benchmark standard experiments performed specifically for calculational benchmarking purposes. Each experiment has been formally documented in reports issued by the organizations conducting each experiment. These reports were reviewed prior to publication and have subsequently been reviewed by a large number of benchmark analysts. The number of calculations performed at the time of the experiments and in benchmark calculations serve as a confirmation of the accuracy of the experimental measurements.

Table 2. Critical experiments with UO₂ and gadolinium

Case No.	Case designation	Enrichment (wt % ²³⁵ U)	Description	Lattice pitch (cm)	Lattice water/fuel volume ratio	Ref.
20	bnw1810b	4.02, 2.46	12 Gd fuel rods in inner zone	1.64	1.62	11
21	bnw1810c	4.02, 2.46	16 Gd fuel rods in inner zone	1.64	1.62	11

Table 3. Critical experiments with MOX LWR fuel

Case No.	Case designation	Enrichment (wt % ²³⁵ U/ wt % ²³⁹ Pu)	Description	Lattice pitch (cm)	Lattice water/fuel volume ratio	Ref.
22	epri70un	0.72/91.8	0 ppm soluble boron, 2 wt % PuO ₂	1.78	1.20	12
23	epri70b	0.72/91.8	681 ppm soluble boron, 2 wt % PuO ₂	1.78	1.20	12
24	epri87un	0.72/91.8	0 ppm soluble boron, 2 wt % PuO ₂	2.21	1.53	12
25	epri87b	0.72/91.8	1090 ppm soluble boron, 2 wt % PuO ₂	2.21	1.53	12
26	epri99un	0.72/91.8	0 ppm soluble boron, 2 wt % PuO ₂	2.51	3.64	12
27	epri99b	0.72/91.8	767 ppm soluble boron, 2 wt % PuO ₂	2.51	3.64	12
28	saxton52	0.72/90.5	Unborated, 22 × 23 lattice, 6.6 wt % PuO ₂	1.32	1.68	13
29	saxton56	0.72/90.5	Unborated, 19 × 19 lattice, 6.6 wt % PuO ₂	1.42	2.17	13
30	saxton56b	0.72/90.5	337 ppm boron, 21 × 21 lattice, 6.6 wt % PuO ₂	1.42	2.17	13
31	saxtn735	0.72/90.5	Unborated, 13 × 13 lattice, 6.6 wt % PuO ₂	1.87	4.70	13
32	saxtn792	0.72/90.5	Unborated, 12 × 12 lattice, 6.6 wt % PuO ₂	2.01	5.67	13
33	saxtn104	0.72/90.5	Unborated, 11 × 11 lattice, 6.6 wt % PuO ₂	2.64	10.75	13
34	pnl4976	MOX: 0.72/91.8 UO ₂ : 4.31/0.0	MOX and UO ₂ rods in uniform pattern, triangular lattice, 2 wt % PuO ₂ in MOX pins	1.60	0.49	14

Many of these experiments have been accepted for benchmarking purposes in numerous fresh-fuel storage and transportation package design and licensing applications. In addition, the use of a comprehensive set of experimental data from a number of independent facilities provides a high degree of confidence that potential inaccuracies, errors, or omissions in any experiment will be accounted for in the determination of calculational bias described later in this report.

3. CRITICALITY CALCULATIONS BASED ON FRESH FUEL EXPERIMENTS

In order to demonstrate the applicability of the SCALE-4.2 system for the range of conditions spanned by the fresh fuel experiments described in the previous section, computational models have been developed based on each experimental configuration. In all the models, approximations were applied where appropriate. Polypropylene or acrylic-base plates and lattice plates were not modeled because their neutronic characteristics are similar to water. Likewise, other structural components such as control and safety rod guides, support angles and channels, and tanks were neglected because the material (e.g., aluminum) was virtually invisible to neutrons or the component was positioned near the periphery of the experiment and had no significant impact on the system k_{eff} . Chemical elements that appeared in materials in trace amounts were also considered negligible in the models. For reference, the SCALE-4.2 input files for these experiments are included in Appendix B.

The following subsection describes the sequences and modules of the SCALE-4.2 system used in the analysis of these computational models. This description is followed by a discussion of the results of calculations performed using these models, in terms of the three classes of experiments described in Sect. 2.

3.1 CRITICALITY SEQUENCES OF THE SCALE-4 CODE SYSTEM

SCALE is a well-established code system that has been widely used in AFR applications for criticality safety analyses via its CSAS analysis sequences.¹⁵ In this work, CSAS sequences CSASN, CSAS25, and CSAS2X are used in the criticality models. All of the sequences invoke a standardized procedure to provide appropriate cross sections for use in calculations. Each procedure begins with the SCALE Material Information Processor,¹⁶ which generates material number densities and related information, prepares geometry data for resonance self-shielding and flux-weighting cell calculations and creates data input files for the cross-section processing codes. The BONAMI¹⁷ and NITAWL-II¹⁸ codes are then used to perform problem-specific (resonance-corrected) cross-section processing. BONAMI applies the Bondarenko method of resonance self-shielding for nuclides that have Bondarenko data included in the cross-section library and creates a formatted library for use by subsequent modules. (Note: The 27-group burnup library does not contain unresolved resonance data; hence BONAMI performs only cross-section formatting procedures with this library.) NITAWL-II performs Nordheim resonance self-shielding corrections for nuclides that have resonance parameters included with their cross-section data. The CSASN sequence terminates at this point; the cross-section library produced from this calculation can be used as is or combined with other cross-section libraries and used in a subsequent standalone criticality calculation. Criticality (k_{eff}) calculations are performed via three-dimensional (3-D) Monte Carlo calculations using KENO V.a.¹⁹ All KENO V.a calculations were performed with at least 600 neutrons per generation and a minimum of 240,000 histories. The CSAS25 sequence automatically invokes KENO V.a after resonance processing is completed. If necessary, the CSAS2X sequence is used in which the 1-D discrete-ordinates code XSDRNPM²⁰ is invoked to perform cell-weighting of cross sections prior to the criticality calculation. Cross sections used in all calculations were obtained from the SCALE 27-group burnup library, a hybrid library originally developed for depletion analyses. This cross-section library contains ENDF/B-IV (actinide) and ENDF/B-V (fission product) data for isotopes important

in spent fuel from commercial reactor fuel designs. SCALE calculations described in this report were performed using SCALE-4.2 on an IBM RS/6000 workstation.

3.2 RESULTS OF CRITICALITY CALCULATIONS USING SCALE-4

The following subsections describe the results for SCALE-4 models based on each of the three sets of critical experiments discussed earlier. Each criticality model is identified by a name corresponding to the case designations given earlier in Tables 1 through 3 for the fresh fuel experiments.

3.2.1 Criticality Calculations Based on LWR-Type UO_2 Experiments

Results of the criticality calculations for the 19 UO_2 -only critical experiments are given in Table 4. In addition to the calculated values of effective multiplication factors and their associated standard deviations, this table includes the average energy group in which fission occurs, which can be used to assess the amount of neutron thermalization associated with a given configuration. Table 5 provides a listing of the energy boundaries, energy range, and average energy for each of the thermal (≥ 3.05 eV) energy groups in the 27-group burnup library, so that one can determine the energy range represented by each average energy group (AEG) value. Note that the AEG is a simple spectrum indicator, as it characterizes the average energy group, and therefore the average neutron energy at which fission occurs. A smaller AEG value represents a higher energy system than a larger AEG (lower energy) value.

The calculational results for this set of criticals are within 1.4% of the known critical condition, with the nominal computed value of k_{eff} ranging from 0.9861 to 1.0000, and a mean value for k_{eff} of 0.9941 ± 0.0036 . These values indicate an average bias of roughly -0.6% in the calculation of k_{eff} over all UO_2 cases. Statistical analyses of k_{eff} vs various independent variables [i.e., enrichment, moderator/ fuel ratios, AEG in which fission occurs, boron concentration, and reference number (see last column of Tables 1 through 3)] indicate a strong correlation between the AEG and the moderator/fuel ratio, and to a lesser extent between AEG and pitch. This correlation is not unexpected, since increased pitch results in an increased moderator/fuel ratio, which in turn would result in a better-moderated and therefore more thermal system. In addition, cases **p3926l4a**, **p3926u4a**, and **p3602s4**, which all utilized reflecting walls, trended toward a higher value of k_{eff} than other cases with no reflection. No other significant correlations were noted.

In general, the 27-group burnup library shows a trend for increasing k_{eff} with increasing AEG. This trend is not observed here, probably due to the relatively small range of AEGs spanned by these experiments. As will be shown later, addition of more UO_2 -only criticals does illustrate this trend.

3.2.2 Criticality Calculations Based on LWR-Type UO_2 Experiments Containing Gadolinium

The **bnw1810** series of experiments used multiple fuel rod types in a single core. Because the SCALE CSAS25 sequence only allows cross-section processing for only one fuel rod cell type per problem, Dancoff factors and resonance data were calculated using CSASN and explicitly specified in the CSAS25 calculation for the two fuel mixtures that were not specified as the fuel

Table 4. Criticality calculations for validation of UO_2 in LWR fuel cask geometries

Case No.	Case designation	k_{eff}	$\pm\sigma$	AEG in which fission occurs
1	ft214r	0.9971	0.0016	21.66
2	ft214v3	0.9924	0.0011	21.64
3	p2438x05	0.9912	0.0014	23.58
4	p2438x17	0.9927	0.0010	23.55
5	p2438x24	0.9924	0.0013	23.58
6	p2438x28	0.9921	0.0014	23.56
7	p392614a	1.0000	0.0015	21.96
8	p3926u4a	0.9994	0.0014	21.31
9	p3602s4	0.9970	0.0016	21.93
10	p4267a	0.9952	0.0011	22.05
11	p4267b	0.9991	0.0012	20.91
12	p4267c	0.9940	0.0011	21.15
13	p4267d	0.9904	0.0013	19.98
14	baw1484a	0.9912	0.0010	22.63
15	bnw1810a	0.9953	0.0011	21.68
16	e196u6n	0.9904	0.0014	22.21
17	e196u87c	0.9946	0.0013	23.77
18	saxu56	0.9861	0.0016	21.90
19	saxu792	0.9972	0.0011	23.42

Table 5. Thermal range energy structure for the SCALE-4 27-group burnup library^a

27BURNUPLIB thermal group No.	Upper energy boundary (eV)	Lower energy boundary (eV)	Group average energy (eV)	Group energy width (eV)
15	3.05	1.77	2.41	1.28
16	1.77	1.30	1.54	1.64
17	1.30	1.13	1.22	0.17
18	1.13	1.00	1.07	0.13
19	1.00	0.800	0.90	0.20
20	0.800	0.400	0.600	0.400
21	0.400	0.325	0.363	0.075
22	0.325	0.225	0.275	0.100
23	0.225	0.100	0.163	0.125
24	0.100	0.0500	0.075	0.0500
25	0.0500	0.0300	0.0400	0.0200
26	0.0300	0.0100	0.0200	0.0200
27	0.0100	0.0000100	0.00501	0.00999

^a See ref. 2.

mixture on the lattice cell description card. The 4.02 wt % UO₂ fuel in the inner zone was specified as the fuel mixture on the lattice cell card for each of these calculations.

The SCALE-4 results for the two gadolinium criticals are presented in Table 6. The first row of the table, in italics, contains the results from case **bnw1810a** for the purposes of comparison. This case was based on the same experimental configuration but contained no gadolinium. Results show that cases both with and without gadolinium are statistically consistent (i.e., grouped within 2 σ of

Table 6. Criticality calculations for B&W-1810 gadolinium experiments

Case No.	Case designation	k _{eff}	$\pm\sigma$	Average energy group (AEG) in which fission occurs
<i>15^a</i>	<i>bnw1810a</i>	<i>0.9953</i>	<i>0.0010</i>	<i>21.68</i>
20	bnw1810b	0.9919	0.0010	21.77
21	bnw1810c	0.9949	0.0010	21.82

^a UO₂-only experiment, included for comparison purposes.

their average). For cases 20 and 21, the average value of k_{eff} is 0.9934 ± 0.0021 , which is consistent with the average result for the 19 UO_2 -only cases. These calculations indicate that SCALE-4 can accurately predict the reactivity effect of gadolinium absorption in LWR fuel.

3.2.3 Criticality Calculations Based on LWR-Type MOX Experiments

Results of the criticality calculations for the 13 MOX critical experiments (cases 22–34) are given in Table 7, along with the results of similar configuration experiments (cases 16–19, in italics). Nominal k_{eff} values for the 13 MOX experiments range from 0.9869 to 1.0077 and have a mean value of 1.0017 ± 0.0059 . The EPRI MOX criticals have an average value of k_{eff} of 1.0028 ± 0.0058 , compared with 0.9925 ± 0.0030 for the corresponding UO_2 -only experiments. Similarly, the Saxton MOX criticals have an average value of k_{eff} of 1.0031 ± 0.0016 , compared with 0.9917 ± 0.0078 for the corresponding UO_2 -only experiments. Therefore, k_{eff} values for the plutonium-bearing MOX experiments are approximately 1% greater than the results for UO_2 cases.

Statistical analyses were performed for relationships between k_{eff} and other independent parameters. As with the UO_2 LWR criticals, a positive correlation is seen between the AEG and the moderator/fuel ratio, and between AEG and pitch, reflecting the effect of enhanced moderation in the larger lattice spacings. In addition, a strong correlation is observed between the AEG and k_{eff} , as illustrated in Fig. 1; no such trend was observed in the UO_2 critical experiments. Note that a bias observed for plutonium-bearing criticals is not limited to the SCALE 27-group burnup library. Similar trends have been identified in other work using other cross-section libraries; hence the bias appears to be inherent in current plutonium cross-section data.^{21,22}

The calculated k_{eff} value for the simulated burnup experiment, case **pnl4976**, is nearly 1% lower than any other MOX case. This difference has two possible explanations: First, the water/fuel volume ratio (and hence the AEG) is much smaller than the other MOX experiments, which is consistent with the trend observed previously. Second, the alternating lattice of PuO_2 - UO_2 and UO_2 fuel rods was difficult to model in the SCALE cross-section resonance processing code NITAWL-II, and may have introduced errors in resonance-region cross sections. To compound this error, this critical was undermoderated and therefore operated in the upper thermal energies, which gave increased weight to resonance energies.

Because NITAWL-II does not consider 2-D effects in the processing of the overlapping resonances of Pu and U, three separate cases were required to generate the problem-dependent cross sections:

1. A CSASN case modeled an infinite array of the MOX rods at the experimental triangular pitch of 1.598 cm. The cross sections for the natural UO_2 and the Zircaloy clad of the MOX rods were obtained from this case.

Table 7. Criticality calculations for validation of LWR-type MOX experiments

Case No.	Case designation	k_{eff}	$\pm\sigma$	AEG in which fission occurs
16	<i>e196u6n^a</i>	0.9904	0.0014	22.21
17	<i>e196u87c^a</i>	0.9946	0.0013	23.77
22	epri70un	0.9956	0.0013	21.10
23	epri70b	0.9955	0.0014	20.66
24	epri87un	1.0037	0.0010	22.62
25	epri87b	1.0071	0.0012	22.07
26	epri99un	1.0077	0.0015	23.09
27	epri99b	1.0072	0.0009	22.67
18	<i>saxu56^a</i>	0.9861	0.0016	21.90
19	<i>saxu792^a</i>	0.9972	0.0011	23.42
28	saxton52	1.0015	0.0012	20.34
29	saxton56	1.0014	0.0018	21.04
30	saxton56b	1.0027	0.0015	20.79
31	saxtn735	1.0031	0.0017	22.56
32	saxtn792	1.0040	0.0018	22.85
33	saxtn104	1.0057	0.0022	23.46
34	pnl4976	0.9869	0.0012	18.21

^a UO₂-only experiment, included for comparison purposes.

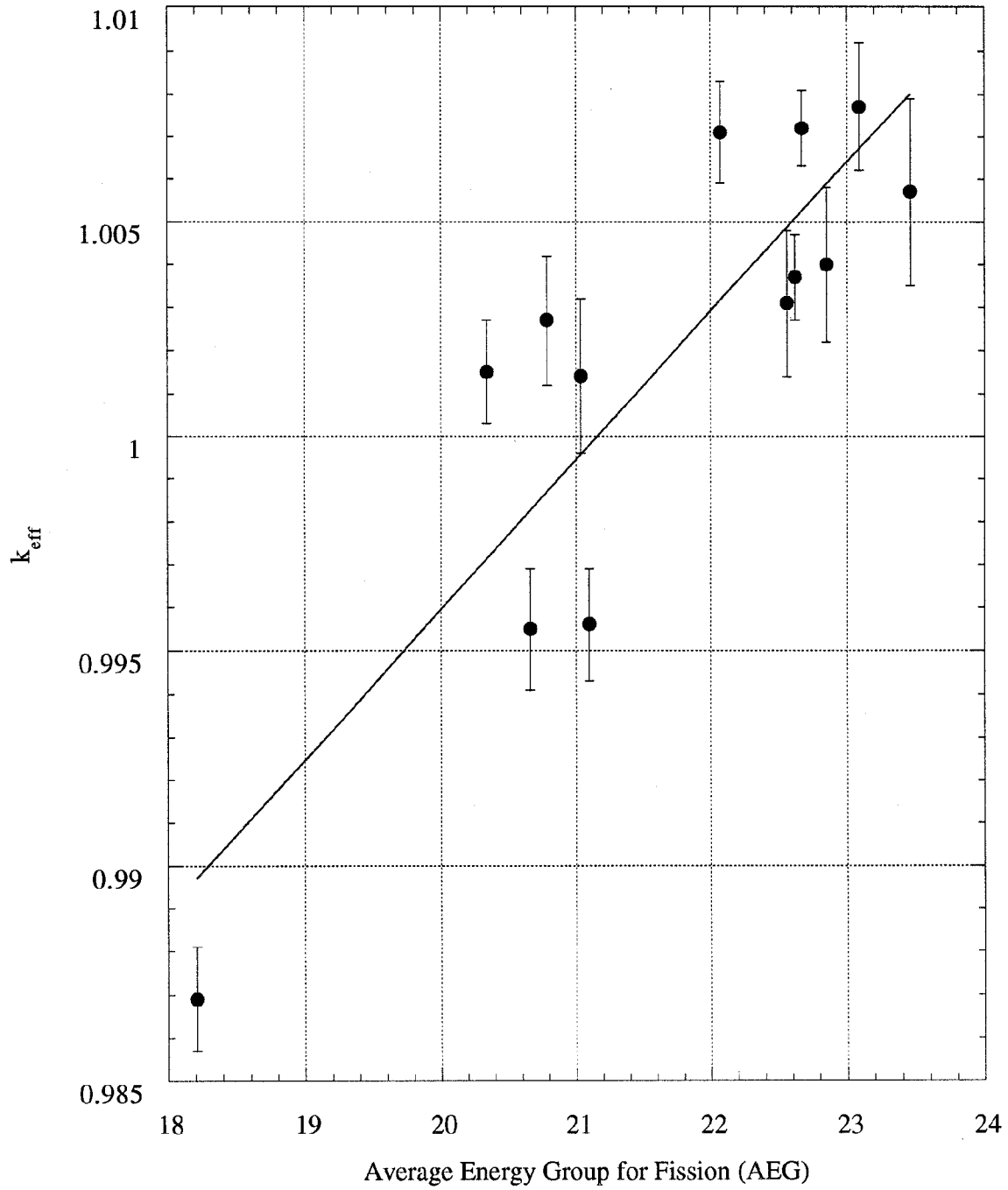


Fig. 1. k_{eff} vs AEG for MOX critical experiments.

2. The cross sections for the PuO_2 in the MOX rods were obtained from a second case; this case did not consider the presence of the surrounding UO_2 rods because a resonance material in the moderator cannot be treated by NITAWL-II (NITAWL-II assumes a $1/E$ flux in the moderator region). In this case, an infinite array of the PuO_2 - UO_2 rods was modeled with a triangular pitch of 2.768 cm, the spacing between the MOX rods. The density of the moderator was multiplied by 0.379, the volume fraction of water in the moderator region of this larger lattice cell. The remainder of the moderator region was occupied by the UO_2 rods and was omitted because of the limitations in NITAWL-II discussed earlier.
3. The third CSASN case modeled an infinite lattice of the 4.31 wt % UO_2 rods at the experimental pitch of 1.598 cm. The cross sections for the 4.31 wt % UO_2 fuel and clad and all the nonfuel materials were taken from this case.

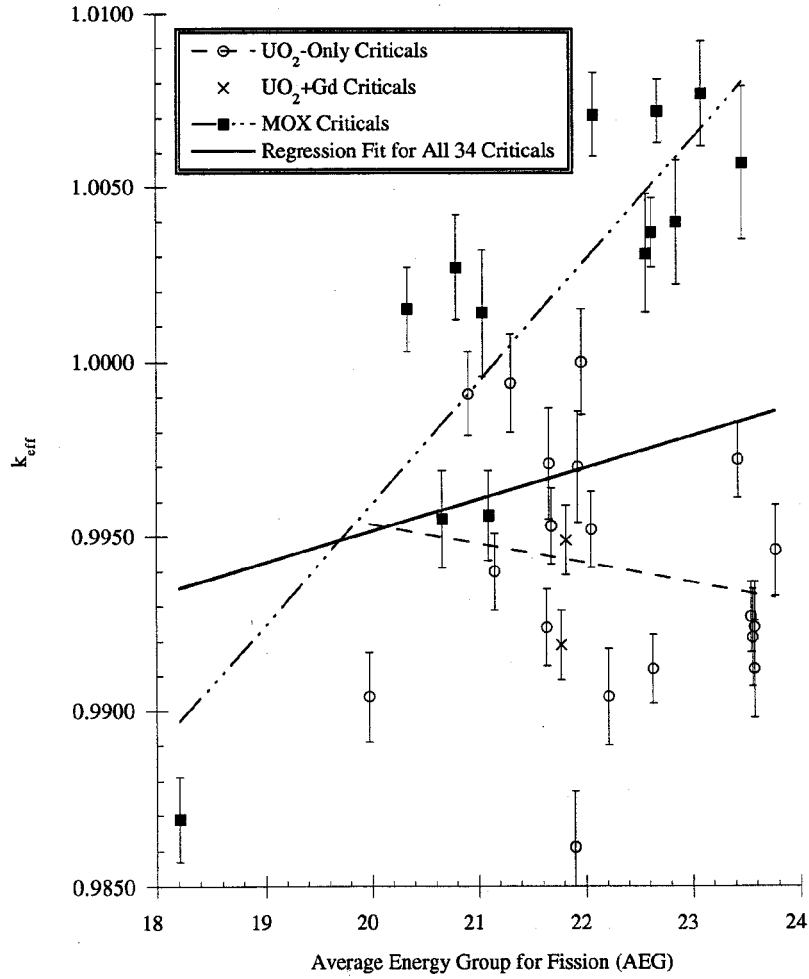
The results of the MOX calculations demonstrate that SCALE-4 does accurately calculate the effective multiplication factor for MOX LWR-type fuel. However, a bias in plutonium cross sections results in an overprediction of k_{eff} for more thermal (lower energy or higher AEG value) systems, and can underpredict k_{eff} for higher energy (smaller AEG) configurations.

3.2.4 Combined Results for all Critical Experiments

Results for each of the three sets of experiments are summarized in Table 8. This summary shows the range of calculated results for each set of experiments and highlights differences and similarities between the sets. Specifically, the $\text{UO}_2 + \text{Gd}$ criticals are consistent with the UO_2 -only criticals, while the MOX criticals show a more broad variation in k_{eff} over the range of AEGs. These differences and similarities are illustrated in Fig. 2, which shows the calculated value of k_{eff} as a function of AEG for all experiments. Error bars represent the stochastic standard deviation calculated by KENO V.a for each value of k_{eff} . Each set of experiments is illustrated by a different marker so as to distinguish between the results of each set. A linear regression fit is drawn for each set of data, with the exception of the two $\text{UO}_2 + \text{Gd}$ cases, which do not present sufficient data points for a meaningful fit. It is worth noting, however, that the two $\text{UO}_2 + \text{Gd}$ results are consistent with the general trend of the UO_2 -only results, suggesting little if any bias due to the presence of gadolinium. The fit for the UO_2 criticals shows a downward trend with increasing AEG; however, this trend is probably due to the wide spread in the data and a relatively narrow range of AEGs, rather than a correlation with AEG. As discussed earlier, statistical analyses showed essentially no correlation between k_{eff} and AEG for the UO_2 fresh fuel criticals for these 34 experiments (although this correlation is observed for an increased number of experiments with a more broad range of AEGs). The solid line in the figure represents the regression fit to all data points, to illustrate the general trend for all fresh fuel critical results; the bias in this fit is due to the plutonium bias in the MOX criticals. These results indicate that the SCALE criticality sequences used in this work together with the hybrid 27BURNULIB cross-section library provide an acceptable estimate of criticality for UO_2 -only, $\text{UO}_2 + \text{Gd}$, and $\text{UO}_2 + \text{PuO}_2$ systems in LWR-type cask geometry configurations.

Table 8. Summary for results for sets of criticality calculations

Experiment subset	Mean k_{eff}	$\sigma(\overline{k_{\text{eff}}})$	Maximum	Minimum
UO ₂ only	0.9941	0.0036	1.0000	0.9861
UO ₂ + Gd fuel	0.9934	0.0021	0.9949	0.9919
UO ₂ + PuO ₂	1.0017	0.0059	1.0077	0.9869
All critical experiments	0.9970	0.0058	1.0077	0.9861

Fig. 2. k_{eff} vs AEG for combined fresh fuel criticals.

4. BIAS AND UNCERTAINTY FROM CRITICAL EXPERIMENTS

For a subcritical configuration, it is desirable to possess a confidence that the calculation of k_{eff} for a system guarantees sufficient subcriticality; this is especially true in the absence of direct experimental measurements. This assurance of subcriticality requires the determination of an acceptable margin between a calculated value of k_{eff} and a maximum acceptable subcritical value, based on known biases and uncertainties associated with the codes and data used to calculate k_{eff} . This section describes three methods for the determination of an upper safety limit (USL) from the bias and uncertainty terms associated with the calculation of criticality. ANSI standards serve as a basis for these approaches and are used in defining uncertainty and bias terms as they relate to criticality experiments and calculations. Descriptions are provided for each of three methods, followed by examples that demonstrate the use of these methods based on calculated results given in the previous section of this report. These examples are used not only to illustrate the application of the various methods, but also to demonstrate the magnitude of the margin associated with each approach when applied to SCALE-4 analyses. USLs are provided for various combinations of results from the 34 fresh fuel criticals; results from a number of additional similar critical experiments are also included in the USL determinations to demonstrate the effect of additional data on each USL method.

4.1 ESTABLISHMENT OF AN UPPER SAFETY LIMIT FOR SUBCRITICALITY

The recommended approach for establishing subcriticality based on the numerical calculation of the neutron multiplication factor is prescribed in Sect. 5.1 of ANSI/ANS-8.17.²³ The following paragraphs describe the recommended approach as set forth in the Standard, with interpretations in terms of application for burnup credit methodologies.

The criteria to establish subcriticality requires that the calculated multiplication factor for a subcritical system, k_s , be less than or equal to an established maximum allowable multiplication factor based on benchmark calculations and uncertainty terms, that is,

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m, \quad (1)$$

where

- k_c = mean value of k_{eff} resulting from the calculation of benchmark criticality experiments using a specific calculational method and data,
- Δk_s = uncertainty in the value of k_s ,
- Δk_c = uncertainty in the value of k_c ,
- Δk_m = additional margin to ensure subcriticality.

Often, Δk_m is assigned an administrative limit of 0.05; however, a value for this margin can also be estimated statistically.

If the calculational bias (β) is defined as $\beta = 1 - k_c$, then the uncertainty in the bias is identical to the uncertainty in k_c (i.e., $\Delta k_c = \Delta \beta$). Thus the subcriticality condition may be rewritten as:

$$k_s + \Delta k_s + \Delta k_m + \beta + \Delta \beta \leq 1. \quad (2)$$

The value k_c and thus the bias β are not necessarily a constant over the range of a parameter of interest. If trends exist which cause the benchmark values of k_{eff} to vary with one or more parameters (e.g., enrichment, burnup, etc.), then β can be determined from a best fit for the calculated k_{eff} values as a function of each of the parameters upon which it is dependent.

The set of critical experiments used as benchmarks in the computation of β should be representative of the composition, configuration, and nuclear characteristics of the system for which k_s is to be determined. However, ANSI/ANS-8.1 allows that the range of applicability may be extended beyond the range of conditions represented by the benchmark experiments by extrapolating the trends established for the bias. When the extrapolation is large relative to the range of data ("large" is undefined by the ANSI standard), the calculational method applied should be supplemented by other methods in order to better estimate the extrapolated bias.

In addition to the bias β determined based on a given computational method, data, and a suite of benchmarks, there is an uncertainty, $\Delta\beta$. This uncertainty may include uncertainties in the critical experiments, statistical and/or convergence uncertainties in the benchmark calculations, uncertainties due to extrapolation beyond the range of experimental data, and uncertainties due to limitations or weaknesses in the geometrical or nuclear modeling of the critical experiments. Similarly, for a given subcritical system, there is an uncertainty Δk_s associated with the calculated k_{eff} value for the system, k_s . This uncertainty includes statistical/convergence and modeling uncertainties, as well as uncertainties in the material, fabrication, and exposure history (not addressed by fresh fuel criticals) of the system components.

Based on the criteria for subcriticality set forth in ANSI/ANS-8.17 (ref. 23) and described above, a USL may be determined based on the analysis of a number of critical systems. The USL is determined such that there is a high degree of confidence that a calculated result is subcritical; a system is considered acceptably subcritical if a calculated k_{eff} plus calculational uncertainties lies at or below this limit (i.e., $k_s + \Delta k_s \leq \text{USL}$). Thus based on Eq. (2), the USL is the magnitude of the sum of the biases, uncertainties, and administrative and/or statistical margins applied to a set of critical benchmarks, such that with a high degree of confidence,

$$\text{USL} = 1 - \Delta k_m - \beta - \Delta\beta. \quad (3)$$

Based on a given set of critical experiments, USLs are determined as a function of key system parameters, such as the AEG causing fission (AEG), fuel enrichment, or fuel/moderator ratio. Because both β and $\Delta\beta$ can vary with a given parameter, the USL is typically expressed as a function of the parameter, within an appropriate range of applicability derived from the parameter bounds.

Three approaches that can be used in calculating a USL are discussed in the following subsection. This discussion is followed by a comparison of USLs calculated by each method for various sets of critical calculations.

4.2 METHODS FOR DETERMINATION OF AN UPPER SAFETY LIMIT

In this subsection, three different methods for determining the USL of a subcritical configuration are presented and discussed. USLs calculated based on each of these methods and selected sets of critical calculations are presented in Sect. 4.3.

4.2.1 USL Method 1: Confidence Band with Administrative Margin

References 24 and 25 discuss a statistical approach in which a USL is determined as the lower bound of a set of two margins applied to a linear fit to a set of experimental data. This approach is illustrated in Fig. 3. In this figure, the upper line (solid) represents a linear regression fit to a set of calculations based on critical experiments, $k_c(x)$. As indicated in the figure, $\beta(x)$ is given as $1 - k_c$. The middle line (long dashes) represents the lower confidence band for a single additional calculation. The width of this band is determined statistically based on the existing data and a specified level of confidence; the greater the standard deviation in the data or the larger the confidence desired, the larger the band width will be. This confidence band, W , accounts for uncertainties in the experiments, the calculational approach, and in calculational data (e.g., cross sections), and is therefore a statistical basis for $\Delta\beta$, the uncertainty in the value of β . W is defined for a confidence level of $(1-\gamma_1)$ using the relationship

$$W = \max\{w(x)|_{x_{\min} \rightarrow x_{\max}}\}, \quad (4)$$

where

$$w(x) = t_{\gamma_1} s_p \left[1 + \frac{1}{n} + \frac{(x - \bar{x})^2}{\sum_{i=1,n} (x_i - \bar{x})^2} \right]^{\frac{1}{2}} \quad (5)$$

and

- n = the number of critical calculations used in establishing $k_c(x)$,
- t_{γ_1} = the Student-t distribution statistic for γ_1 and $n-2$ degrees of freedom,
- \bar{x} = the mean value of parameter x in the set of calculations,
- s_p = the pooled standard deviation for the set of criticality calculations.

The function $w(x)$ is a curvilinear function. For simplicity, it is desirable to obtain a constant width margin. Hence, for conservatism, the confidence band width W is defined as the maximum of $(w(x_{\min}), w(x_{\max}))$, where x_{\min} and x_{\max} are the minimum and maximum values of the independent parameter x , respectively. Typically, W is determined at a 95% confidence level.

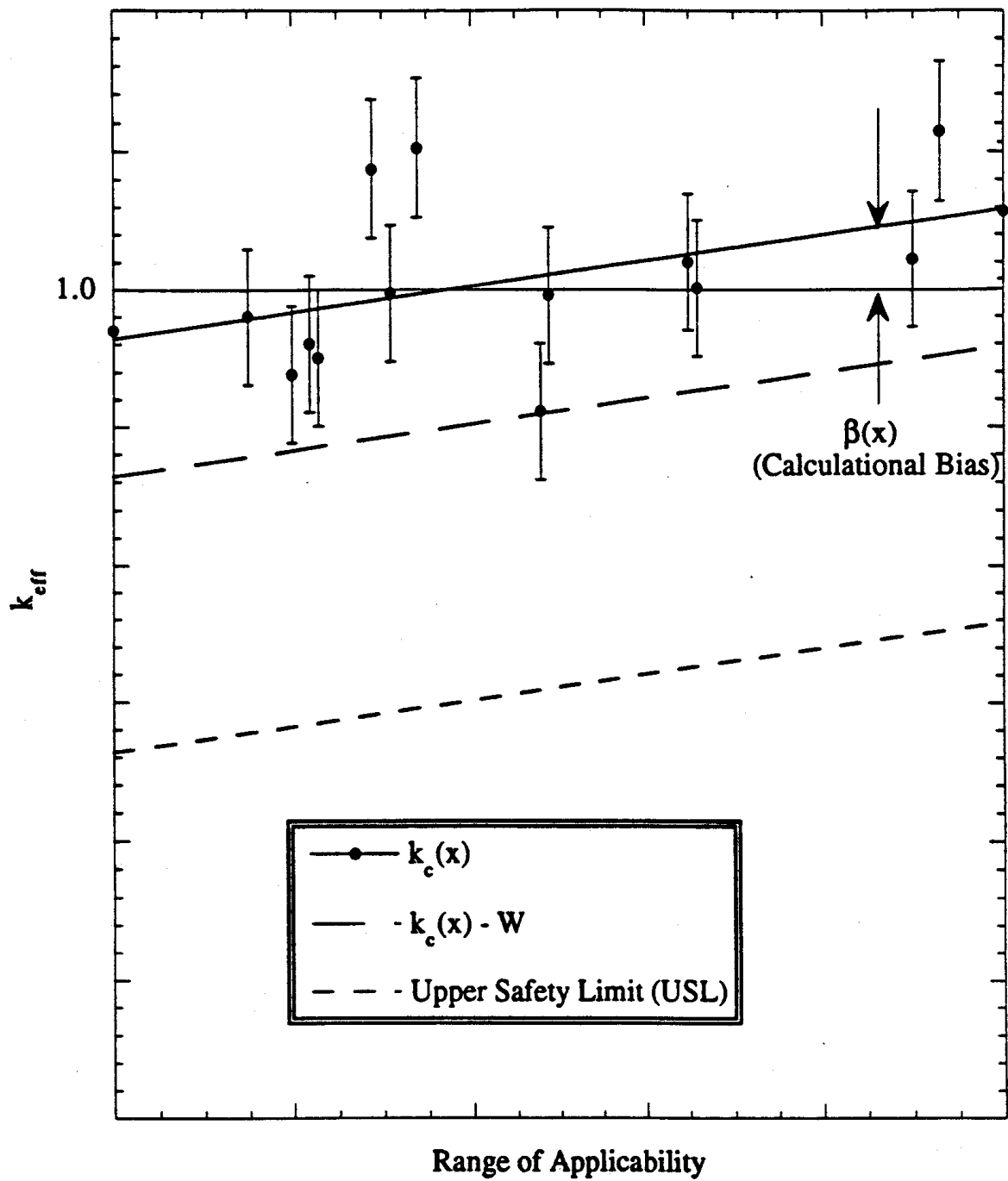


Fig. 3. Confidence band and safety margin applied to a set of criticality calculations.

The pooled standard deviation is obtained from the pooled variance ($s_p = \sqrt{s_p^2}$), where

s_p^2 is given as

$$s_p^2 = s_{k(x)}^2 + s_w^2, \quad (6)$$

where $s_{k(x)}^2$ is the variance (or mean-square error) of the regression fit, and is given by:

$$s_{k(x)}^2 = \frac{1}{(n-2)} \left[\sum_{i=1,n} (k_i - \bar{k})^2 - \frac{\left\{ \sum_{i=1,n} (x_i - \bar{x})(k_i - \bar{k}) \right\}^2}{\sum_{i=1,n} (x_i - \bar{x})^2} \right], \quad (7)$$

and s_w^2 is the within-variance of the data:

$$s_w^2 = \frac{1}{n} \sum_{i=1,n} \sigma_i^2, \quad (8)$$

where σ_i is the standard deviation associated with k_i for a Monte Carlo calculation. For deterministic codes that do not have a standard deviation associated with a computed value of k , the standard deviation is zero.

The bottom line (short dashes) in the figure represents the USL, based on an additional margin of subcriticality. This safety margin provides further assurance of subcriticality, and represents the quantity Δk_m defined earlier. In USL Method 1, Δk_m is given an arbitrary administrative value; as mentioned earlier, a value of 0.05 is typically assigned. Using these formulations, the USL Method 1 is defined as:

$$USL_1(x) = 1.0 - \Delta k_m - W - \beta(x). \quad (9)$$

4.2.2 USL Method 2: Single-Sided Uniform Width Closed Interval Approach

In this method, sometimes also referred to as a lower tolerance band (LTB) approach, statistical techniques with a more rigorous basis²⁴⁻²⁷ are applied in order to determine a combined lower confidence band plus safety margin. In other words, in the administrative margin approach of Sect. 4.2.1, $\Delta\beta$ and Δk_m are determined independently, while in the LTB method, a combined statistical lower bound is determined in terms of the product $C_{\alpha/p} \cdot s_p$, where s_p is the pooled variance

of k_c described earlier, and $C_{\alpha/p}$ is a statistically determined multiplier. Thus the USL Method 2 is given as

$$USL_2(x) = 1.0 - (C_{\alpha/p} \cdot s_p) - \beta(x). \quad (10)$$

The term $C_{\alpha/p} \cdot s_p$ provides a band for which there is a probability p that with an α confidence an additional calculation of k_{eff} for a critical system will lie within the band. For example, a $C_{95/99.5}$ multiplier produces a USL for which there is a 95% confidence that 995 out of 1000 future calculations of critical systems will yield a value of k_{eff} above the USL. Calculation of the multiplier $C_{\alpha/p}$ is somewhat complicated and beyond the scope of this report; reference 28 provides a more detailed discussion of this statistical technique and the determination of $C_{\alpha/p}$. In essence, this approach provides a more statistically based safety margin, Δk_m , which can be determined as the difference $(C_{\alpha/p} \cdot s_p) - W$. In criticality safety applications, such a statistically determined approach generally yields a margin of much less than 0.05, which serves to illustrate the conservatism that may be associated with an administrative margin. Often in the use of Method 1 in the determination of a USL, it is advantageous to apply Method 2 in tandem to demonstrate that the 5% margin is conservative relative to a purely statistical basis; this concurrent application of Method 2 is especially important when a limited number of data points are used in determination of $k_c(x)$, or when the calculated values have a large standard deviation.

4.2.3 USL Method 3: Worse Case with Administrative Margin

In this approach, the bias and associated uncertainty are combined, and are estimated by assuming that $\beta(x) + \Delta\beta = 1 - k_{min} = \beta_{max}$, where k_{min} is the minimum value of k_{eff} is taken from a set of critical calculations. In other words, the confidence band associated with a set of calculations is assumed to be bounded by the "worst case" calculation (i.e., the case that results in the lowest calculated value of k_{eff}). For additional conservatism, β_{max} is required to be equal to or greater than zero. Extra safety margin is allowed by including an arbitrary administrative margin, as applied in Method 1, such that the USL Method 3 is defined as

$$USL_3(x) = 1 - \Delta k_m - \beta_{max}. \quad (11)$$

Although this approach provides a straightforward and simple method for setting a USL, it has no mathematical basis from which one may derive a level of confidence. Thus there is no basis for confidence that future calculations will be bounded by the assumed bias. If the minimum value of k_{eff} results from a single poor measurement or poor calculational model, a USL based on this value is likely to be overly conservative; on the other hand, however, if the low point is one of several low-lying points, the statistical probability of a single future calculation being lower is increased, and the approach may be nonconservative relative to other methods. Furthermore, because such an approach does not treat the effect of variation in calculational bias with other parameters (e.g., AEG), it may be conservative only in the range of this parameter near the worst-case calculation, and non-conservative in other ranges. In addition, the lower bound cannot be increased by any number of additional calculations, but can be reduced if a lower value of k_{eff} is found in subsequent calculations.

4.2.4 Application of Upper Safety Limit Methods

For a given parameter, any of these three methods is generally considered applicable over the range of that parameter in the set of calculations used to determine the USL. However, as discussed earlier, ANSI/ANS-8.1 allows the range of applicability to be extended beyond this range by extrapolating the trends established for the bias. No precise guidelines are specified for the limits of extrapolation. Thus engineering judgment and additional uncertainty should be applied when extrapolating more than a few percent beyond the range of the parameter bounds.

Based on the fresh fuel criticals described earlier in this report, it is possible to determine a set of USLs based on any of the various parameters studied (e.g., AEG, pitch, moderator/fuel ratio, etc.). However, for these results the AEG is the only parameter for which a correlation with k_{eff} is noted. The following section demonstrates the calculation of the USL as a function of AEG, using each of the three methods described above. These examples will demonstrate the conservatism associated with each method and may be used for guidance in applying each of the methods for any appropriate set of benchmarks, any given criticality code or code system, or for a different cross-section library.

4.3 CALCULATION OF UPPER SAFETY LIMITS

In this section, each of the three methods described in the previous section is applied to KENO V.a results for the set of 34 fresh fuel critical calculations. In addition, results based on subsets of these data and supersets including the results of additional critical calculations are analyzed in order to demonstrate the effect of changes in data on each of the methods. The USLs are determined as a function of the AEG as calculated by KENO V.a. These calculations are presented to serve as an example of the use of these methods and to provide a means for an analyst to confirm his interpretation of the approach.

Tables 4, 6, and 7 of Sect. 3 provide the results calculated for each of the fresh fuel criticals. In addition to the calculated value of k_{eff} and its stochastic uncertainty for each case, these tables provide the average energy group for fission, as computed by KENO V.a using the SCALE 27BURNUPLIB cross-section library. Using the approaches described earlier, the various terms required to determine the USL by each method are computed. Table 9 summarizes the intermediate results and the three USL values computed for the combined criticals.

Figure 4 shows the k_{eff} results for all 34 fresh fuel criticals, together with lines representing the regression fit $[k_c(x)]$, the 95% confidence band for a single calculation $[k_c(x) - W]$, the USL based on Method 1 $[USL_1 = k_c(x) - W - 0.05]$, the USL based on Method 2 $[USL_2 = k_c(x) - (C_{95/99.5} \cdot s_p)]$, and the USL based on Method 3 $[USL_3 = 1.0 - 0.05 - \beta_{\text{max}}]$. Note the substantial conservatism of Method 1 relative to Method 2. The deviation of the individual values with respect to $k_c(x)$ is not especially large, indicating that the SCALE-4 results have a relatively small uncertainty in the bias, which gives a reasonably high lower tolerance band (USL_2). This results in a value for Δk_m of roughly 0.016, compared with the assumed administrative margin of 0.05 used in the determination of USL_1 based on a 95%/99.5% confidence level in the calculation of $C_{\omega p}$; at a 99%/99.9% confidence level (calculation not shown), $C \cdot s_p$ is 0.03613, which translates to $\Delta k_m \sim 0.025$, or about half of the assumed 0.05 margin. Note also that for this set of critical calculations

Table 9. Parameters used in USL calculation for fresh fuel criticals

Parameter	Value
n	34
Linear regression fit, k (AEG)	$0.9769 + (\text{AEG} \times 9.1152 \times 10^{-4})$
Bias [$\beta(\text{AEG})$]	$0.0231 - (\text{AEG} \times 9.1152 \times 10^{-4})$
Minimum AEG (x_{\min})	18.21
Maximum AEG (x_{\max})	23.77
Bias at minimum AEG [$\beta(x_{\min})$]	0.006501
Bias at maximum AEG [$\beta(x_{\max})$]	0.001433
Minimum k_{eff}	0.9861
β_{\max} (bias at minimum k_{eff})	0.0139
Average AEG (\bar{x})	21.99
Average k_{eff} (\bar{k})	0.9970
Variance of fit, $s_{k(x)}^2$	3.4152×10^{-5}
Within-data variance, s_w^2	1.8477×10^{-6}
Pooled variance, s_p^2	3.6000×10^{-5}
Pooled standard deviation, s_p	6.0000×10^{-3}
Student-t @ (n-2) deg. of freedom, γ_1	1.694
$W_{95\%}$ [max of $w(x_{\min})$, $w(x_{\max})$]	0.01167
$C_{95/99.5}$	4.554
$C_{95/99.5} \cdot s_p$	0.02733
$C \cdot s_p - W$	0.01566
USL ₁ (confidence band with administrative margin)	$0.9152 + (\text{AEG} \times 9.1152 \times 10^{-4})$
USL ₂ (single-sided uniform width closed interval)	$0.9496 + (\text{AEG} \times 9.1152 \times 10^{-4})$
USL ₃ (worst case with administrative margin)	0.9361

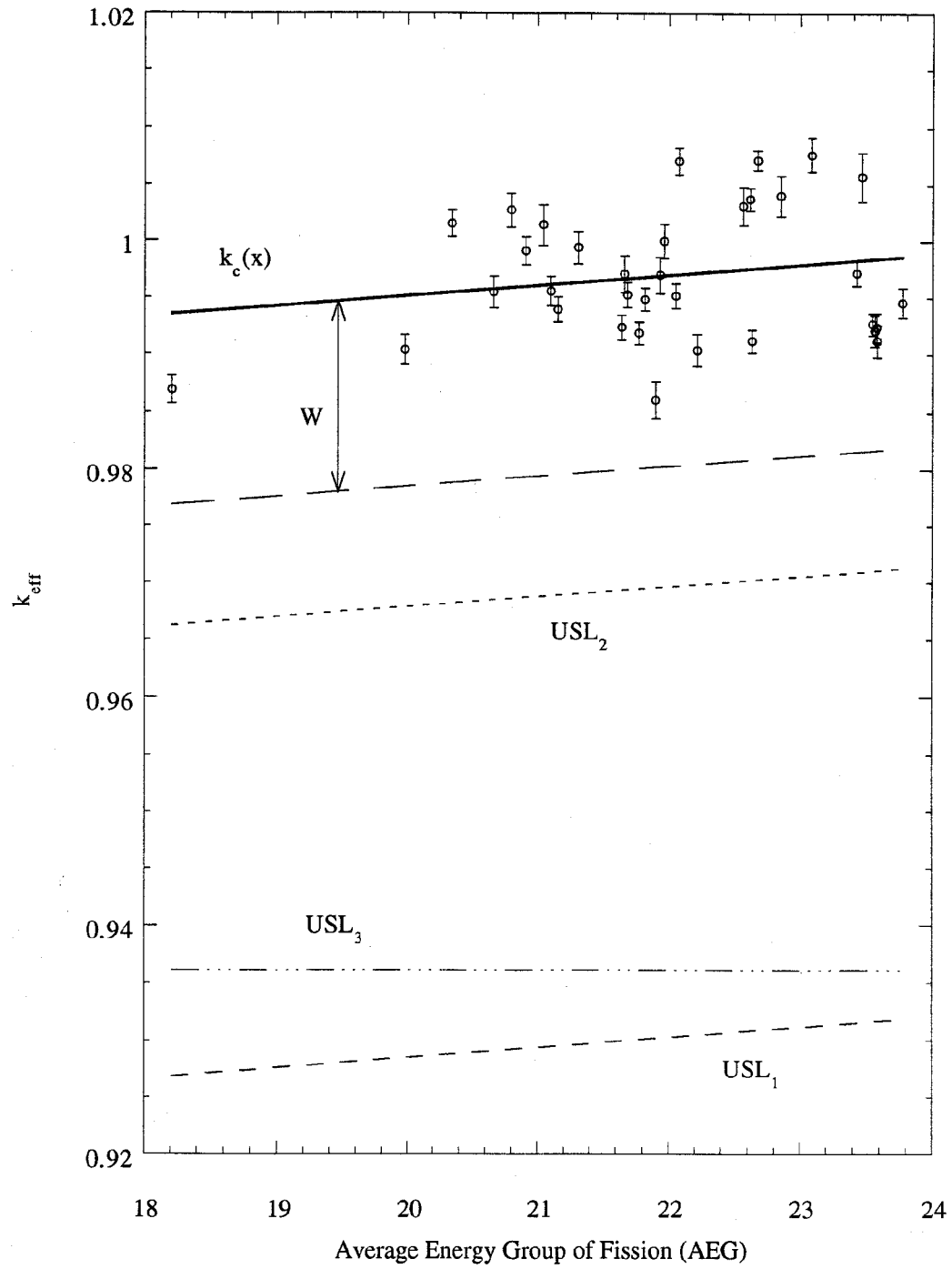


Fig. 4. USLs computed by Methods 1, 2, and 3 for the 34 fresh fuel criticals.

USL₁ is more conservative than USL₃ over the full range of the validation. This is because there were multiple low-lying values of k_{eff} , resulting in a larger confidence band for a single future calculation than the assumed bounding maximum bias (i.e., $W > \beta_{\text{max}}$).

Although these results demonstrate the relative differences between the three methods for determining a USL, the relative behaviors of Methods 1 and 2 are statistical in nature and are coupled to the distribution of the critical experiments themselves. Thus it would be of interest to determine the relative USLs for various different sets of calculations. To facilitate this comparison, subsets of the combined 34 cases can be studied to assess the effects of smaller groups of criticals. Additionally, results for other relevant critical experiments can be included to demonstrate the effect of larger collections. Specifically, a collection of seven critical calculations based on the burned fuel analyses of reactor restart criticals, described in detail in ref. 29, can be used to expand the data base to include phenomena similar to spent fuel conditions. The set can be further augmented by a set of 59 recently developed fresh fuel critical models developed in addition to the 34 cases included in this report for a more broad-based validation effort;^{21,30} 39 of these additional criticals are UO₂-only cases. Results (k_{eff} , σ , and AEG) for the members of each of these two sets of additional criticality calculations are included in Appendix C; the specific details of each configuration are available in the original references.^{29,30} Table 10 summarizes the results of USL calculations for each combination of criticality calculations.

Table 10 gives the linear equations for the USL as a function of AEG for Methods 1 and 2; since Method 3 does not account for trends in the bias, this USL is assumed constant over the full range of AEGs. Because the y-intercept term of this equation can be misleading, especially when the slope is large, USLs are also reported as evaluated at a value of 22, near the mean AEG value for 34 fresh fuel criticals. In general, USL₁ and USL₂ tend to increase with an increasing number of criticals, due to better statistical bases, as illustrated in Fig. 5. The cases with 19 UO₂-only and 13 MOX-only experiments are exceptions to this trend; this is probably caused by a reduced deviation in k_{eff} values due to a similarity in physical configurations and material composition. With the exception of the MOX-only set, the Method 3 USL does not change for any combination; in fact, the USL computed by Method 3 can only remain constant or decrease with added numbers of critical calculations.

In order to apply a USL for burnup credit in a spent fuel cask design, it is necessary to determine that the AEG expected for such a design lies in the range of roughly 18.0 to 24.0 when computed using KENO V.a and the 27BURNUPLIB cross-section library. The exact AEG will be strongly tied to the specifics of the cask design and loading. However, an estimate of the approximate AEG which might be observed in such a design can be determined from existing models. Related and ongoing work studying the sensitivity of k_{eff} to various parameters in a conceptual cask design³¹ for a range of enrichments, burnup, and cooling times gives a range of computed AEGs from 21.7 to 22.2. This range is well within the range of AEGs spanned by the 34 critical experiments detailed in this document and is located in the range of the highest density of critical calculation results. Hence in terms of AEG, a USL determined over the range of fresh fuel appears to be appropriate for spent fuel cask analyses.

Note that the combined set of 58 UO₂-only criticals shows a positive trend with AEG. As was noted earlier, this correlation with AEG is a known bias in the SCALE ENDF/B-IV 27-group libraries. This trend is not observed for the 19 UO₂-only criticals subset of the 34 critical experiments described in this report. This lack of a trend is probably due to the limited number of experiments and the fact that these experiments do not extend into the upper thermal energy regions where the bias is most pronounced.

Table 10. Summary of USL calculations for various sets of data

Description	No. of exp.	W	β_{\max}	USL ₁ (USL ₁ @ AEG=22)	USL ₂ (USL ₂ @ AEG=22)	USL ₃ (USL ₃ @ AEG=22)
UO ₂ -only cases (from Table 4)	19	0.00774	0.0139	0.9487 – AEG× 5.5429×10 ⁻⁴ (0.9365)	0.9867 – AEG× 5.5429×10 ⁻⁴ (0.9745)	0.9361 (0.9361)
MOX-only cases (from Table 6)	13	0.00764	0.0131	0.8685 + AEG× 3.4872×10 ⁻³ (0.9452)	0.9056 + AEG× 3.4872×10 ⁻³ (0.9823)	0.9369 (0.9369)
UO ₂ + MOX (Table 4 + Table 6)	32	0.01192	0.0139	0.9159 + AEG× 8.8254×10 ⁻⁴ (0.9353)	0.9497 + AEG× 8.8254×10 ⁻⁴ (0.9691)	0.9361 (0.9361)
UO ₂ + MOX + Gd (Tables 4–6)	34	0.01167	0.0139	0.9152 + AEG× 9.1152×10 ⁻⁴ (0.9353)	0.9486 + AEG× 9.1152×10 ⁻⁴ (0.9697)	0.9361 (0.9361)
Original 34 + 7 reactor criticals	41	0.01201	0.0139	0.9405 – AEG× 1.9729×10 ⁻⁴ (0.9362)	0.9750 – AEG× 1.9729×10 ⁻⁴ (0.9707)	0.9361 (0.0961)
Original 34 + 59 additional fresh fuel criticals	93	0.01267	0.0139	0.9257 + AEG× 4.3915×10 ⁻⁴ (0.9354)	0.9619 + AEG× 4.3915×10 ⁻⁴ (0.9716)	0.9361 (0.0961)
Original 34 + 59 additional + 7 reactor criticals	100	0.01261	0.0139	0.9342 + AEG× 7.0783×10 ⁻⁵ (0.9358)	0.9706 + AEG× 7.0783×10 ⁻⁵ (0.9721)	0.9361 (0.0961)
19 UO ₂ -only cases + 39 additional UO ₂ - only cases	58	0.00857	0.0139	0.92130 + AEG× 6.7077×10 ⁻⁴ (0.9361)	0.96095 + AEG× 6.7077×10 ⁻⁴ (0.9757)	0.9361 (0.9361)

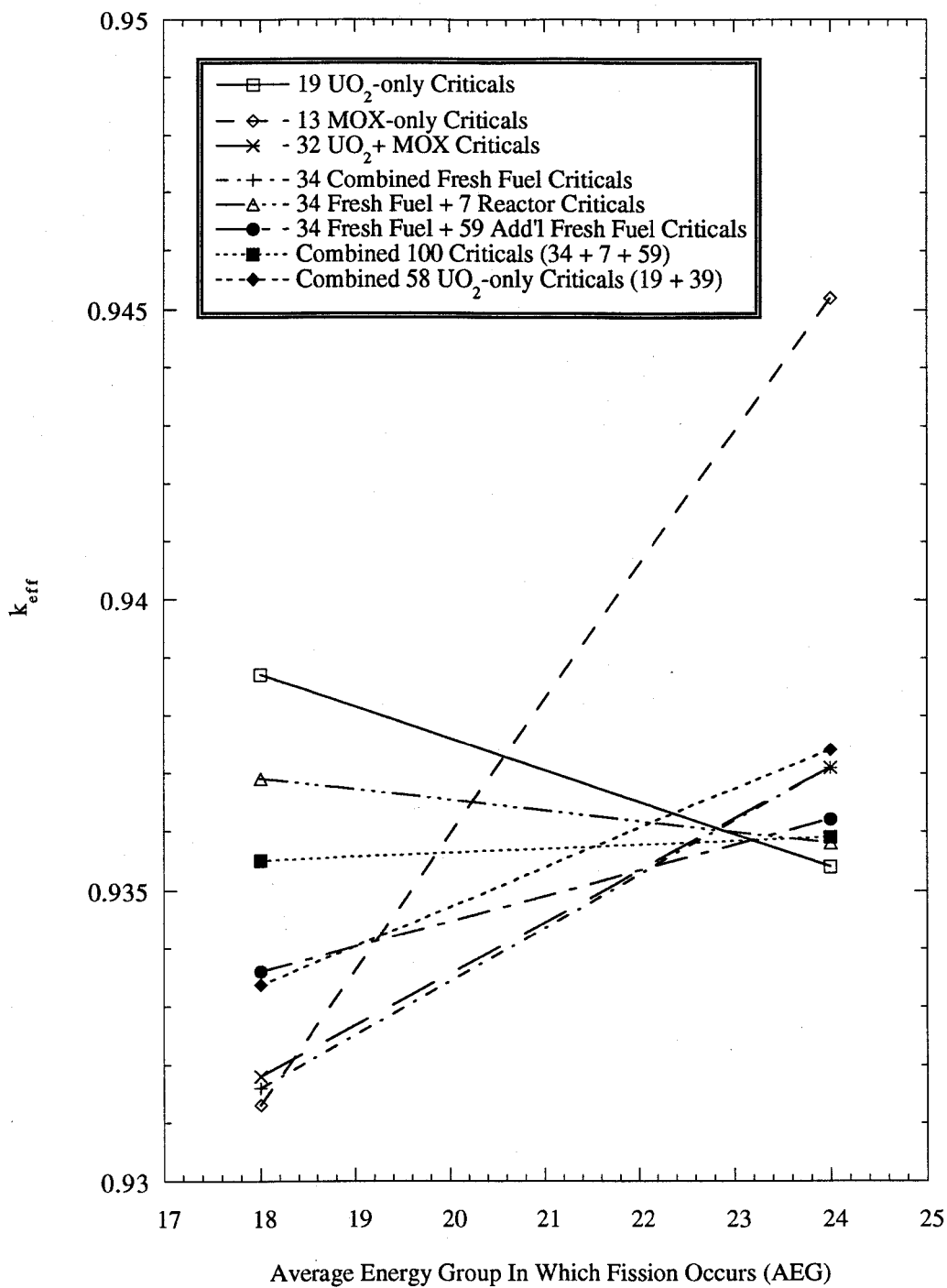


Fig. 5. Method 1 USL as a function of combinations of critical calculations.

5. CONCLUSIONS

Any methodology used in the safety evaluation of a spent fuel cask must be validated in accordance with the ANSI/ANS-8.1 Standard. Current methodologies applied in spent fuel transportation and storage applications are based on the assumption that fuel is in its most reactive state (i.e., unburned). Hence such approaches, while overly conservative, are relatively easy to validate. Because of the complex physical processes involved in the production, depletion, and decay of isotopes during one or more fuel cycles, burnup credit methods require substantially more effort to validate. Burnup credit methods that take credit for fission-product poisoning will require additional effort in order to validate the effect of fission products on bias and uncertainty terms; however, the criticals described here are appropriate for burnup credit methods which take credit only for reactivity effects due to actinide depletion and activation.

Fresh fuel experiments may be applied as a portion of the validation process for criticality methods for burnup credit applications. Included in this report were fresh fuel critical experiments having geometric, material, and nuclear characteristics similar to PWR spent fuel cask environments. These problems included 19 UO_2 critical experiments with geometries related to various aspects of fuel loading in transportation and storage casks. In addition, there were two experiments that included gadolinium in the fuel, and 13 MOX critical experiments. Criticality calculations based on these experiments demonstrate the ability of the SCALE-4 methodology developed at ORNL to predict a value of k_{eff} very close to the known value of 1.0 (within 1.4%) for the fresh fuel criticals. The calculated k_{eff} values of the fresh fuel critical experiments ranged from 0.9861 to 1.0077.

Three approaches were presented for the determination of a USL that will ensure an adequate margin of subcriticality for a given code system, data, and a set of critical calculations. Based on the results of criticality calculations performed for the above critical experiments using the SCALE-4 code and the SCALE 27-group burnup library (27BURNUPLIB), the calculation of USLs was demonstrated for three methods. Results indicate that the first method, referred to as the "confidence band with administrative margin" method, or simply Method 1, generally gives a generous margin for uncertainty over the more statistical rigor of Method 2, and is more reasonable and often more conservative than that of Method 3.

Further work to expand the data base of critical experiments is desirable. Fresh fuel criticals are valuable in assessing the effect of geometry on calculational methods; many such experiments have been performed based on cask-like configurations. However, these experiments lack many of the isotopes present in spent fuel (i.e., fission products and some actinides) and cannot represent operating history effects. Thus experiments using spent fuel or simulated spent fuel, with axially varying burnup, are desirable to provide added confidence in the capability of computer codes to represent and predict the behavior of such systems under design basis conditions.

The 34 criticals described in this report were originally selected as generally representative of LWR configurations, and as such were not selected to characterize or to represent any specific configuration. Additional fresh fuel criticals may be required to validate methods for a specific spent fuel design. Nevertheless, the results presented in this paper indicate that fresh fuel critical experiments with characteristics applicable to spent fuel transportation and storage casks can be accurately modeled with current analysis methods such as those provided in SCALE-4.

6. REFERENCES

1. *American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, ANSI/ANS-8.1-1983. (Reaffirmed November 1988)
2. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III (February 1995). Available from Radiation Shielding Information Center as CCC-545.
3. M. C. Brady and T. L. Sanders, "A Validated Methodology for Evaluating Burnup Credit in Spent Fuel Casks," *Proc. International Conference on Nuclear Criticality Safety*, Christ Church, Oxford, United Kingdom, September 9-13, 1991.
4. S. M. Bowman et al., "Validation of SCALE-4 for LWR Fuel in Transportation and Storage Cask Conditions," *Trans. Am. Nucl. Soc.* **62**, 338-340 (1990).
5. S. R. Bierman, *Criticality Experiments With Neutron Flux Traps Containing Voids*, PNL-7167, Battelle Pacific Northwest Laboratory, 1990.
6. S. R. Bierman et al., *Critical Separation Between Subcritical Clusters of 2.35 Wt% ^{235}U Enriched UO_2 Rods in Water with Fixed Neutron Poisons*, PNL-2438, Battelle Pacific Northwest Laboratory, 1977.
7. S. R. Bierman et al., *Criticality Experiments with Subcritical Clusters of 2.35 Wt% and 4.31 Wt% ^{235}U Enriched UO_2 Rods in Water with Uranium or Lead Reflecting Walls*, PNL-3926, Battelle Pacific Northwest Laboratory, 1981.
8. S. R. Bierman and E. D. Clayton, *Criticality Experiments with Subcritical Clusters of 2.35 wt % and 4.31 wt % ^{235}U Enriched UO_2 Rods in Water with Steel Reflecting Walls*, PNL-3602, Battelle Pacific Northwest Laboratory, 1981.
9. B. M. Durst et al., *Critical Experiments with 4.31 wt % ^{235}U Enriched UO_2 Rods in Highly Borated Water Lattices*, PNL-4267, Battelle Pacific Northwest Laboratory, 1982.
10. M. N. Baldwin et al., *Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel*, BAW-1484-7, Babcock and Wilcox Company, 1979.
11. L. W. Newman et al., *Urania Gadolinia: Nuclear Model Development and Critical Experiment Benchmark*, BAW-1810, Babcock and Wilcox Company, 1984.
12. R. I. Smith and G. J. Konzek, *Clean Critical Experiment Benchmarks for Plutonium Recycle in LWRs*, EPRI NP-196, Vols. I and II, Electric Power Research Institute, 1976 and 1978.

13. E. G. Taylor et al., *Saxton Plutonium Program Critical Experiments for the Saxton Partial Plutonium Core*, WCAP-3385-54, Westinghouse Electric Corp., Atomic Power Division, 1965.
14. S. R. Bierman et al., *Criticality Experiments with Low Enriched UO₂ Rods in Water Containing Dissolved Gadolinium*, PNL-4976, Battelle Pacific Northwest Laboratory, February 1984.
15. N. F. Landers and L. M. Petrie, "CSAS4: An Enhanced Criticality Safety Analysis Module with Search Options," Sect. C4 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III (February 1995). Available from Radiation Shielding Information Center as CCC-545.
16. N. F. Landers, L. M. Petrie, and J. A. Bucholz, "The Material Information Processor for SCALE," Sect. M7 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III (February 1995). Available from Radiation Shielding Information Center as CCC-545.
17. N. M. Greene, "BONAMI-S: Resonance Self-Shielding by the Bondarenko Method," Sect. F1 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III (February 1995). Available from Radiation Shielding Information Center as CCC-545.
18. N. M. Greene, L. M. Petrie, and R. M. Westfall, "NITAWL-II: SCALE System Module for Performing Resonance Shielding and Working Library Production," Sect. F2 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III (February 1995). Available from Radiation Shielding Information Center as CCC-545.
19. L. M. Petrie and N. F. Landers, "KENO V.a: An Improved Monte Carlo Criticality Program with Supergrouping," Sect. F11 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III (February 1995). Available from Radiation Shielding Information Center as CCC-545.
20. N. M. Greene and L. M. Petrie, "XSDRNP-S: A One-Dimensional Discrete-Ordinates Code for Transport Analysis," Sect. F3 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III (February 1995). Available from Radiation Shielding Information Center as CCC-545.

21. M. D. DeHart and S. M. Bowman, *Validation of the SCALE Broad Structure 44-Group ENDF/B-V Cross-Section Library for Use in Criticality Safety Analyses*, NUREG/CR-6102 (ORNL/TM-12460), U.S. Nuclear Regulatory Commission, September 1994.
22. R. J. Brissenden, "Increasing the Physical Realism of the MONK Criticality Code," in *Proc. of the Topical Meeting on Physics and Methods in Criticality Safety*, September 19-23, 1993, Nashville, Tenn., 1994.
23. *American National Standard for Nuclear Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors*, ANSI/ANS-8.17-1984. (Reaffirmed August 1989).
24. H. R. Dyer, W. C. Jordan, and V. R. Cain, "A Technique for Code Validation for Criticality Safety Calculations," *Trans. Am. Nucl. Soc.* **63**, 238 (June 1991).
25. M. E. Easter, *Validation of KENO V.a and Two Cross-Section Libraries for Criticality Calculations of Low-Enriched Uranium Systems*, ORNL/CSD/TM-223, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., July 1985.
26. D. C. Bowden and F. A. Graybill, "Confidence Bands of Uniform and Proportional Width for Linear Models," *Am. Stat. Assoc. J.* **61**, 182 (March 1966).
27. N. L. Johnson, Ed., "Query," *Technometrics*, **10** 207 (February 1968).
28. V. R. Cain, *A Computer Code to Perform Analyses of Criticality Validation Results*, Y/DD-574, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, September 1992.
29. M. D. DeHart et al., *SCALE-4 Analysis of Pressurized Water Reactor Critical Configurations*, ORNL/TM-12294, Volumes 1-5, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., 1995.
30. S. M. Bowman et al., "Validation of SCALE-4 for Burnup Credit Applications," *Nucl. Tech.* **110**, 53 (April 1995).
31. M. D. DeHart, *Sensitivity and Parametric Evaluations of Significant Aspects of Burnup Credit for PWR Spent Fuel Packages*, ORNL/TM-12973, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab. (in press).

APPENDIX A

PHYSICAL DESCRIPTION OF CRITICAL EXPERIMENTS

The following sections provide descriptions of the physical layout and material specifications provided in refs. 5 through 14 for the critical experiments included in this report. These descriptions were used as a basis for the KENO V.a models described in Appendix B. Experiment numbers (1 through 34) and designations (e.g., **ft214r**) correspond to those assigned in Tables 1 through 3 of the main body of the report.

FLUX TRAP EXPERIMENTS (CASES 1 AND 2)

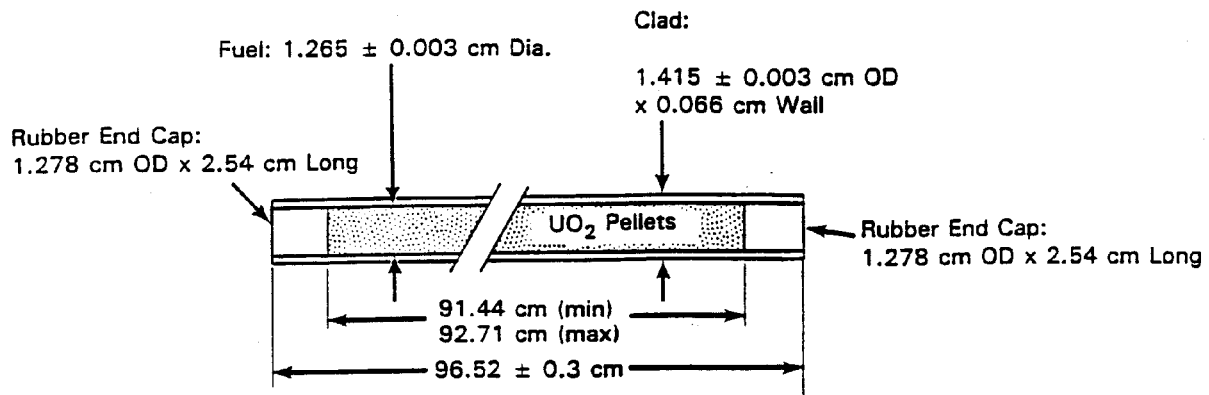
The first set of experiments⁵ listed in Table 1, designated as **ft214r** and **ft214v3**, consisted of four fuel assemblies of 4.31 weight percent (wt %) UO₂ rods in a 1.891-cm-square lattice pitch, arranged in a 2 × 2 array. Details of the fuel rod design are given in Fig. A.1. The assemblies were separated by a 3.73-cm-wide neutron flux trap created by 0.673-cm-thick Boral™ plates. The flux trap plates are described in Table A.1. Voids were created in the flux trap region of the second experiment by inserting three 0.63-cm-thick aluminum plates. This step resulted in voiding of 51% and decreased the critical size of the experiment by approximately 9.5%. These experiments test the capability of the methodology to model neutron flux traps effectively.

In the first experiment, **ft214r**, three of the fuel assemblies were 16 × 16 arrays of fuel rods, and the fourth fuel assembly was a 15 × 15 fuel rod array with seven additional fuel rods in the 16th row (Fig. A.2). The experimenter's advice in ref. 5 is to treat the seven additional rods estimated to achieve criticality as a full row of partial fuel-water cells. However, calculations have been performed with SCALE-4 that demonstrated that explicit representation of the additional fuel rods needed to achieve criticality yields virtually identical results. Experiment **ft214v3** had three fuel assemblies that were 14 × 15 fuel rod arrays and one assembly consisting of a 15 × 15 fuel rod array (Fig. A.3). The additional seven rods estimated to achieve criticality should be added in a fifteenth row to one of the 14 × 15 fuel assemblies. The axial view for both flux trap experiments is illustrated in Fig. A.4.

Table A.1. Description of neutron flux trap
plates in experiments **ft214r** and **ft214v3**

Element	wt %
Al	62.54
B	29.22
C	8.16
O	0.06
Fe	0.02
Core density, g/cm ³	2.64
Core thickness, cm	0.470
Length, cm	96
Width, cm	45

Source: ref. 5.



Cladding: 6061 Aluminum Tubing

Loading

Enrichment - 4.306 ± 0.013 wt% ²³⁵U
 Oxide Density - 10.40 ± 0.06 g/cm³
 UO₂ - 1203.38 ± 4.12 g/Rod
 U - 1059.64 ± 4.80 g/Rod

Uranium Composition:

²³⁴U - 0.022 ± 0.002 wt%
²³⁵U - 4.306 ± 0.013 wt%
²³⁶U - 0.022 ± 0.002 wt%
²³⁸U - 95.650 ± 0.017 wt%

End Cap:

C- 58 ± 1 wt% S- 1.7 ± 0.2 wt%
 H- 6.5 ± 0.3 wt% O- 22.1 wt% (Balance)
 Ca- 11.4 ± 1.8 wt% Si- 0.3 ± 0.1 wt%

Notes:

1. Error limits are one standard deviation
2. End Cap Density is 1.321 g/cm³

Fig. A.1. Description of 4.31 wt % ²³⁵U-enriched UO₂ fuel rods used in experiments **ft214r**.

Assembly Number :214R
 Lattice Pitch :1.691 \pm 0.001 cm
 Safety Rods :Out of System
 Control Rods :Out of System
 Fuel Rods :945 (see comments)
 Fuel :4.31 wt% ²³⁵U Enriched UO₂
 Flux Trap Width, W :3.73 \pm 0.02 cm
 Plates :Boral
 Boron :0.36 \pm 0.02 gB/cm²
 Voiding Material :None
 Comments :952 Rods Predicted for
 Delayed Criticality

ORNL-DWG 93Z-13119

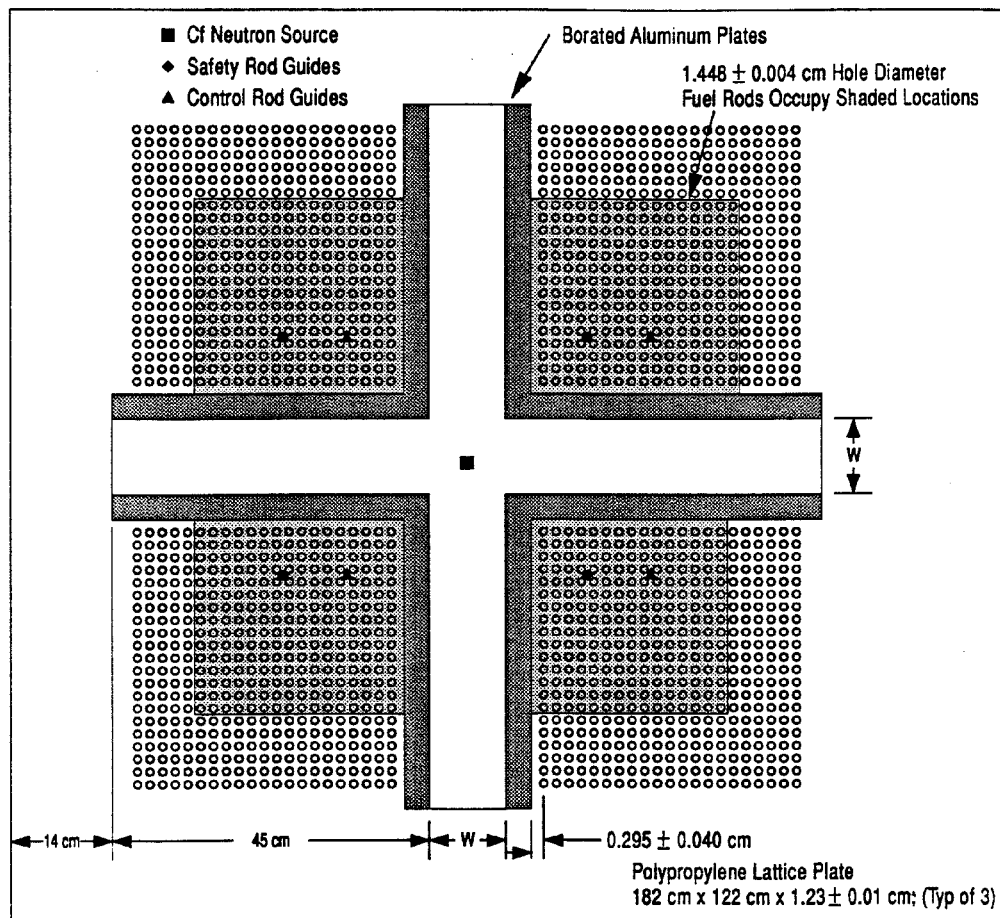


Fig. A.2. Experiment **ft214r**. *Source:* ref. 5.

Assembly Number : 214V3
 Lattice Pitch : 1.891 ± 0.001 cm
 Safety Rods : Out of System
 Control Rods : Out of System

 Fuel Rods : 855 (see comments)
 Fuel : 4.31 wt% ^{235}U Enriched UO_2
 Flux Trap Width, W : 3.73 ± 0.02 cm
 Plates : Boral
 Boron : 0.36 ± 0.02 gB/cm²
 Voiding Material : 0.63 ± 0.001 cm tk Al Plate
 Comments : 862.1 ± 1.2 Rods Predicted for Delayed Criticality

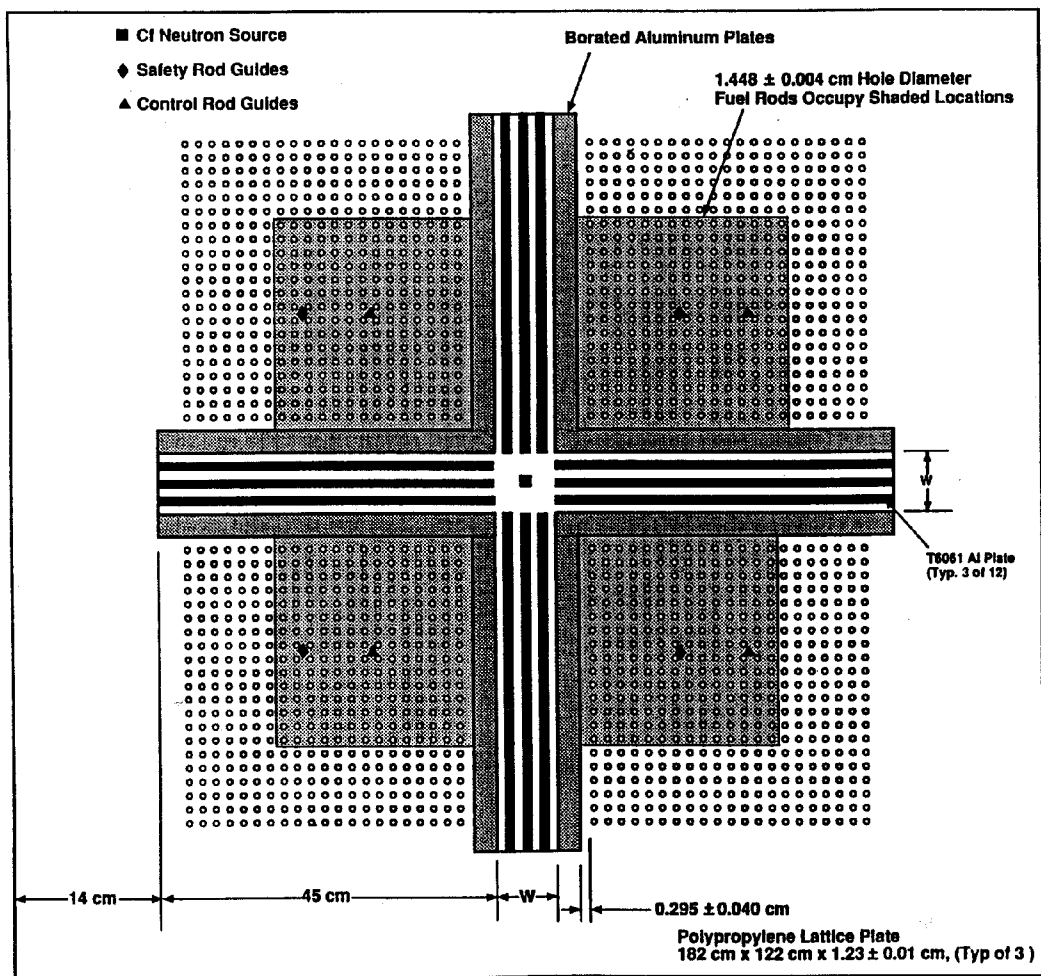


Fig. A.3. Experiment 214v3. *Source:* ref. 5.

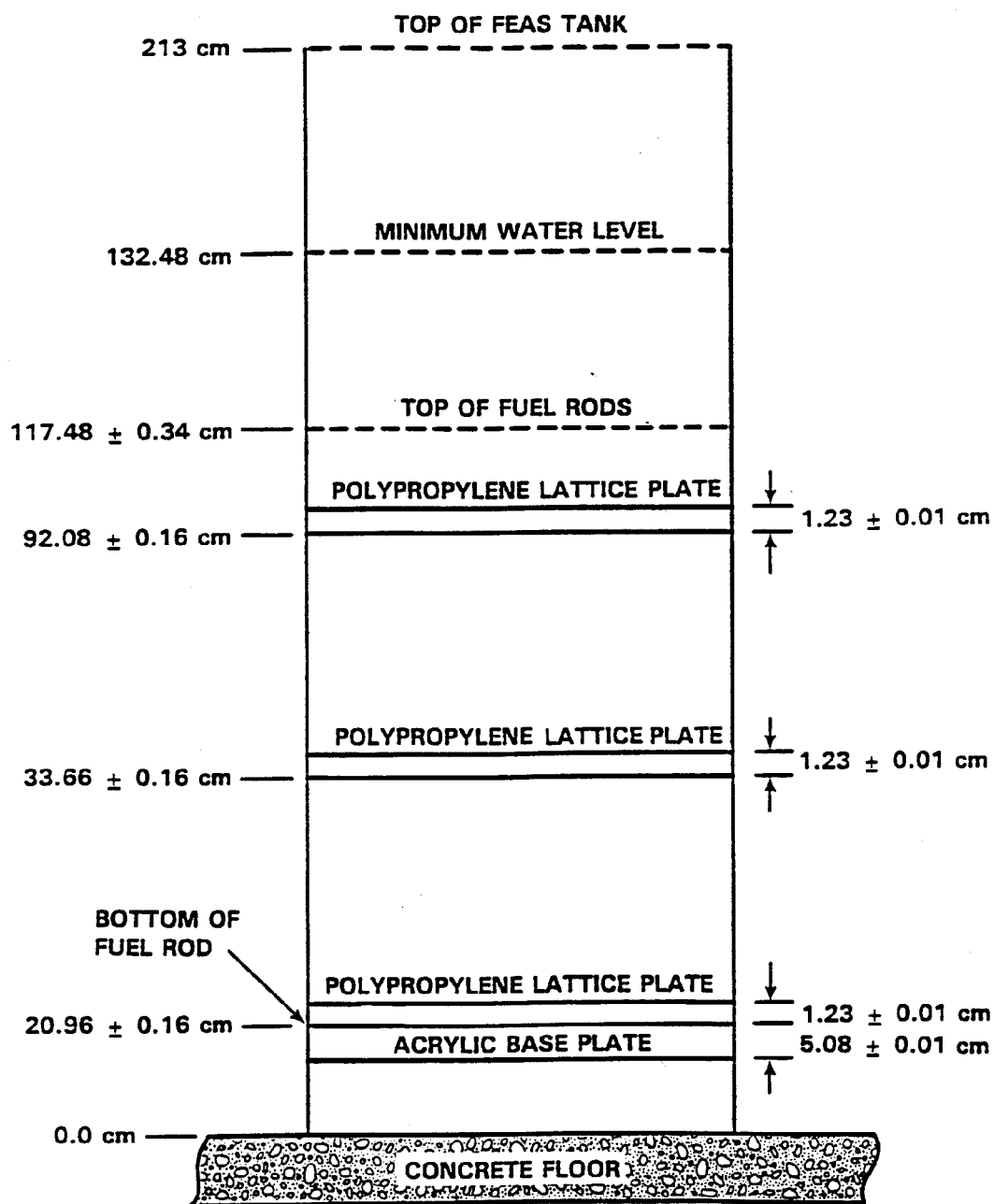


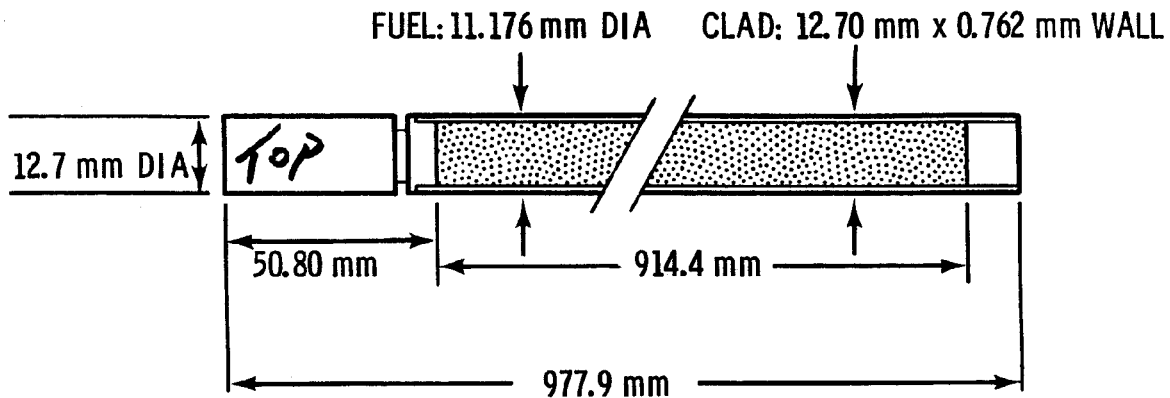
Fig. A.4. Experimental assembly elevations for **ft214r** and **ft214v3**. *Source*: ref. 5.

PNL-2438 ABSORBER PLATE EXPERIMENTS (CASES 3, 4, 5, AND 6)

The second group of experiments⁶ (**p2438x05**, **p2438x17**, **p2438x24**, and **p2438x28**) consisted of three fuel assemblies of 2.35 wt % UO_2 rods in a 2.032-cm-square lattice pitch arranged in a row. Absorber plates of Boral[™], aluminum, or stainless steel were inserted between the fuel assemblies (0.645 cm from the cell boundary of the center assembly) to determine the effect on the critical separation between the fuel assemblies. Modeling these experiments demonstrates the ability of the calculational techniques to predict the effect of absorber plates between fuel assemblies. A description of the 2.35 wt % UO_2 fuel rods is provided in Fig. A.5. Planar and axial views of the experiments are shown in Fig. A.6.

Experiment **p2438x05** contained no plates between the fuel assemblies. All three fuel assemblies were 20×16 fuel rod arrays with a critical spacing of 8.39 cm between assemblies (measured from outer edge of fuel rod). Experiment **p2438x17** contained Boral[™] plates. The chemical composition of the Boral[™] is listed in Table A.2. The Boral[™] plates were 36.5 cm wide by 91.5 cm long and 0.713 cm thick (including 0.102-cm-thick aluminum cladding on both sides of the B_4C -Al absorber). The center fuel assembly was a 20×16 array, and the two outer assemblies were 22×16 arrays. The critical separation distance between assemblies was 5.05 cm. Experiment **p2438x24** used aluminum plates between three 20×16 fuel assemblies. Although aluminum is not generally considered a neutron absorber, it is a common material in fuel baskets and acts as a voiding material in flooded conditions. The plates were 35.6 cm wide by 91.5 cm long and 0.625 cm thick. The critical spacing between fuel assemblies was 8.67 cm. Lastly, experiment **p2438x28** contained stainless-steel-304 plates between three 20×16 fuel assemblies. The plates were 35.6 cm wide by 91.5 cm long and 0.485 cm thick. The critical spacing was 6.88 cm between assemblies.

DESCRIPTION OF 2.35 wt% ^{235}U ENRICHED UO_2 RODS



CLADDING: 6061 ALUMINUM TUBING SEAL WELDED WITH A LOWER END PLUG OF 5052-H32 ALUMINUM AND A TOP PLUG OF 1100 ALUMINUM

TOTAL WEIGHT OF LOADED FUEL RODS: 917 gm (AVERAGE)

LOADING:

825 gm OF UO_2 POWDER / ROD, 726 gm OF U/ROD, 17.08 gm OF U-235/ROD

ENRICHMENT - 2.35 ± 0.05 w/o U-235

FUEL DENSITY - 9.20 mg/mm^3 (84% THEORETICAL DENSITY)

Fig. A.5. Description of 2.35 wt % ^{235}U -enriched UO_2 fuel rods used in absorber plate experiments. *Source*: ref. 6.

experiments. Source: ref. 6.

Table A.2. Boral™ composition in experiment p2438x17

Element	Boral™ (2.49 g/cm ³) wt %
Al	62.39
B	28.70
C	7.97
Cr	0.05
Cu	0.09
Fe	0.33
Mg	0.05
Mn	0.05
Na	0.02
Ni	0.02
Si	0.20
S	0.03
Zn	0.10

Source: ref. 6.

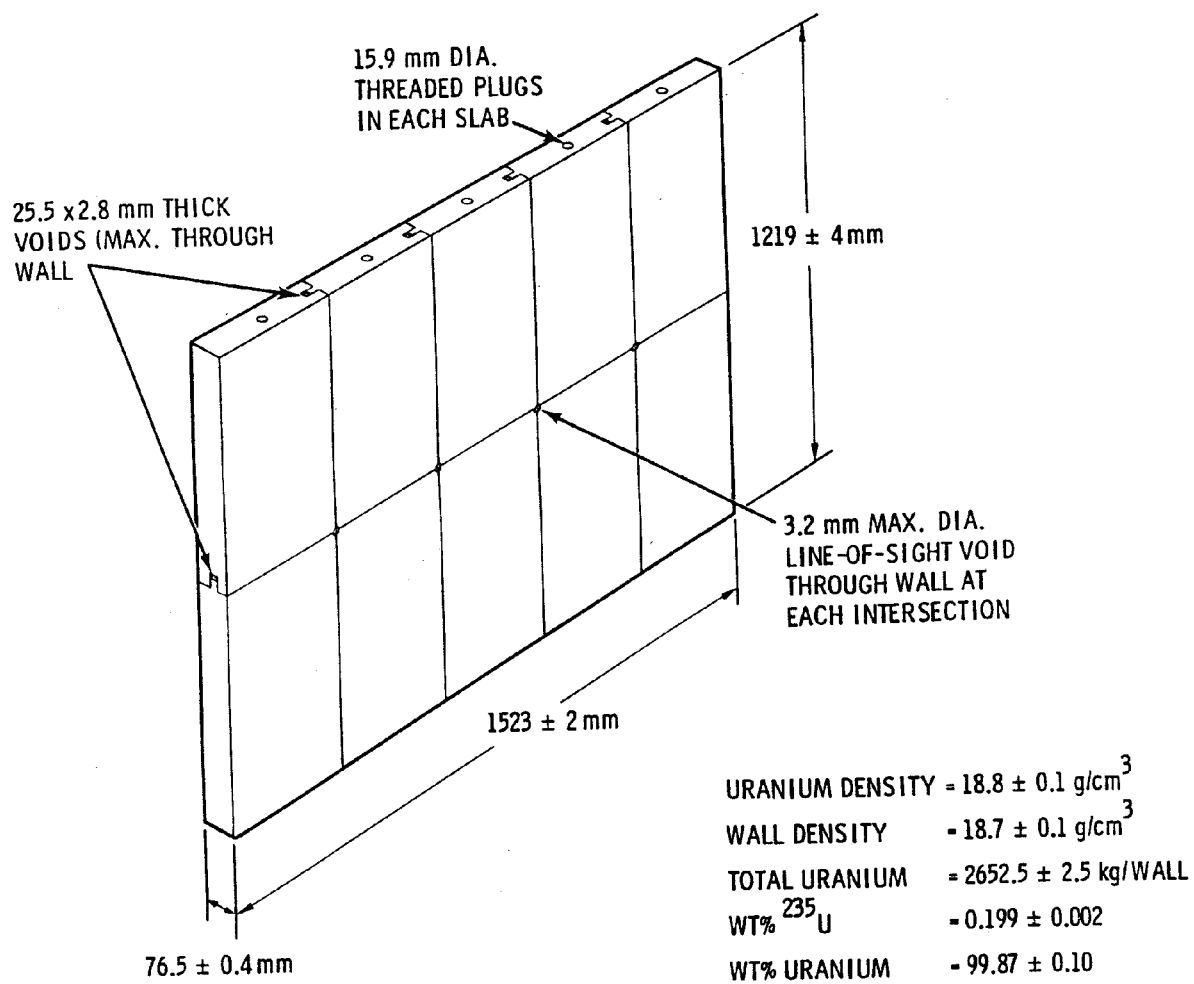
PNL-3926/3602 SHIELDING WALL EXPERIMENTS (CASES 7, 8, AND 9)

The third set of experiments^{7,8} (p3926l4a, p3926u49, and p3602s4) consisted of three fuel assemblies of 4.31 wt % UO₂ rods in a 1.892-cm-square lattice pitch arranged in a row, similar to the setup of the PNL-2438 absorber plate experiments. Shielding walls of depleted uranium, lead, or steel were positioned on both sides of the fuel assemblies, 1.956 cm from the cell boundary of the assemblies. These experiments simulate the effect of the cask shielding materials on k_{eff} .

The fuel in these experiments is identical to that used in the flux trap experiments, as described in Fig. A.1; the experimental setup is identical to that used in the absorber plate experiments, as illustrated in Fig. A.6. The three wall types are shown in Figs. A.7 through A.9. Each experiment utilized three 12 × 16 fuel assemblies. Criticality was controlled by the separation distance between assemblies. The separation distances were measured from rod surface to rod surface in these experiments and are listed in Table A.3.

PNL-4267 SOLUBLE BORON EXPERIMENTS (CASES 10, 11, 12, AND 13)

The fourth set of experiments⁹ was selected to examine the effects of adding soluble boron to the water moderator. These experiments used a single array of 4.31 wt % UO₂ rods at two different lattice pitches, 1.890 cm and 1.715 cm, in order to study the effect of water-to-fuel volume ratios on highly borated systems. Although the wide-pitched assembly (357 rods) required fewer rods to achieve criticality than the narrow-pitched assembly (509 rods) with no boron in the system, the



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Fig. A.7. Assembled depleted uranium wall for depleted uranium shielding wall experiment.
 Source: ref. 7.

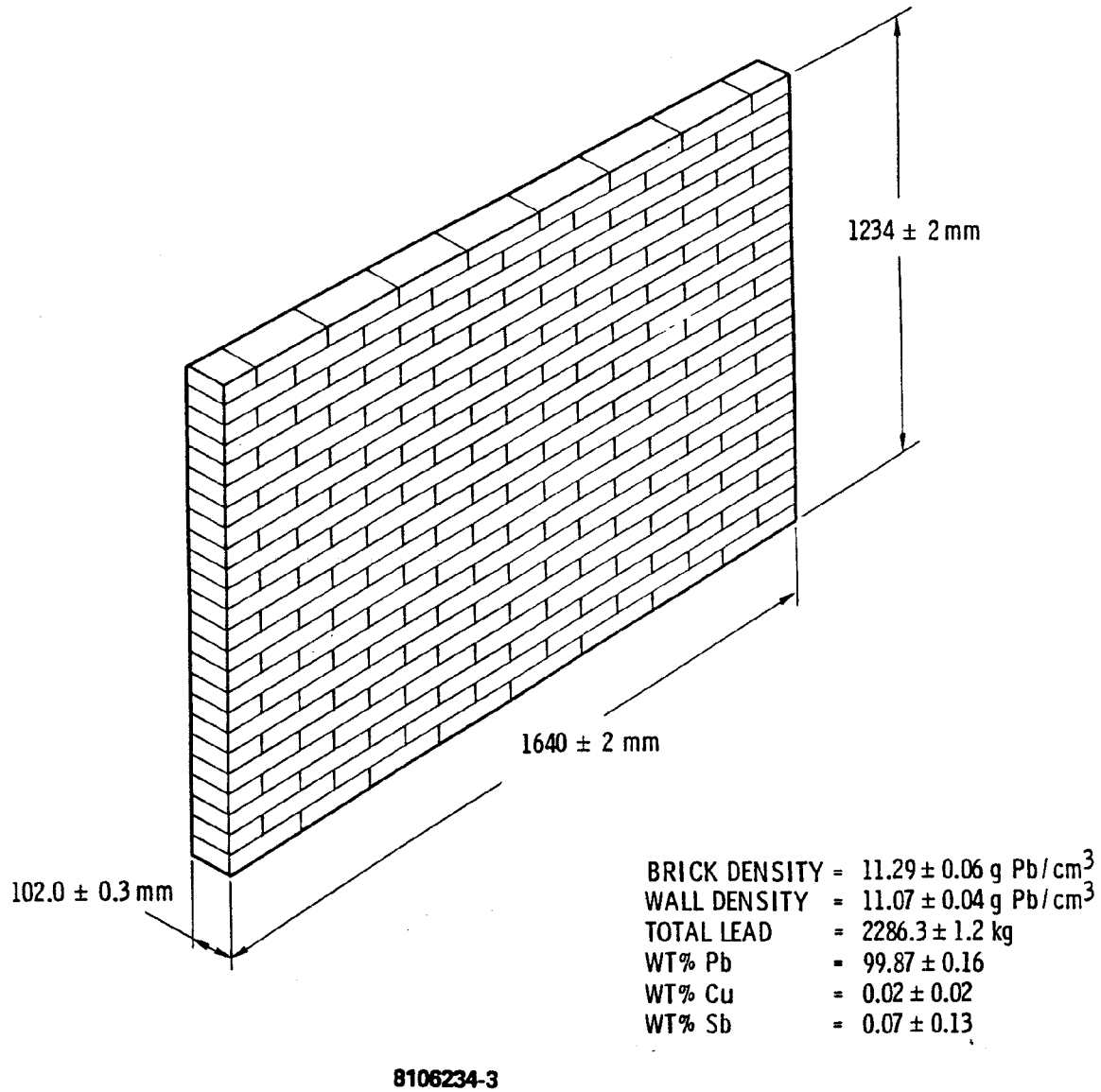


Fig. A.8. Assembled lead wall for lead shielding wall experiment. *Source:* ref. 7.

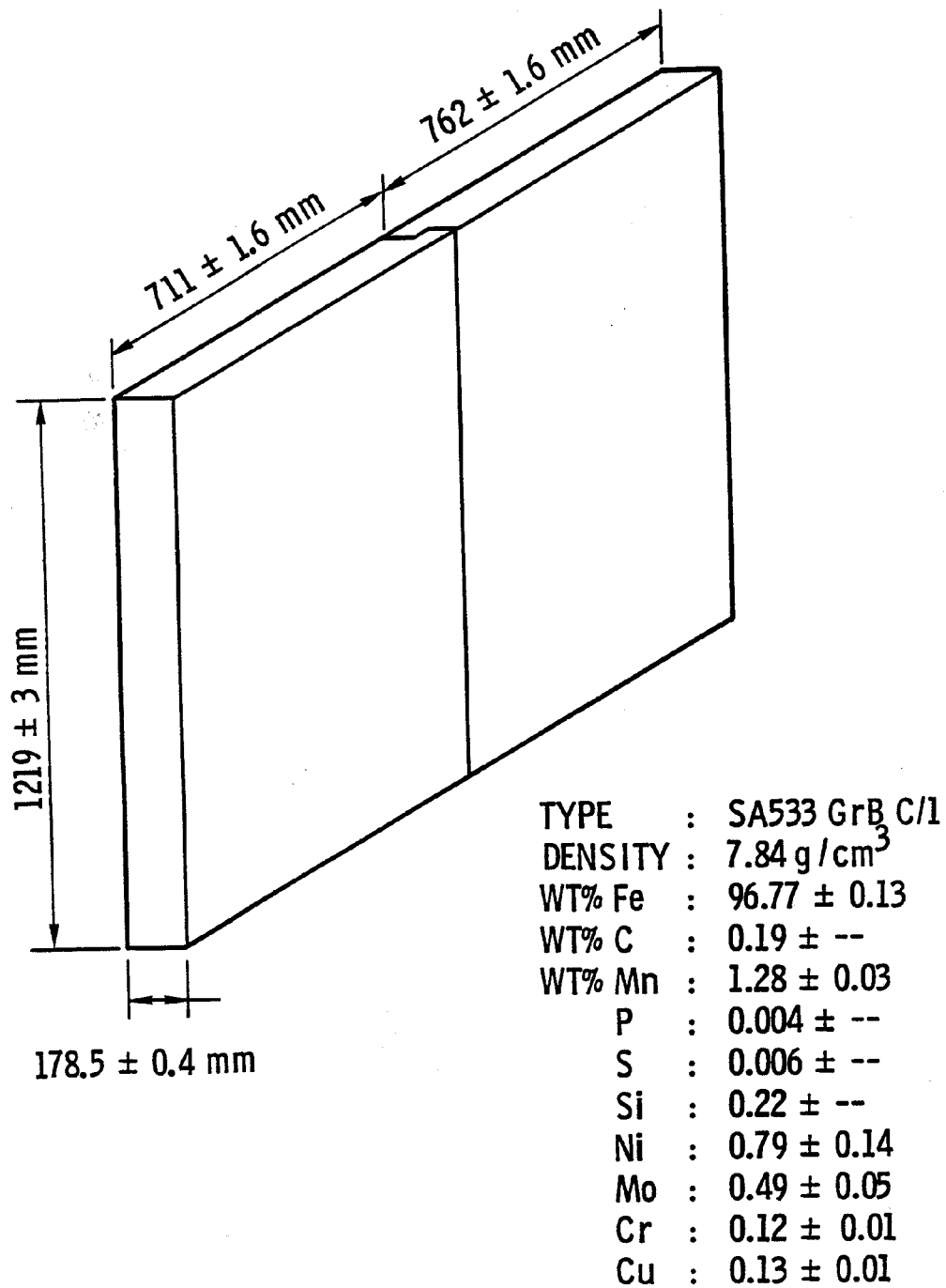


Fig. A.9. Assembled steel wall for steel shielding wall experiment. *Source*: ref. 8.

Table A.3. Critical separation between assemblies
for shielding wall experiments

Wall type	Critical separation (cm) ^a
Uranium	19.24 (ref. 7)
Lead	17.43 (ref. 7)
Steel	15.84 (ref. 8)

^a Measured from rod surface to rod surface of adjacent assemblies.

opposite was true for the borated cases (1237 vs 1192 rods, respectively). With no boron, the wide-pitched assembly has greater moderation and is more reactive than the narrow-pitched assembly, and therefore requires fewer fuel rods. For the borated cases, the greater moderation of the wide-pitched assembly results in greater boron worth and lower reactivity (requiring more fuel rods) compared with the narrow-pitched experiment.

The specifications for the 4.31 wt % UO_2 fuel rods are identical to those given previously in Fig. A.1. The experimental setup is illustrated in Fig. A.10. The container was surrounded by a unborated water reflector on all four sides. The boron concentration and array size for each experiment are given in Table A.4.

BAW-1484 ABSORBER ROD EXPERIMENT (CASE 14)

The next experiment,¹⁰ experiment **baw1484a**, consisted of nine fuel assemblies of 2.46 wt % UO_2 arranged in a 3×3 array. Each assembly was a 14×14 array of fuel rods with a 1.636-cm lattice pitch. The assemblies were separated by a water gap containing 84 equally spaced B_4C neutron absorber rods. The width of the water gap was equal to the fuel rod lattice pitch. Criticality was controlled by varying the water level. The aluminum-clad fuel rods are described in Table A.5 and Fig. A.11. The B_4C pins were aluminum tubes filled with natural B_4C powder. The aluminum tubes had a 1.113-cm outer diameter and a wall thickness of 0.089 cm. The bottom ends were sealed with aluminum plugs, 0.952 cm long, and the tops were sealed with removable cork plugs. Each pin contained 156 g of B_4C , which constituted a column that extended about 30 cm above the water level. The B_4C is compacted to a linear density of 0.879 g/cm, which is a density of 1.28 g/cm³. The certified chemical analysis of the B_4C powder is given in Table A.6. The experimental setup is illustrated in Figs. A.12 and A.13. The critical moderator level was 145.68 cm for this experiment.

B&W-1810 UO_2 EXPERIMENT FOR GADOLINIUM COMPARISON (CASE 15)

A set of three UO_2 - Gd_2O_3 experiments¹¹ was performed by B&W with various configurations. A baseline case using UO_2 only was performed, designated here as **bnw1810a**, using a combination of 4.02 wt % and 2.46 wt % UO_2 rods. Criticality was achieved by varying the soluble boron concentration in the moderator. The core configuration is illustrated in Fig. A.14, which gives a

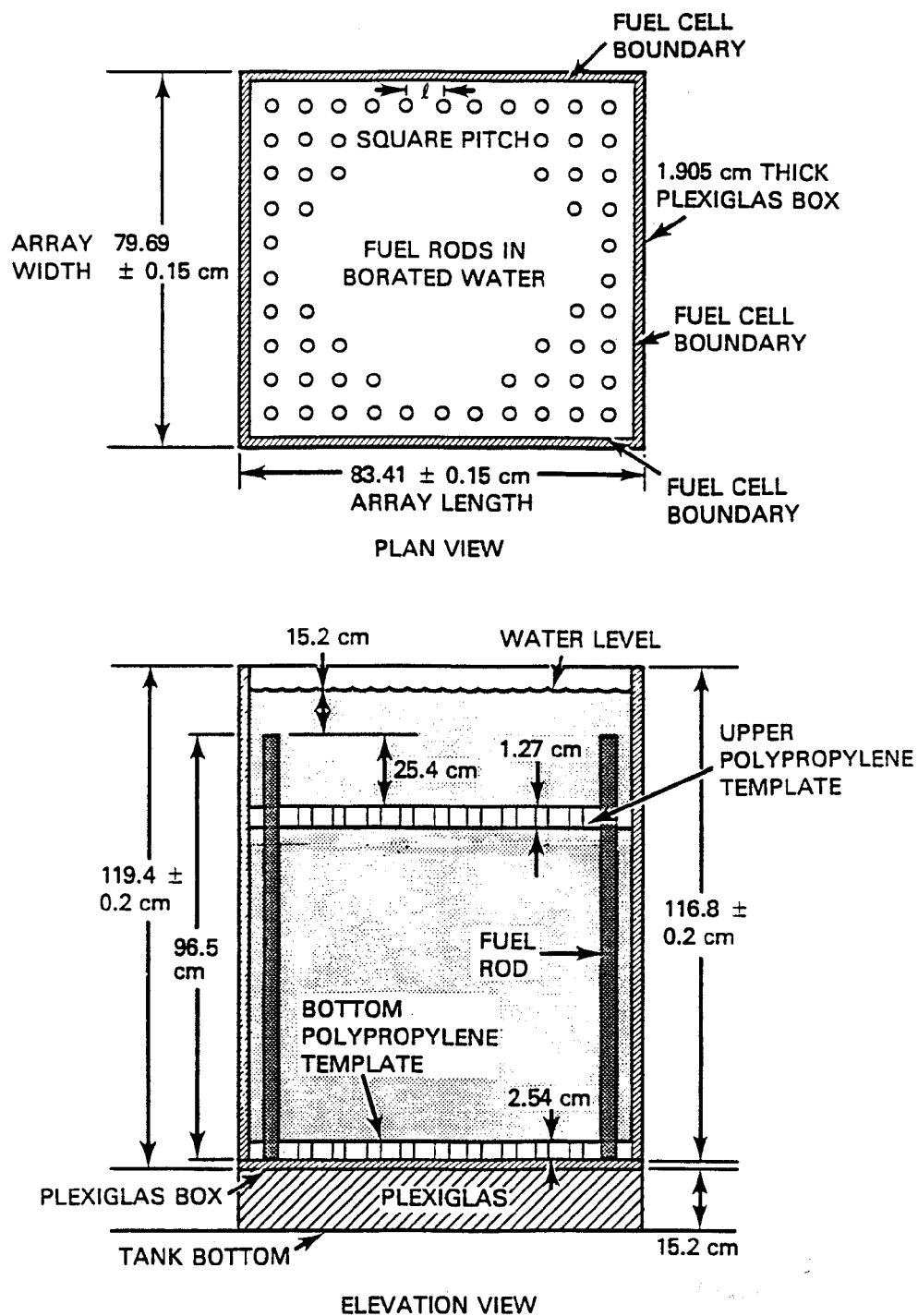


Fig. A.10. Experimental setup for soluble boron experiments. *Source:* ref. 9.

Table A.4. Critical array dimensions of soluble boron experiments

Experiment No.	Square pitch (cm)	Boron ^a concentration g/l	Critical array width No. of rods	Total rods ^b for criticality
173	1.890	0.0	40	357
177	1.890	2.55	40	1237
178	1.715	0.0	44	509
181	1.715	2.55	44	1192

^a Boron added in the form of H₃BO₃.

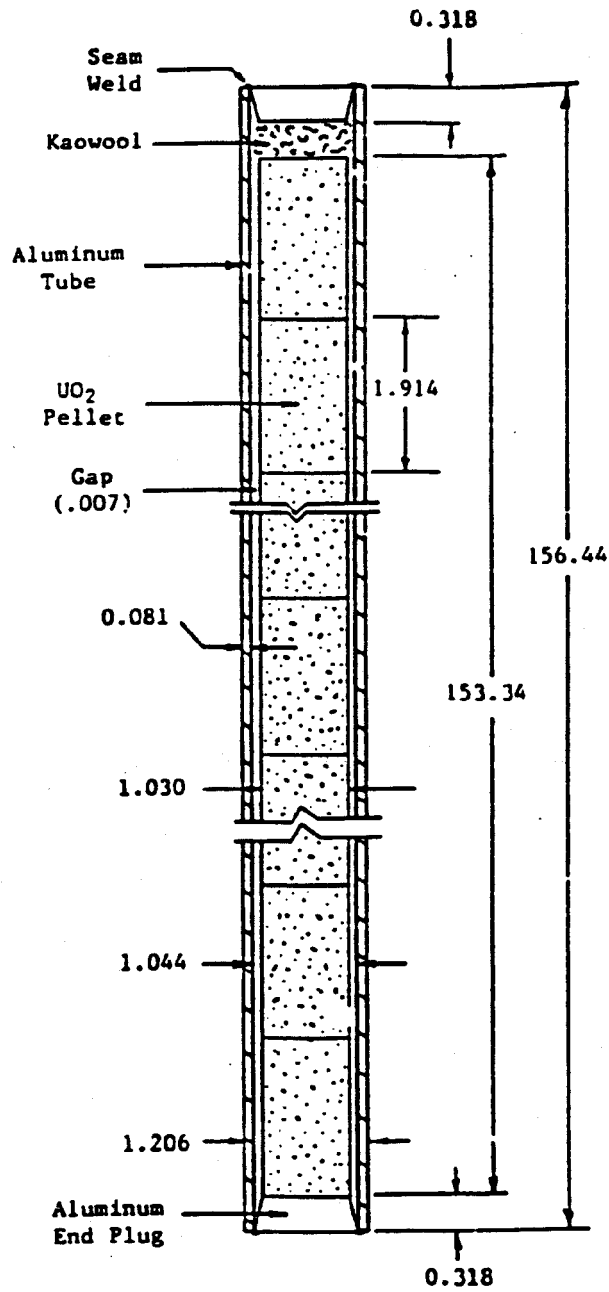
^b The error in critical rod number is <0.5%.⁹

Source: ref. 9.

Table A.5. Properties of 2.46% enriched UO₂ fuel rods in experiment **bawl484a**

Parameter	Value
Outside diameter, cm	1.206
Wall thickness, cm	0.081
Wall material	Aluminum
Pellet diameter, cm	1.030
Total length, cm	156.44
Active fuel length, cm	153.34
Pellet length, cm	1.914
Wt of UO ₂ , g/rod	1305.5
Wt U/wt UO ₂ , %	88.13
Wt of U, g/rod	1150.5
Wt of ²³⁵ U, g/rod	28.29
Enrichment, ²³⁵ U/U wt %	2.459
Pellet density, g/cm ³	10.29
Bulk density, g/cm ³	10.22

Source: ref. 10.



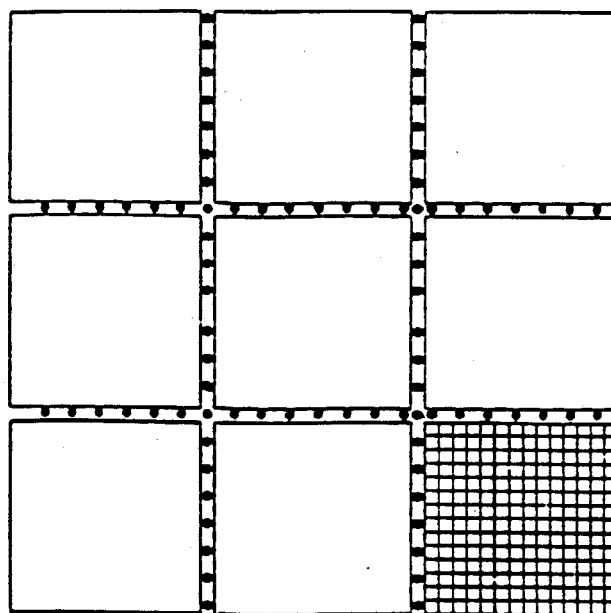
Note: All dimensions in centimeters.

Fig. A.11. Dimensions of 2.46% enriched UO₂ fuel rod in experiment **baw1484a**.
 Source: ref. 10.

Table A.6. Certified chemical analysis of
B₄C for experiment **bawl484a**

Total boron	77.8 wt %
Total carbon	20.8 wt %
Anhydrous B ₂ O ₃	0.10 wt %
Boron plus carbon	98.6 wt %

Source: ref. 10.



- Fuel Rod Position
- B₄C Pin

Note: The large squares represent 14 × 14 fuel assemblies as shown in the lower right-hand corner.

Fig. A.12. Experiment bawl484a loading diagram. *Source:* ref. 10.

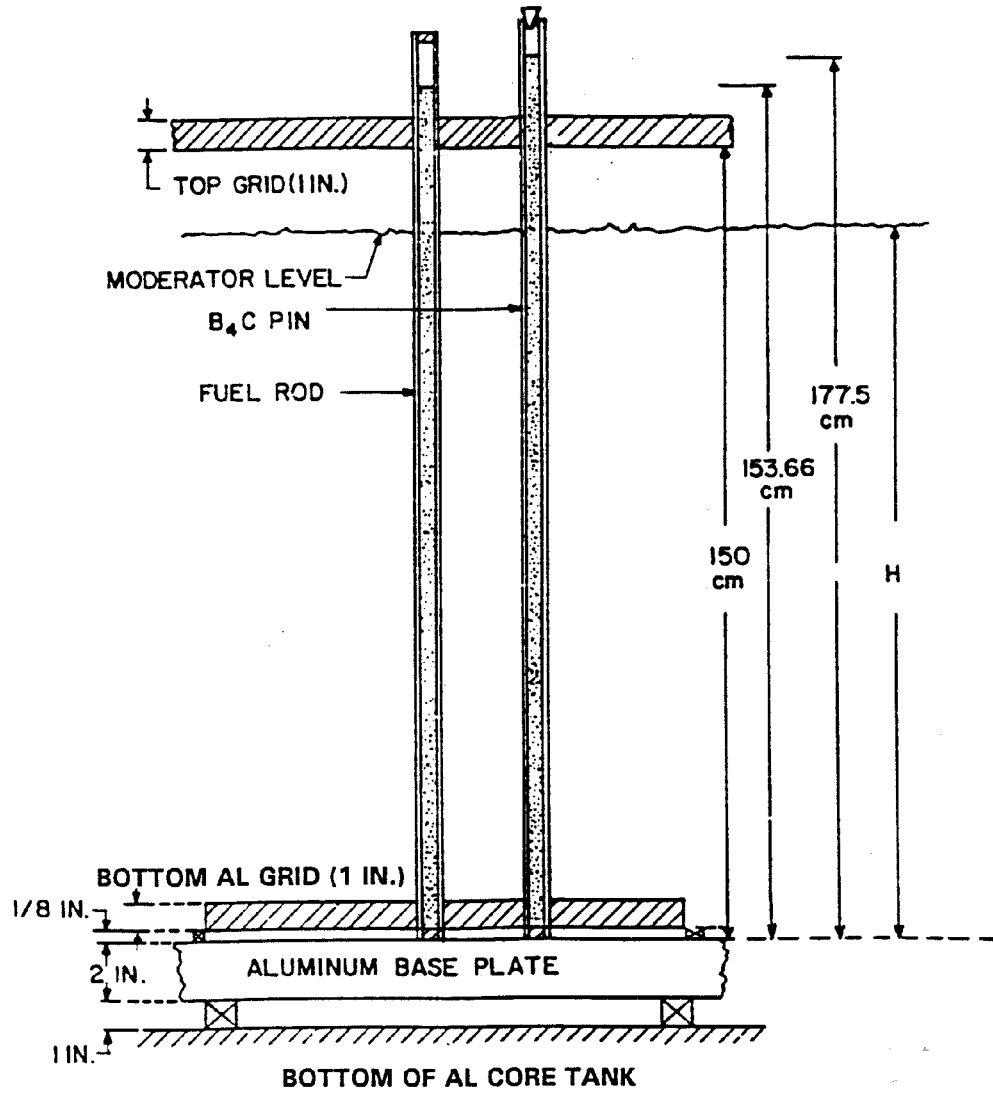


Fig. A.13. Experiment **baw1484a** vertical dimensions. *Source:* ref. 10.

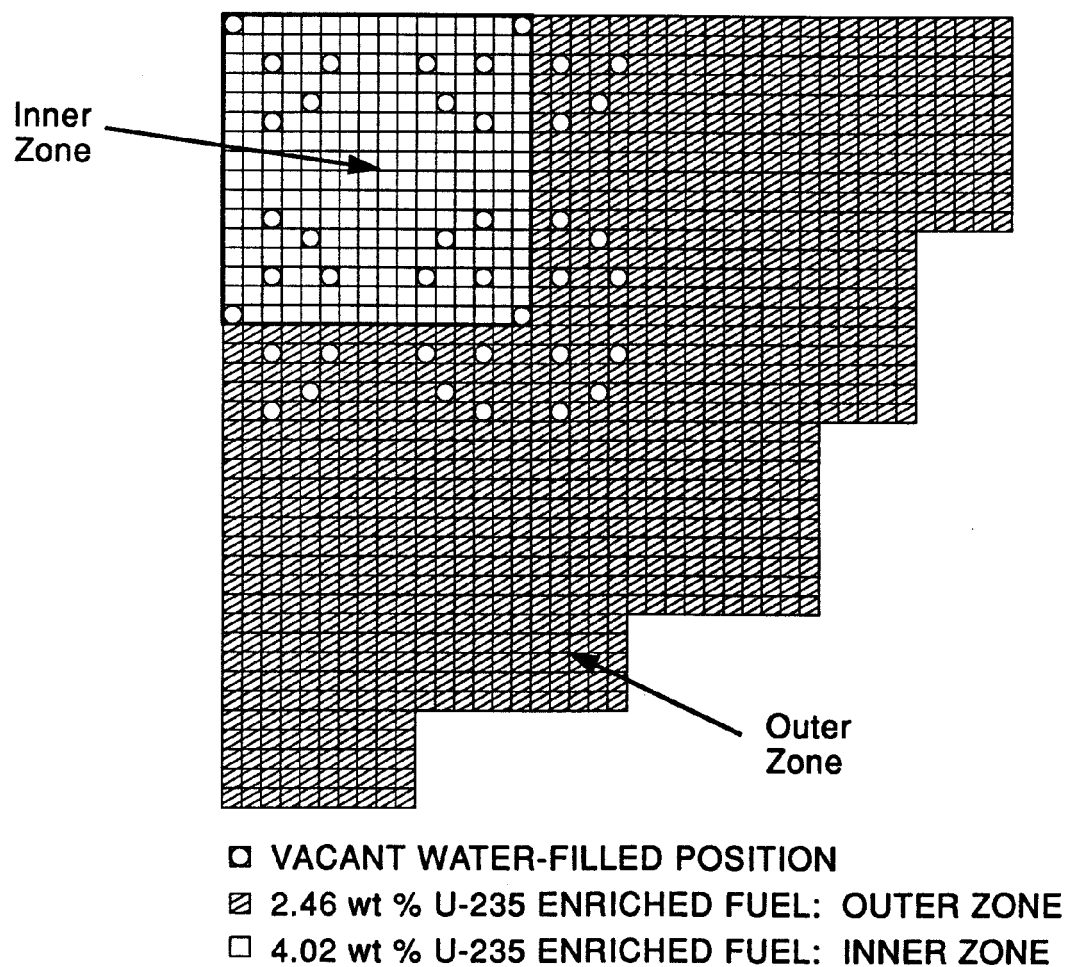


Fig. A.14. Experiment **bnw1810a** quarter-core (symmetric) loading diagram. *Source:* ref. 10.

quarter-core representation of the entire core. As shown in the figure, the core was divided into two fuel zones. The inner zone of the core (31×31 lattice cells) was comprised of the 4.02 wt % fuel; the physical properties of this fuel are given in Table A.7. The outer zone of the core was comprised of 2.46 wt % fuel, identical to that used in the absorber rod experiment of case 14, as described in Table A.5 and Fig. A.11. The core critical conditions are described in Table A.8.

EPRI-196 UO_2 EXPERIMENTS FOR MOX COMPARISON (CASES 16 AND 17)

Several experiments were performed at Pacific Northwest Laboratory (PNL) for the Electric Power Research Institute (EPRI) to study the effect of the presence of plutonium isotopes in LWR-type fuel.¹² In these experiments, MOX fuel rods were used, composed primarily of UO_2 (98 wt %), with the balance being PuO_2 . To provide a baseline for assessing the effect of the Pu isotopes, two experiments (**e196u6n** and **e196u87c**) were performed using fuel rods comprised only of 2.35 wt % enriched UO_2 . The fuel rods used in these experiments were identical to those used in the earlier absorber plate experiments, as illustrated in Fig. A.5. The axial arrangement of the experiments is illustrated in Fig. A.15. At least 12 in. of water was located below the lower solid aluminum plate. The specifications for the aluminum "eggcrate" grids are given in Fig. A.16. This figure shows dimensions for both the UO_2 and MOX lattices; the details of the MOX experiments will be discussed later in this Appendix. Note that a single grid spacer was used for both the 0.615-in. (1.562-cm) and 0.870-in. (2.210-cm)-pitch experiments, **e196u6n** and **e196u87c**, respectively. This was accomplished by loading every other lattice location in the wider lattice spacing experiment for each grid. This alternative arrangement increased the lattice spacing by a factor of $\sqrt{2}$. The core layouts for the experiments are shown in Figs. A.17 and A.18. A water reflector of at least 12 in. was located on all sides of each experiment. The number of rods and boron concentrations at critical are given in Table A.9.

SAXTON UO_2 EXPERIMENTS FOR MOX COMPARISON (CASES 18 AND 19)

A series of MOX and UO_2 critical experiments was also performed at the Westinghouse Reactor Evaluation Center (WREC) as part of the Saxton Plutonium Program.¹³ Like the EPRI-196 experiments, two UO_2 -only experiments (saxu56 and saxu792) were performed to provide a nonplutonium basis for comparison with plutonium-bearing experiments. However, the UO_2 fuel was a relatively highly enriched 5.74 wt % ^{235}U , compared with 2.35 wt % in the EPRI set. Each of these experiments consisted of a single array of fuel rods in a square-lattice arrangement, at different pitches. The fuel rod specifications are provided in Table A.10. The fuel rods were loaded in single rectangular arrays as specified in Table A.11. An axial view of the experimental setup is shown in Fig. A.19. Three grid plates were used to support the fuel rods. The fuel rod holes in the aluminum grid plates were 1.008 cm in diameter. The grid plates were supported at each corner with 1.111-cm (7/16-in.) stainless steel support rods covered with 1.588-cm (5/8-in.) aluminum pipe.

Table A.7. Physical properties of 4.02 wt % enriched
UO₂ fuel rods in B&W-1810 experiments

Parameter	Value
Outside diameter, cm (in.)	1.2078 (0.4755)
Wall material	Type 304 stainless steel
Fuel diameter, cm (in.)	1.1278 (0.444)
Total length, cm (in.)	181.6 (71.5)
Active fuel length, cm (in.)	169.4 (66.7)
Weight of fuel, g/rod	1600
Weight of uranium, g/rod	1408
Weight of ²³⁵ U, g/rod	56.61
Enrichment, ²³⁵ U/U, wt %	4.020
Fuel density, g/cm ³	9.46

Source: ref. 11.

Table A.8. Experiment description for **bnw1810a**

Parameter	Value
Number of 2.46 wt % ²³⁵ U fuel pins	3920
Number of 4.02 wt % ²³⁵ U fuel pins	888
Number of gadolinium fuel pins	0
Number of water holes	153
Critical boron concentration (ppm)	1899.3 ± 0.9

Source: ref. 11.

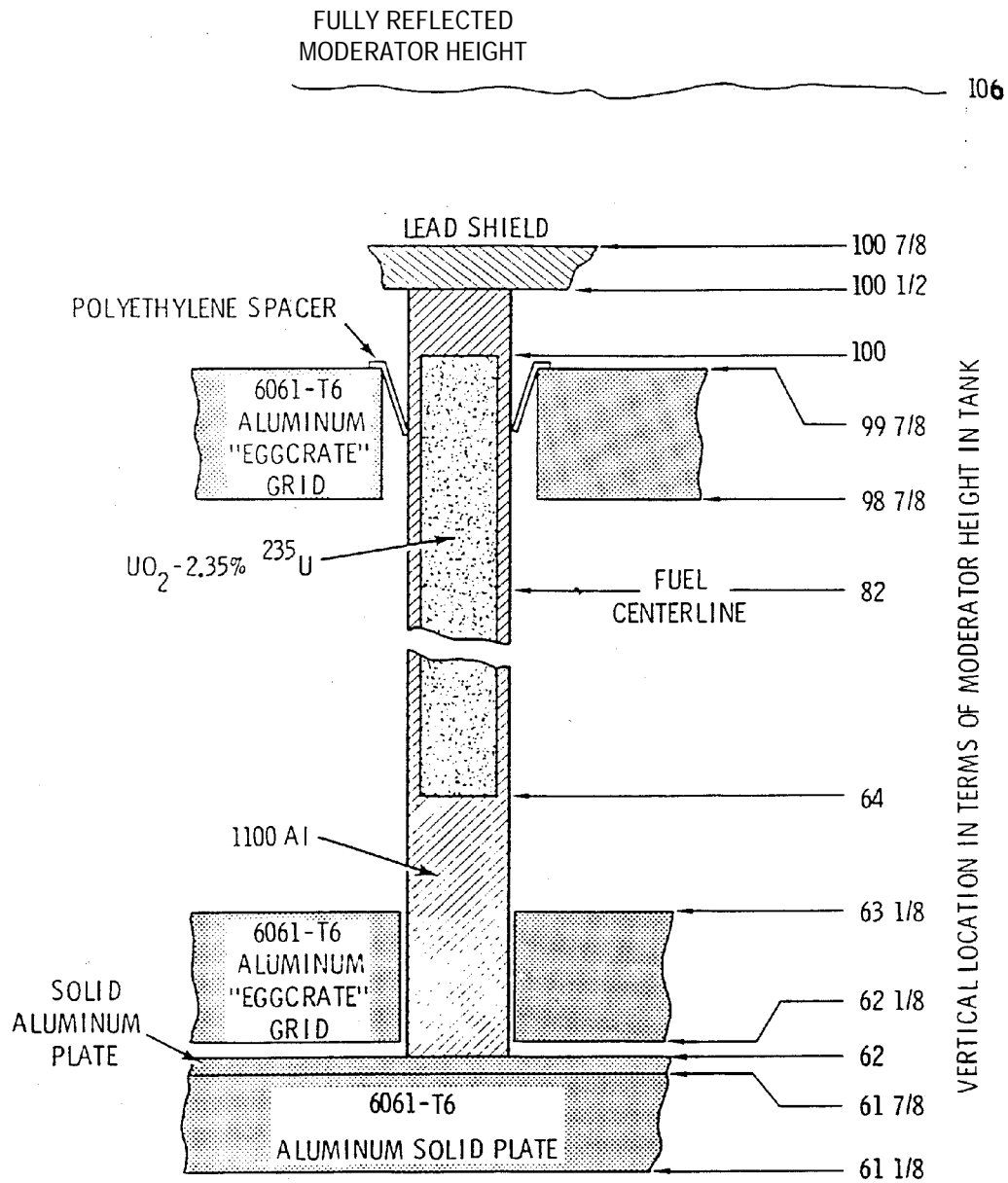
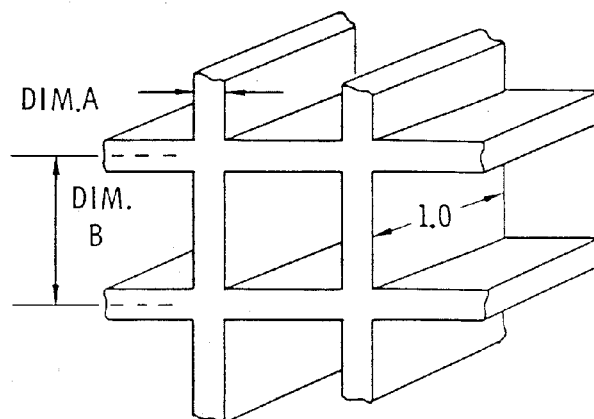


Fig. A.15. Axial core structure dimensions for EPRI-196 UO_2 experiments. *Source:* ref. 12.



FUEL TYPE	PITCH	GRID	DIM.A	DIM B
UO_2 -2.35% ^{235}U	0.615 0.87	UPPER LOWER	0.032 0.090	0.615
UO_2 -2 WT% PuO_2 (8% ^{240}Pu)	0.87	UPPER LOWER	0.032 0.032	0.615
UO_2 -2 WT% PuO_2 (8% ^{240}Pu)	0.70 0.99	UPPER LOWER	0.125 0.125	0.70

Fig. A.16. Dimensions of "eggcrate" lattice grids for EPRI-196 UO_2 and MOX experiments. *Source:* ref. 12.

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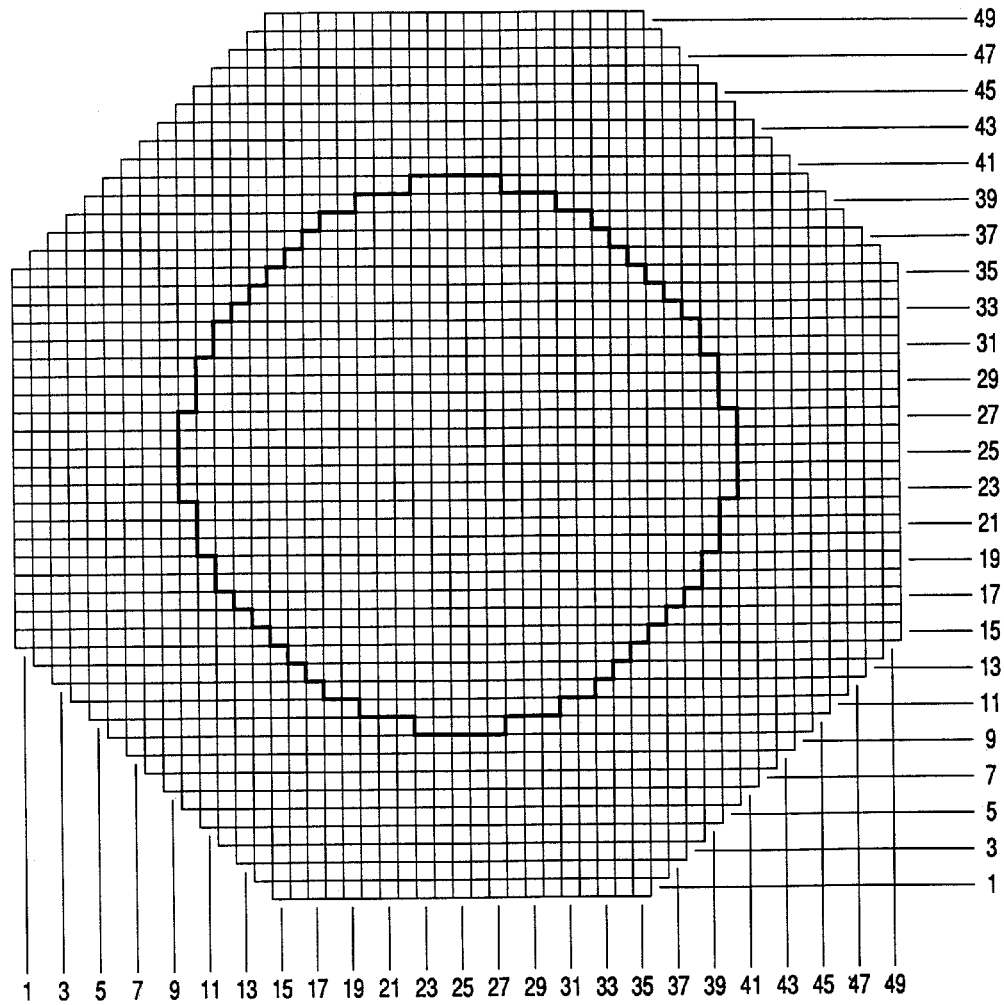


Fig. A.17. EPRI 0.615-in.-pitch UO₂ core. *Source:* ref. 12.

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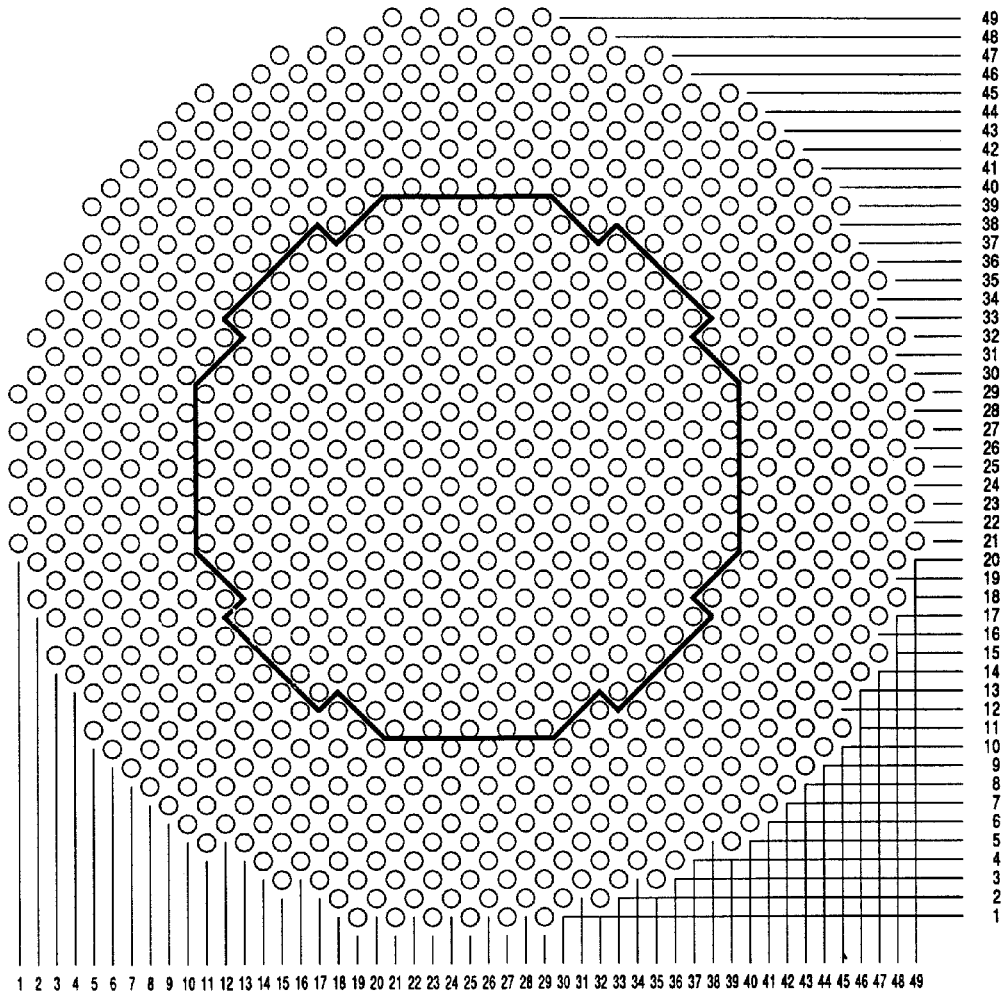


Fig. A.18. EPRI 0.870-in.-pitch UO_2 core. *Source:* ref. 12.

Table A.9. EPRI-196 UO₂ critical experiment descriptions

Fuel type	Pitch (in./cm)	Water/fuel volume ratio	Critical No. of rods	Boron concentration (ppm)
UO ₂	0.615/1.562	1.196	708	0.9
UO ₂	0.870/2.210	3.687	342	0.9

Source: ref. 12.

Table A.10. Saxton UO₂ fuel rod specifications

Pellet diameter, cm (in.)	0.907 (0.357)
Clad OD, cm (in.)	0.993 (0.391)
Clad ID, cm (in.)	0.917 (0.361)
Clad material	304 SS
% theoretical density	93
Fuel length, cm (in.)	92.96 (36.6)
Enrichment	5.74 wt % ²³⁵ U
Theoretical density (g/cc)	10.96 (UO ₂)
Weight percent of ²³⁹ Pu	N/A
Weight percent of ²⁴⁰ Pu	N/A
Weight percent of ²⁴¹ Pu	N/A
Weight percent of ²⁴² Pu	N/A

Source: ref. 13.

Table A.11. Saxton UO₂ critical experiment descriptions

Pitch (in./cm)	Water/fuel volume ratio	Critical H ₂ O height (cm)	Critical no. of rods	Boron concentration (ppm)
0.56/1.422	1.933	83.71	361 (19×19)	0
0.792/2.012	5.067	90.60	182 (13×14)	0

Source: ref. 13.

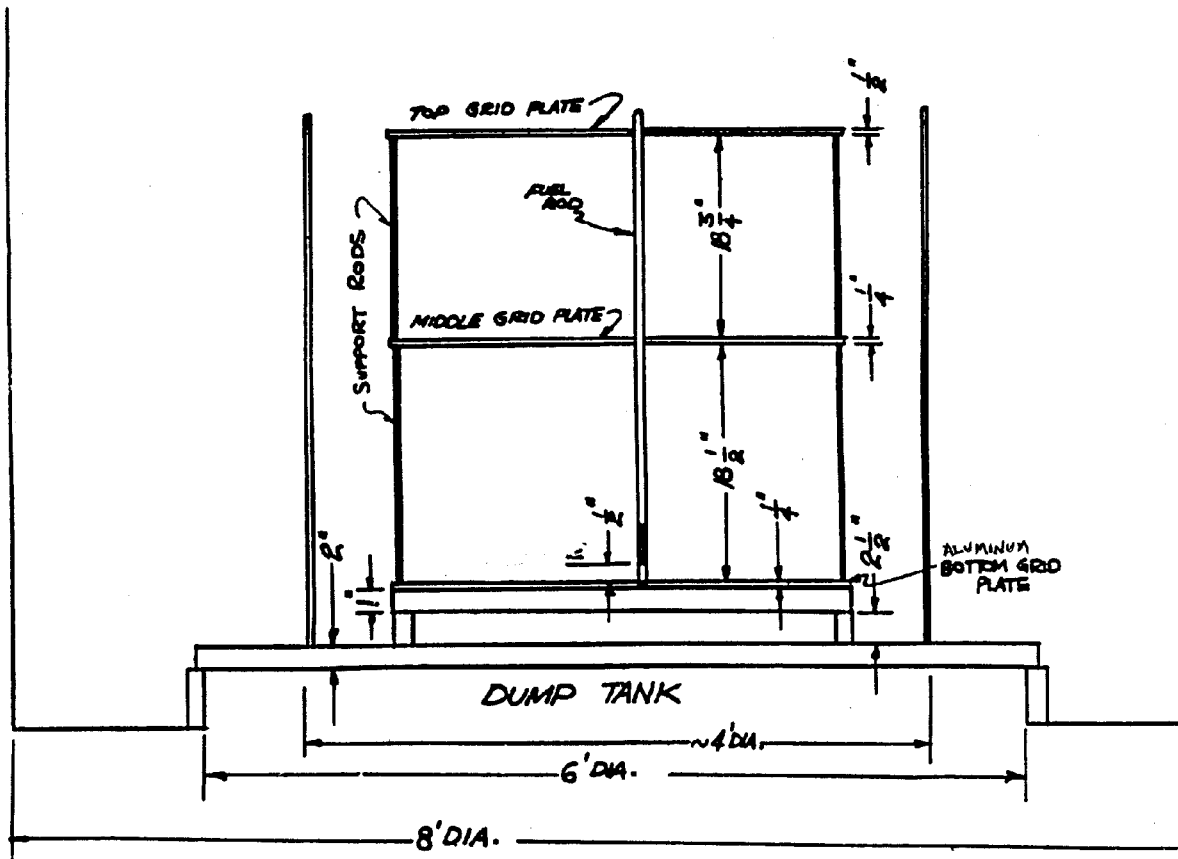


Fig. A.19. Axial view of Saxton experimental setup. *Source*: ref. 13.

UO₂ GADOLINIUM EXPERIMENTS (CASES 20 AND 21)

These two experiments (**bnw1810b** and **bnw1810c**)¹¹ were based on the UO₂-only configuration of case 15 (**bnw1810a**), with the addition of UO₂-Gd₂O₃ rods in place of selected 4.02 wt % UO₂-only rods. The UO₂-Gd₂O₃ fuel rods contained 4 wt % Gd₂O₃ and 96 wt % UO₂ (1.944 wt % ²³⁵U). The cores simulated a 15 × 15 lattice PWR checkerboard loading of assemblies containing the gadolinium fuel rods. The center 45 × 45 lattice cells of each core can be divided by imaginary lines into nine "fuel assemblies." Five of these assemblies contain varying numbers of UO₂-Gd₂O₃ fuel rods. The inner zone (31 × 31 lattice cells) contained 4.02 wt % UO₂ fuel rods, and the outer zone contained 2.46 wt % UO₂ fuel rods. The fuel loadings for the two experiments are described in Table A.12 and illustrated in quarter core representations in Figs. A.20 and A.21. The 2.46 wt % UO₂ fuel rods were described previously in Table A.5 and Fig. A.11; the 4.02 wt % UO₂ were described earlier in Table A.7. The UO₂-Gd₂O₃ rods are described below in Table A.13.

EPRI-196 MOX EXPERIMENTS (CASES 22–27)

Eight LWR fuel critical experiments conducted at PNL for EPRI included two UO₂-only (2.35 wt % ²³⁵U) and 6 MOX (98 wt % UO₂ and 2 wt % PuO₂) water-moderated experiments (epri70b, epri70un, epri87b, epri87un, epri99b, and epri99un).¹² The UO₂-only experiments were described earlier (cases 16 and 17). The PuO₂ in the MOX fuel contained 8 wt % ²⁴⁰Pu. Although the relative distribution of the plutonium isotopes differs from that found in burned LWR fuel, the ratio of Pu/²³⁵U (2.79) bounds that calculated for such fuel (approximately 1.01). MOX fuel rods were loaded in three different lattice pitches, both with and without boron. A description of the MOX rods is given in Fig. A.22. These experiments were performed from December 1975 to March 1976. The plutonium isotopic distribution and calculated atom densities based on an analysis performed in August 1976 are presented in Table A.14. As noted in the table, the ²⁴¹Pu and ²⁴¹Am number densities were then adjusted to February 1976 based on a half-life of 14.5 years for ²⁴¹Pu. The axial view of the experiments is illustrated in Figs. A.23. There was at least 12 in. of water below the lower solid aluminum plate. The specifications for the aluminum "eggcrate" grids are given earlier in Fig. A.16. Note that the 0.87-in.-pitch experiments used a 0.615-in.-lattice-pitch grid and both the 0.70-in.- and 0.99-in.-pitch experiments used the 0.70-in. grids. This arrangement was accomplished by loading every other lattice location in the wider lattice spacing experiment for each grid. This increased the lattice spacing by a factor of $\sqrt{2}$. The core layouts for the experiments are shown in Figs. A.24 through A.29. A water reflector of at least 12 in. was positioned on all sides of each experiment.

SAXTON MOX EXPERIMENTS (CASES 28–33)

A series of MOX and UO₂ critical experiments were also performed at the Westinghouse Reactor Evaluation Center (WREC) as part of the Saxton Plutonium Program.¹³ The MOX fuel in these experiments was 6.6 wt % PuO₂ (9 wt % ²⁴⁰Pu) compared with 2 wt % in the PNL experiments. The Pu/²³⁵U ratio was 10.02, compared with 2.79 in the other set. Each of these experiments also consisted of a single large array of fuel rods in a square lattice arrangement. Six MOX experiments at five different pitches were chosen (saxton52, saxton52b, saxtn735, saxtn792, and saxtn104).

Table A.12. Gadolinium experiment descriptions

Core	Core description	No. of 2.46 wt % ²³⁵ U fuel pins	No. of 4.02 wt % ²³⁵ U fuel pins	No. of Gd fuel pins	No. of water holes	Moderator boron concentration (ppm)
bnw1810b	15 × 15, 12 Gd pin configuration, checkerboard, 1/4 Gd loading in diagonals	3920	860	28	153	1653.8 ± 0.7
bnw1810c	15 × 15, 16 Gd pin configuration, checkerboard, 1/4 Gd loading in diagonals	3920	852	36	153	1579.4 ± 0.9

Source: ref. 11.

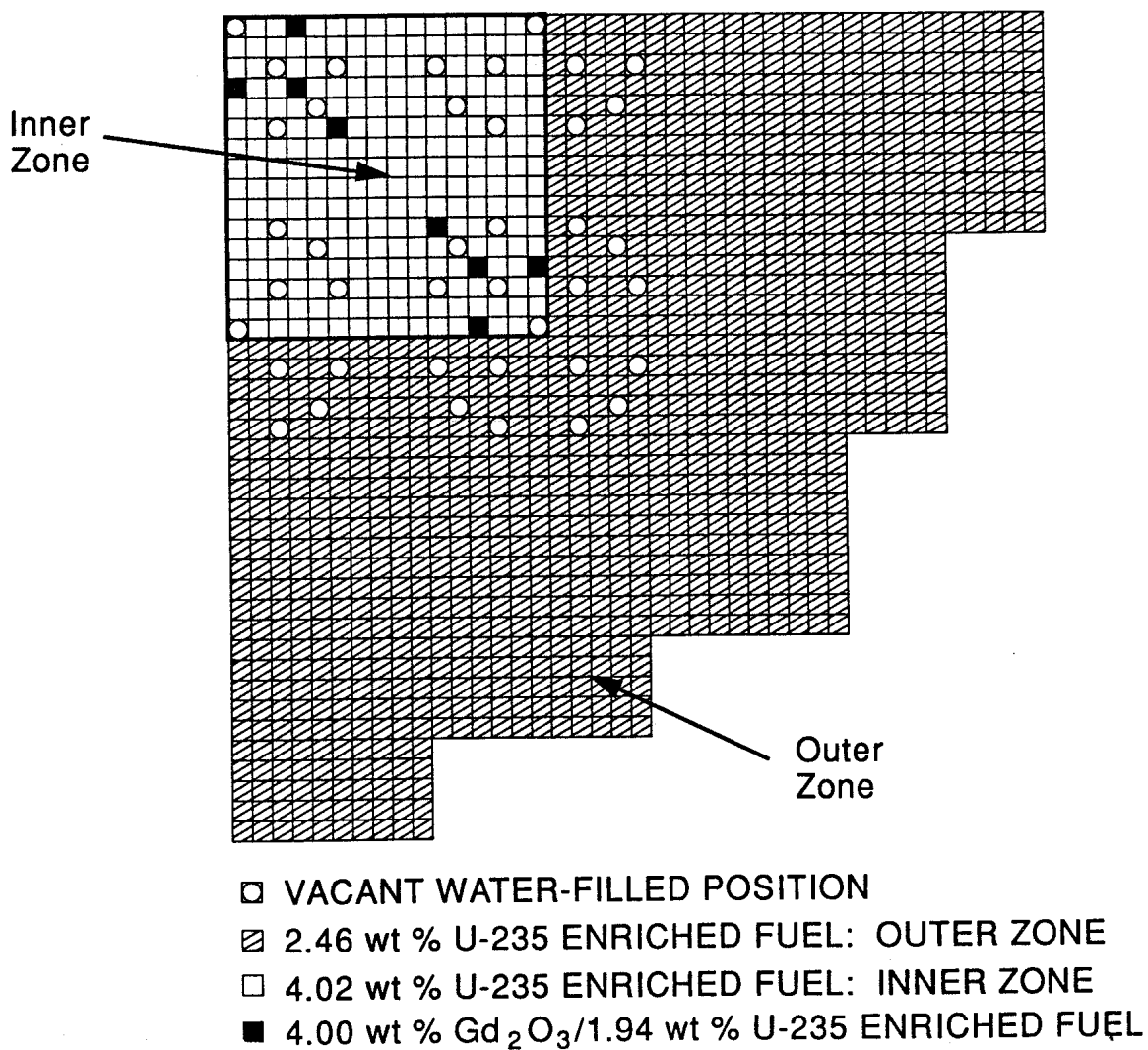


Fig. A.20. Gadolinium experiment **bnw1810b** quarter-core (symmetric) loading diagram.
 Source: ref. 11.

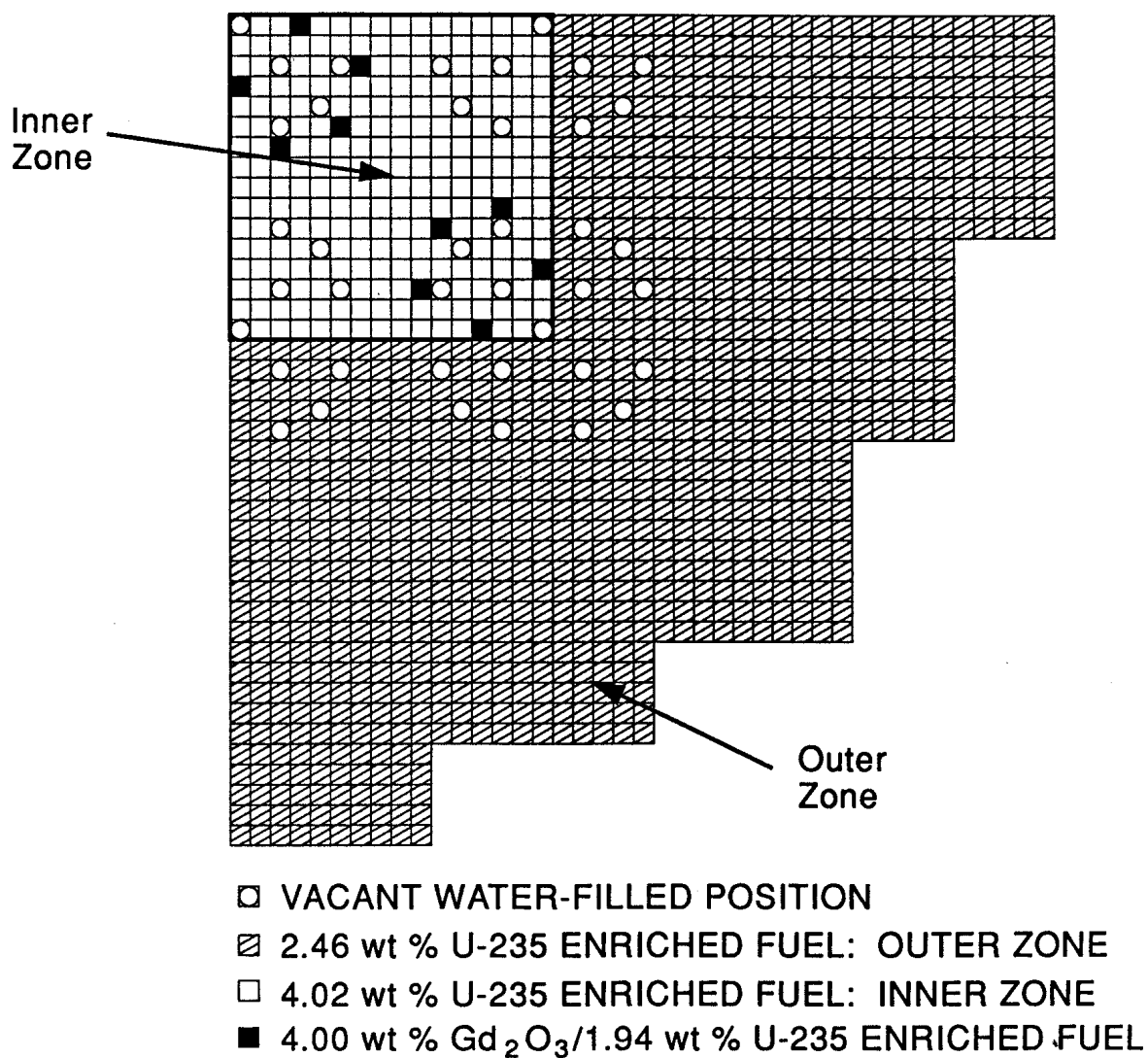


Fig. A.21. Gadolinium experiment **bnw1810c** quarter-core (symmetric) loading diagram.
 Source: ref. 11.

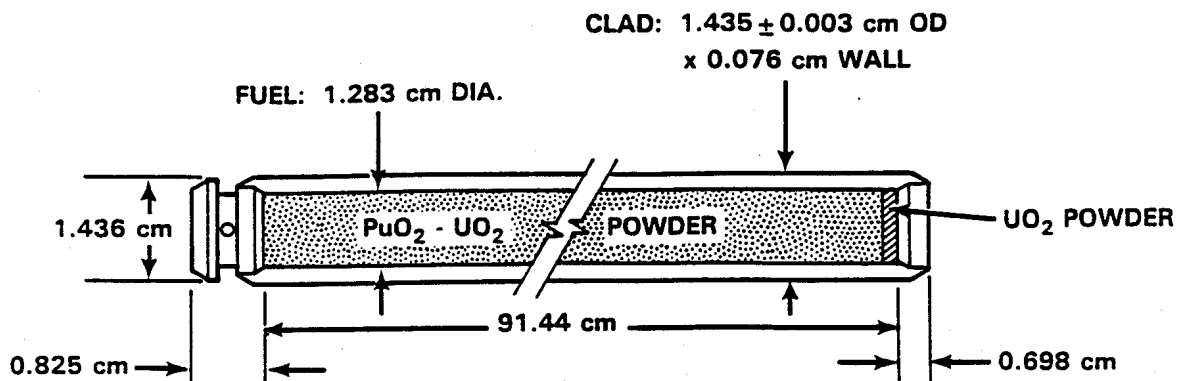
Table A.13. Physical properties of 1.944 wt % enriched
 $\text{UO}_2\text{-Gd}_2\text{O}_3$ fuel rods for gadolinium experiments

Parameter	Value
Outside diameter, cm (in.)	1.0973 (0.432)
Wall thickness, cm (in.)	0.0813 (0.032)
Wall material	Type 6063 aluminum
Fuel diameter, cm (in.)	1.030 (0.4055)
Total length, cm (in.)	160.0 (63.0) ^a
Active fuel length, cm (in.)	153.4 (60.4)
Wt % UO_2	96
Wt % Gd_2O_3	4
Enrichment, $^{235}\text{U}/\text{U}$, wt %	1.944
Fuel density, g/cm^3	10.22 ^b

^a Includes 0.125-in.-thick Al plug at top and bottom.

^b Assumed to be identical to that of the 2.46 wt % UO_2
 Al clad rods (see Table A.5).

Source: ref. 29.



CLADDING: ZIRCALOY-2 TUBING WITH PLUGS SEAL WELDED AT BOTH ENDS

LOADING:

ENRICHMENT - 2.00 WT% PuO_2 IN NATURAL UO_2

OXIDE DENSITY - 9.54 g/cm^3

$\text{PuO}_2 + \text{UO}_2$ - 1128g/ROD

Pu - 20.169 ± 0.004 g/ROD

U - 970.306 ± 0.225 g/ROD

UO_2 POWDER - NATURAL URANIUM ABOUT 0.2 cm THICK

Fig. A.22. Description of MOX fuel rods for EPRI experiments. *Source:* ref. 12.

Table A.14. MOX fuel compositions in EPRI experiments

Measured data		
Isotopic wt % $^{238}\text{Pu}^a$		0.009 ± 0.002
Isotopic wt % $^{239}\text{Pu}^a$		91.835 ± 0.018
Isotopic wt % $^{240}\text{Pu}^a$		7.760 ± 0.018
Isotopic wt % $^{241}\text{Pu}^a$		0.367 ± 0.004
Isotopic wt % $^{242}\text{Pu}^a$		0.028 ± 0.002
Concentration (ppm) $^{241}\text{Am}^b$		64.6 ± 0.3
Wt % U ^b		86.02 ± 0.06
Wt % Pu ^b		1.788 ± 0.001
Calculated atom densities of fuel constituents		
Isotope	Atom density (atoms/b-cm)	
	February 1976	August 1976
^{238}Pu		3.8850×10^{-8}
^{239}Pu		3.9477×10^{-4}
^{240}Pu		3.3218×10^{-5}
$^{241}\text{Pu}^c$	1.6023×10^{-6}	1.5645×10^{-6}
^{242}Pu		1.1887×10^{-7}
$^{241}\text{Am}^c$	1.5024×10^{-6}	1.5402×10^{-6}
^{234}U		1.2462×10^{-6}
^{235}U		1.4891×10^{-4}
^{236}U		2.0943×10^{-9}
^{238}U		2.0619×10^{-2}
Oxygen		4.3763×10^{-2}
ρ (oxide mixture) =		9.54 g/cm^3

^a Uncertainties are at the 95% confidence level (3σ).

^b Uncertainties are at the 67% confidence level (1σ). (ppm) ^{241}Am concentration is given in terms of the total $\text{UO}_2\text{-PuO}_2$ mixture weight.

^c Calculated as follows:

Half-life of $^{241}\text{Pu} = 14.5 \text{ y}$

$\lambda_{^{241}\text{Pu} \rightarrow ^{241}\text{Am}} = 0.047803/\text{y}$

$N_{^{241}\text{Pu}}(\text{February } 1976) e^{-\lambda t} = N_{^{241}\text{Pu}}(\text{August } 1976)$, where $t = 0.5 \text{ y}$

$N_{^{241}\text{Am}}(\text{February } 1976) = N_{^{241}\text{Am}}(\text{August } 1976) - \Delta^{241}\text{Pu}$.

Source: ref. 12.

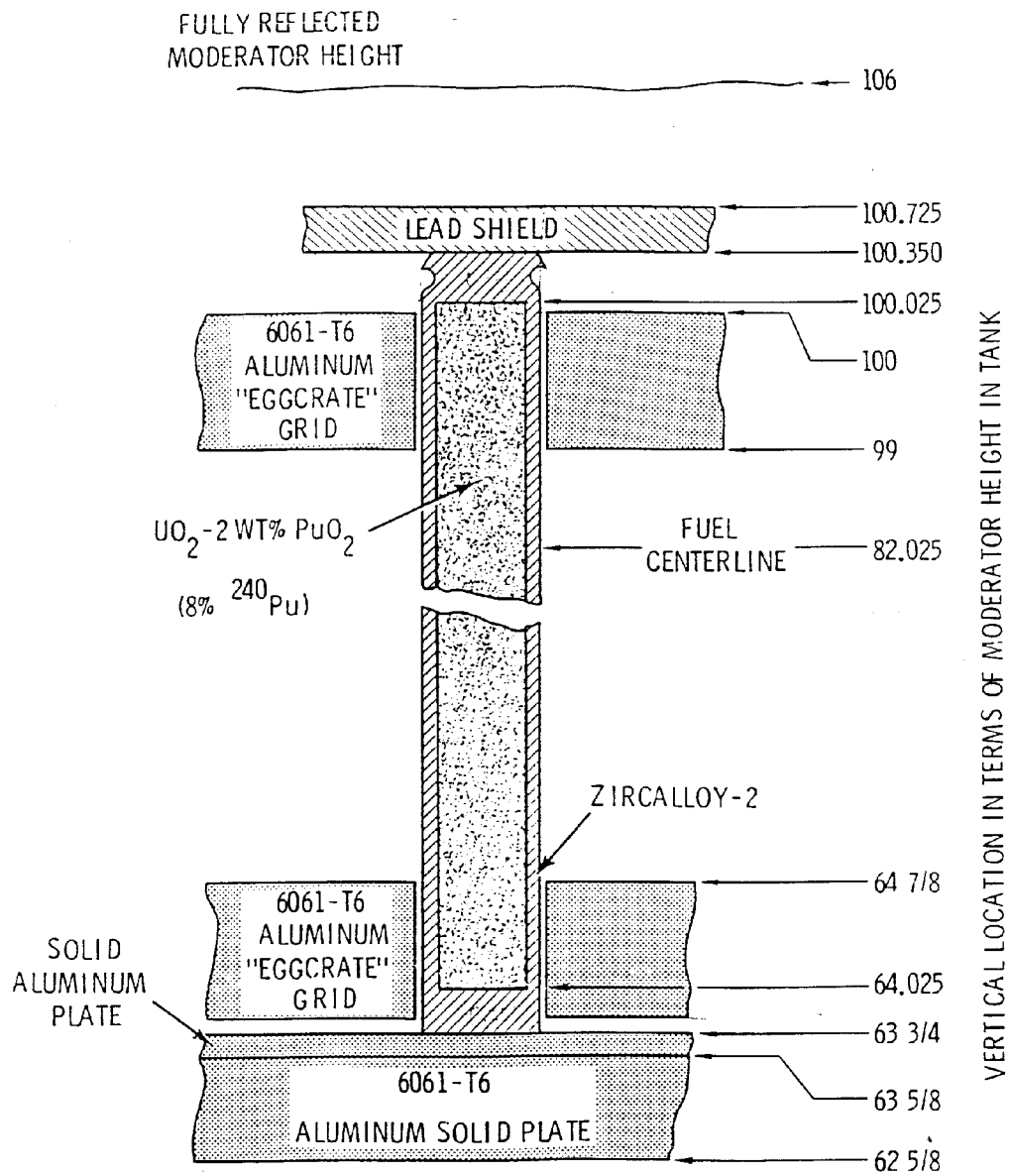


Fig. A.23. $\text{UO}_2-2\text{ wt } \% \text{PuO}_2$ "eggcrate" core structure dimensions for EPRI experiments.
 Source: ref. 12.

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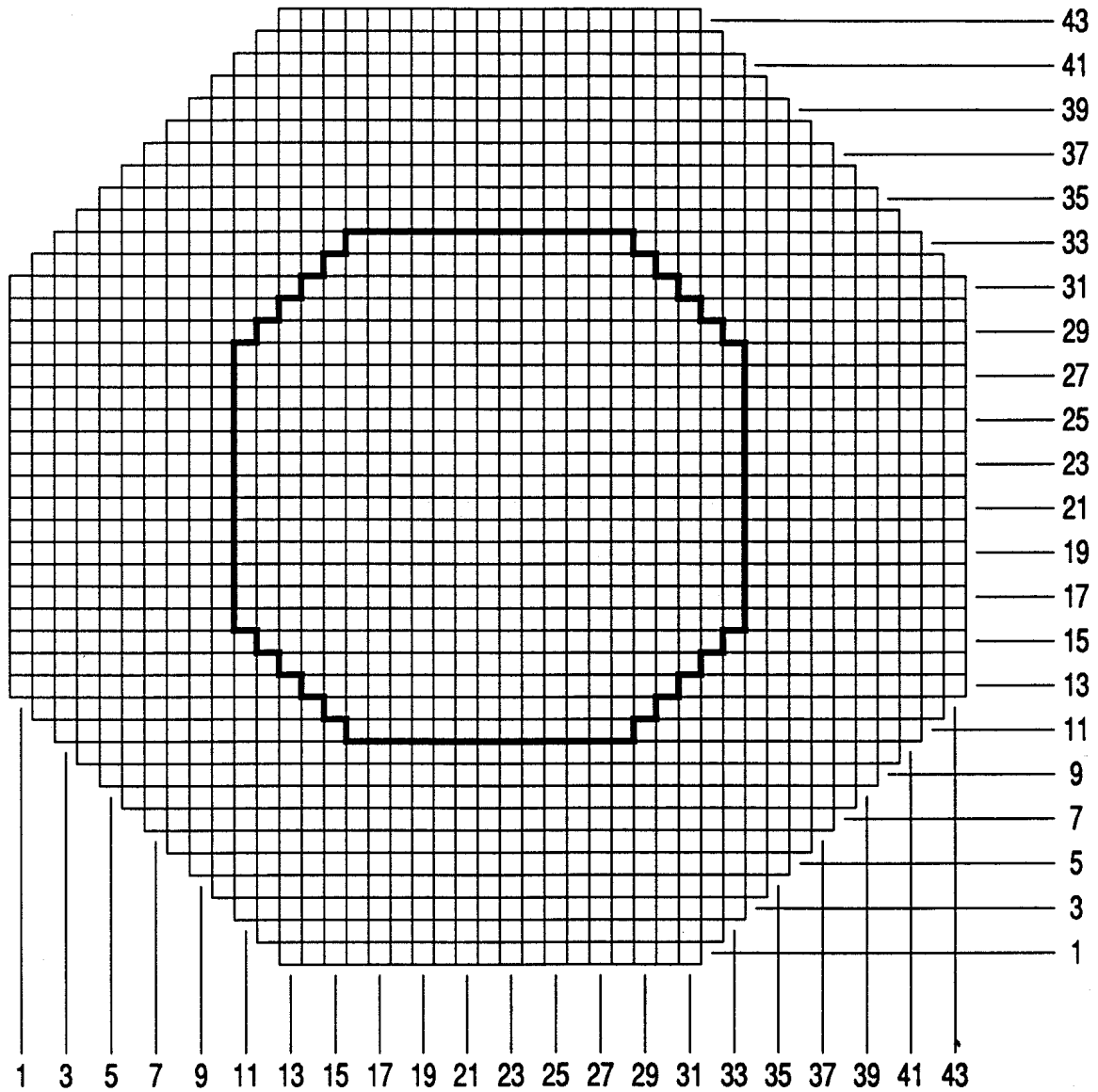


Fig. A.24. Unborated EPRI 0.70-in. UO_2 -2 wt % PuO_2 core. *Source:* ref. 12.

ORNL-DWG 93Z-13102

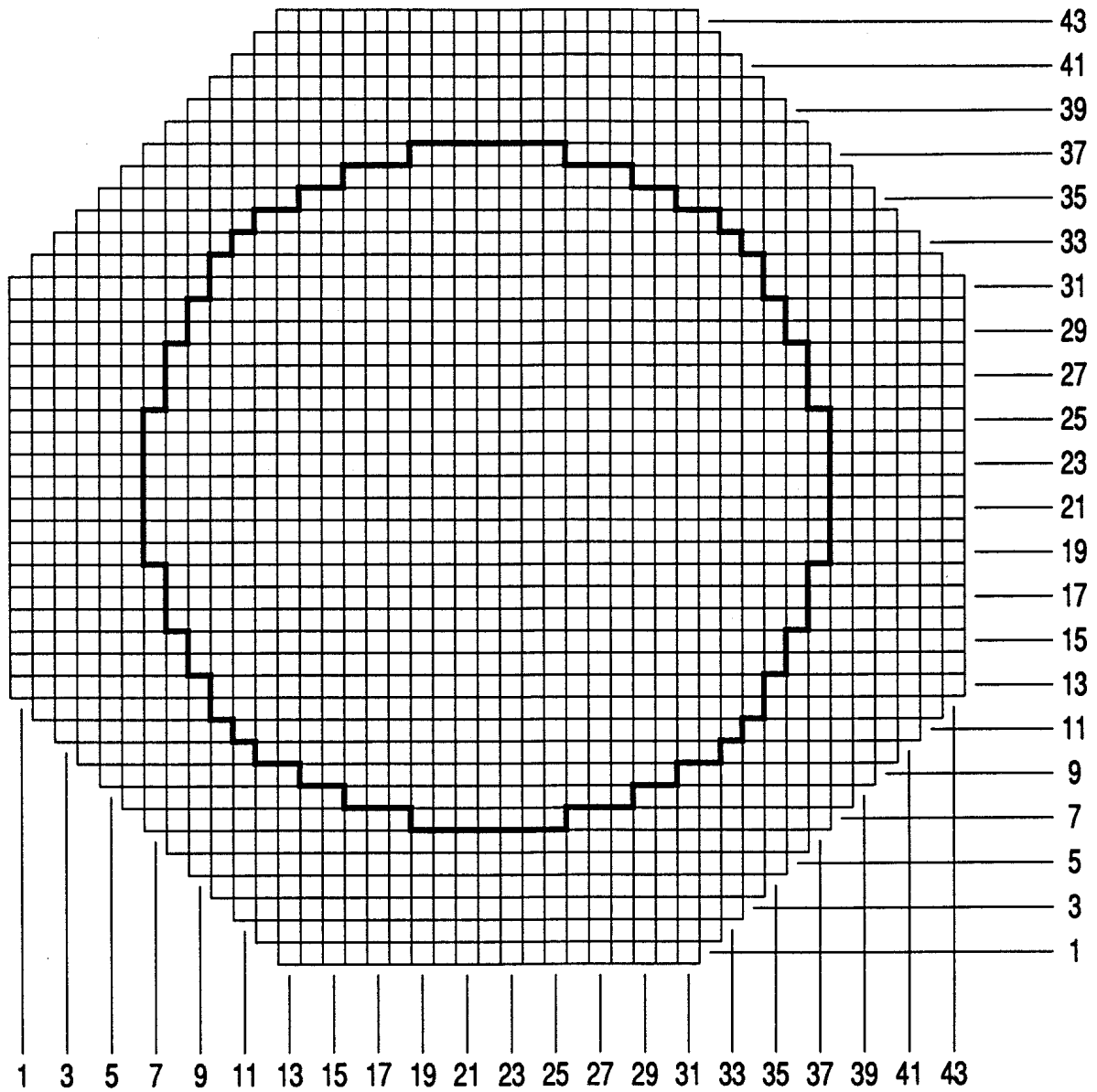


Fig. A.25. Borated EPRI 0.70-in. UO_2 -2 wt % PuO_2 core. *Source:* ref. 12.

ORNL-DWG 93Z-13095

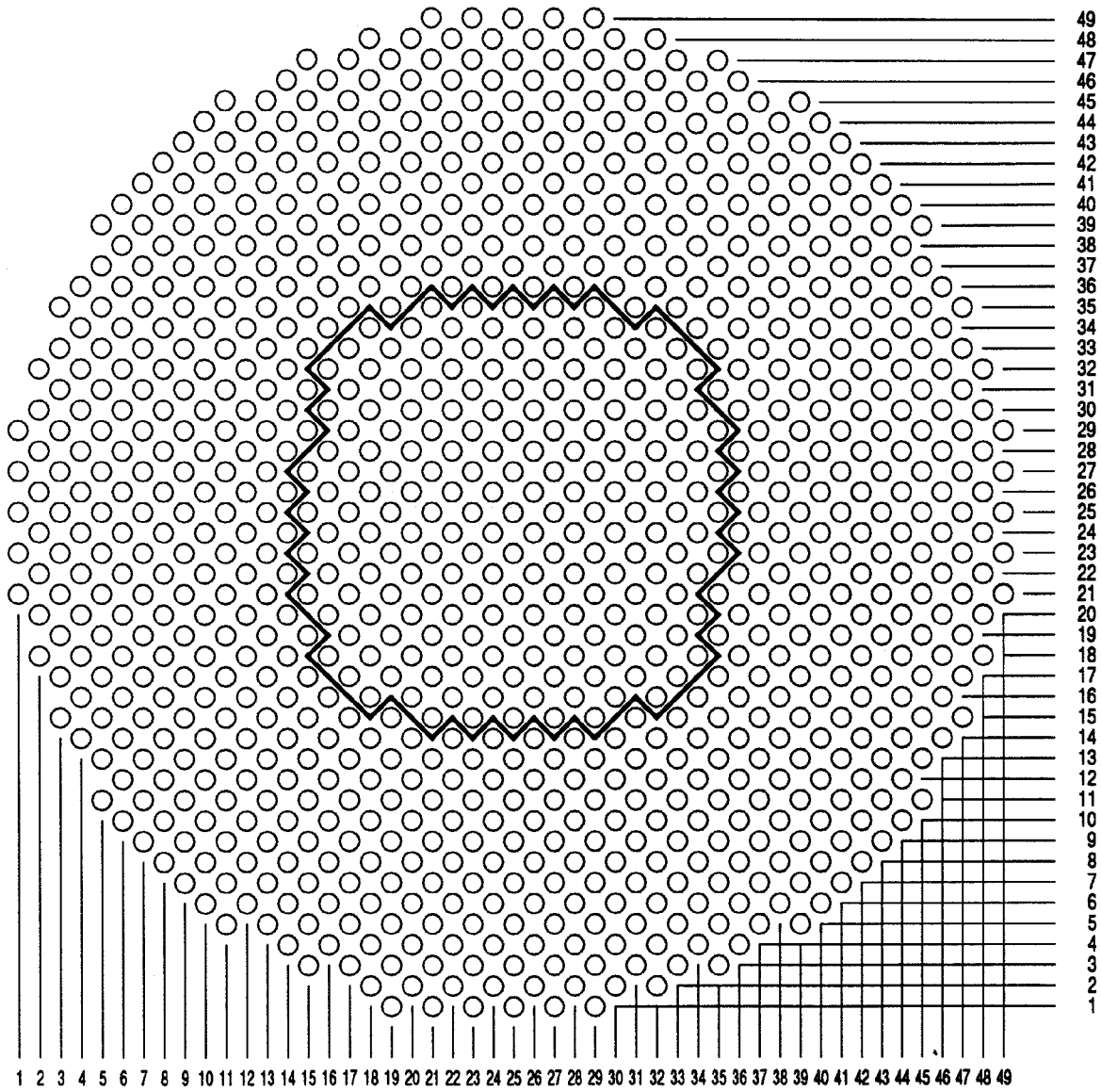


Fig. A.26. Unborated EPRI 0.87-in. UO_2 -2 wt % PuO_2 core. *Source:* ref. 12.

ORNL-DWG 93Z-13096

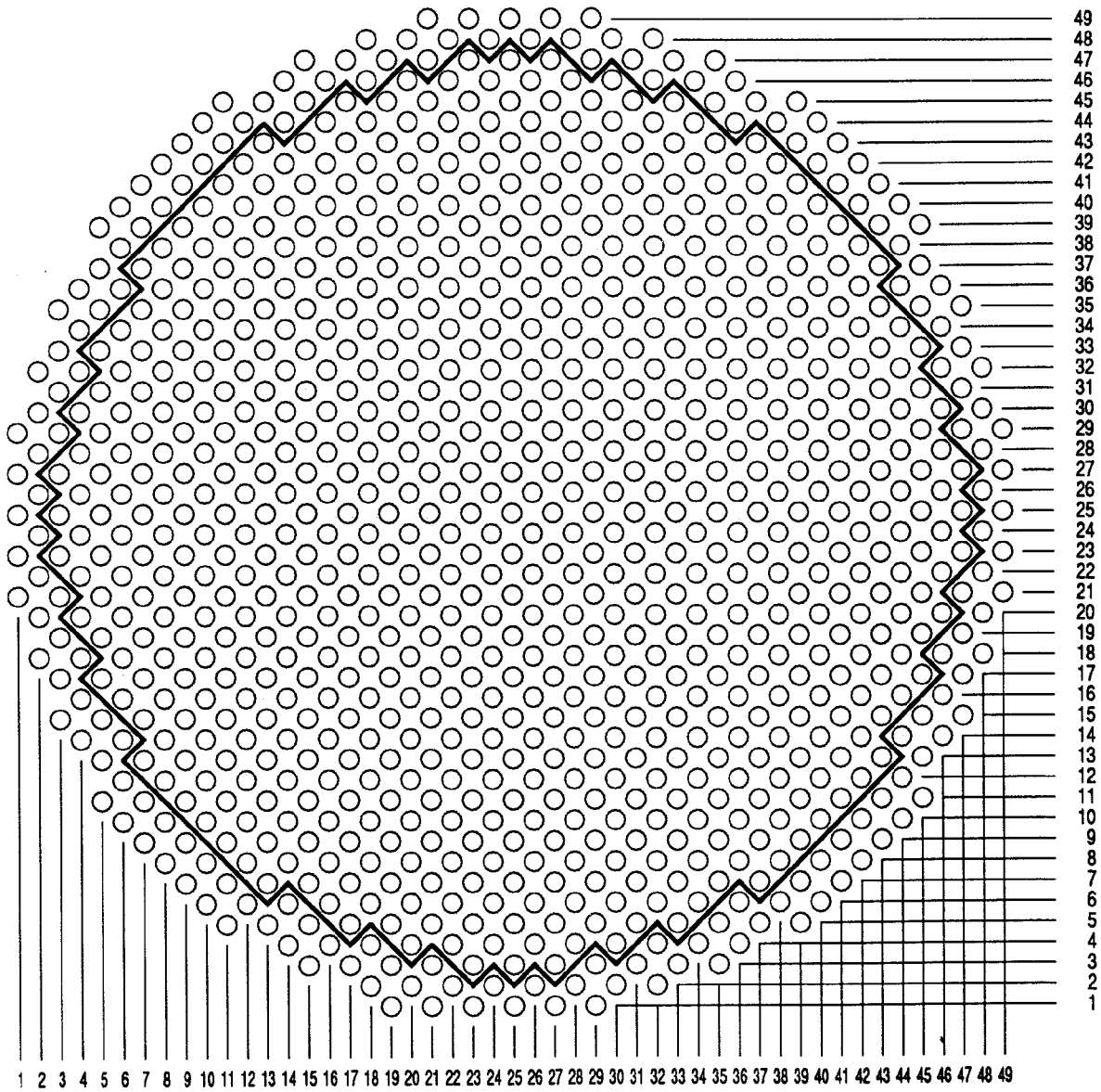


Fig. A.27. Borated EPRI 0.87-in. UO_2 -2 wt % PuO_2 core. *Source:* ref. 12.

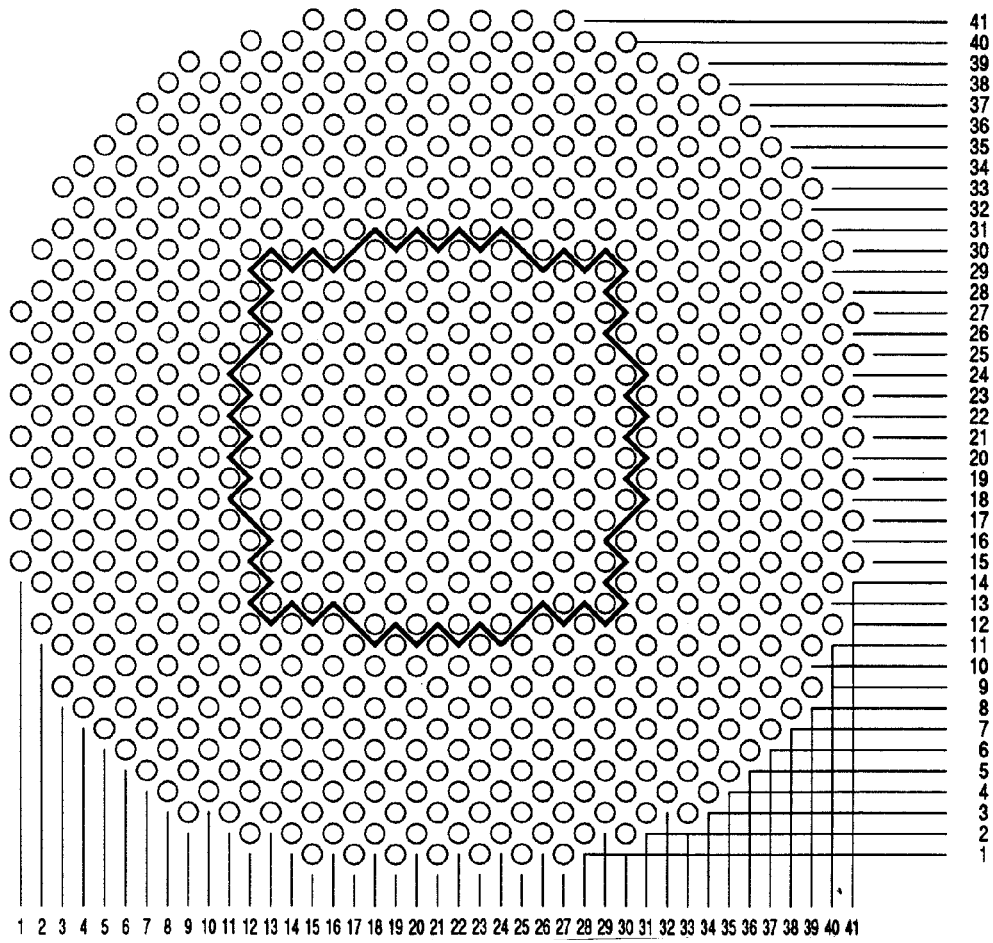


Fig. A.28. Unborated EPRI 0.99-in. UO_2 -2 wt % PuO_2 core. *Source:* ref. 12.

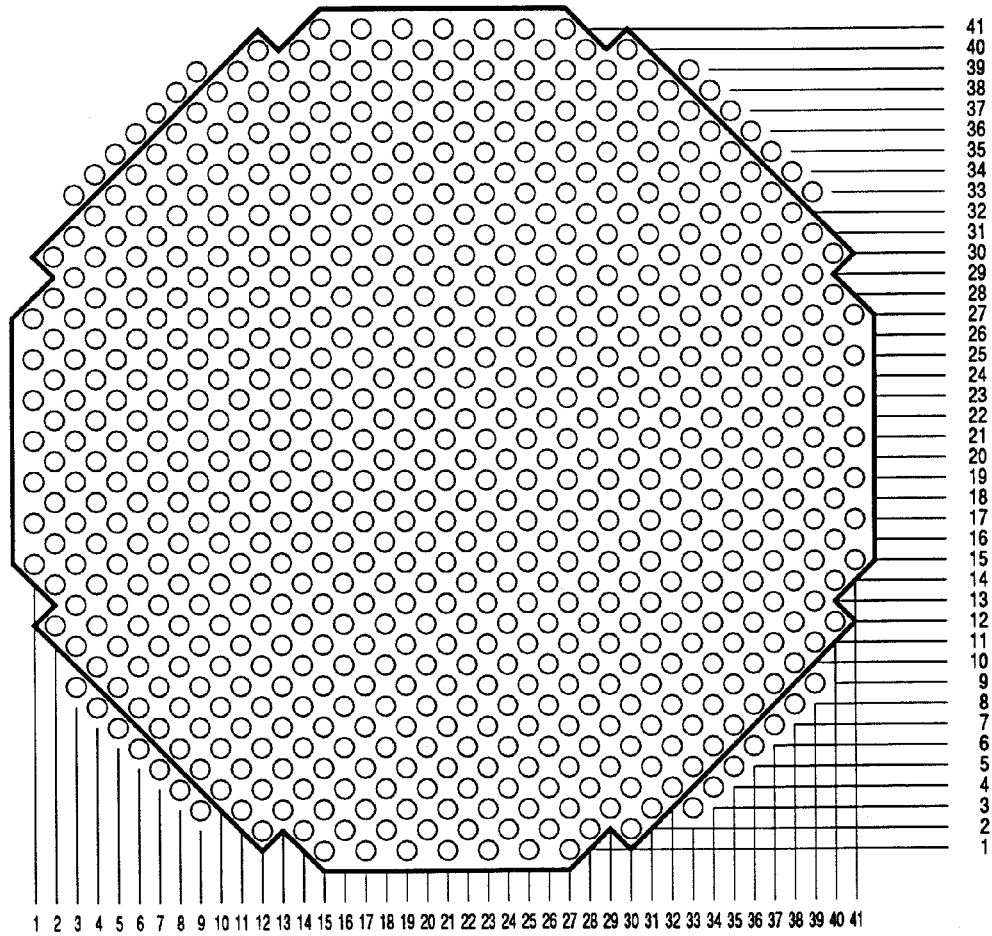


Fig. A.29. Borated EPRI 0.99-in. UO_2 -2 wt % PuO_2 core. *Source:* ref. 12.

The experiments are listed in Table A.15. The fuel rod specifications for both fuel types are provided in Table A.16. An axial view of the experimental setup was shown in Fig. A.19. As with the UO_2 -only experiments, three grid plates were used to support the fuel rods. The fuel rod holes in the aluminum grid plates were 1.008 cm in diameter. The grid plates were supported at each corner with 1.111-cm (7/16-in.) stainless steel support rods covered with 1.588-cm (5/8-in.) aluminum pipe.

Table A.15. Saxton MOX critical experiment descriptions

Pitch (in./cm)	Water/fuel volume ratio	Critical H_2O height (cm) ^a	Critical No. of rods	Boron concentration (ppm)
0.52/1.321	1.681	84.56	506 (22x23)	
0.56/1.422	2.165	82.96	361 (19x19)	0
0.56/1.422	2.165	89.70	441 (21x21)	337
0.735/1.867	4.699	70.11	169 (13x13)	0
0.792/2.012	5.673	78.43	144 (12x12)	0
1.04/2.642	10.754	81.17	121 (11x11)	0

^a Measured from the bottom of the fuel.

Source: ref. 13.

Table A.16. Saxton MOX fuel rod specifications

Pellet diameter, cm (in.)	0.857 (0.3374)
Clad O.D., cm (in.)	0.993 (0.391)
Clad I.D., cm (in.)	0.875 (0.3445)
Clad material	Zircaloy 4
% theoretical density	94
Fuel length, cm (in.)	92.96 (36.6)
Enrichment	6.6 wt % PuO_2
Theoretical density (g/cc)	11.46 (PuO_2)
Weight percent of ^{239}Pu	90.49
Weight percent of ^{240}Pu	8.57
Weight percent of ^{241}Pu	0.89
Weight percent of ^{242}Pu	0.04

Source: ref. 13.

PNL-4976 MOX EXPERIMENT (CASE 34)

The final MOX experiment (**pnl4976**) simulated the uranium depletion and plutonium buildup of spent fuel by placing MOX and UO₂ fuel rods in a uniform distribution to obtain a Pu/²³⁵U ratio approximating that of 20,000-MWd/MTU burnup. The experiment consisted of a large circular array of 583 PuO₂-UO₂ rods (2 wt % PuO₂, 98 wt % natural UO₂) and 1174 4.31 wt % enriched UO₂ rods in a triangular lattice. The specifications for the MOX rods are identical to those used in the EPRI experiments (Table A.14, Figs. A.22 and A.23), except for the plutonium composition, which is given in Table A.17. The UO₂ rods are identical to those previously described in Fig. A.1. The fuel rods were placed at a triangular-lattice pitch of 1.598 cm. Each PuO₂-UO₂ rod was surrounded by six UO₂ rods (see Fig. A.30). The axial view of the experiment is illustrated in Fig. A.31.

Table A.17. Plutonium composition for experiment **pnl4976**

Isotopic wt % ²³⁸ Pu	0.10 ± 0.001
Isotopic wt % ²³⁹ Pu	91.806 ± 0.551
Isotopic wt % ²⁴⁰ Pu	7.876 ± 0.394
Isotopic wt % ²⁴¹ Pu	0.277 ± 0.008
Isotopic wt % ²⁴² Pu	0.031
Concentration (ppm) ²⁴¹ Am	76

Source: ref. 14.

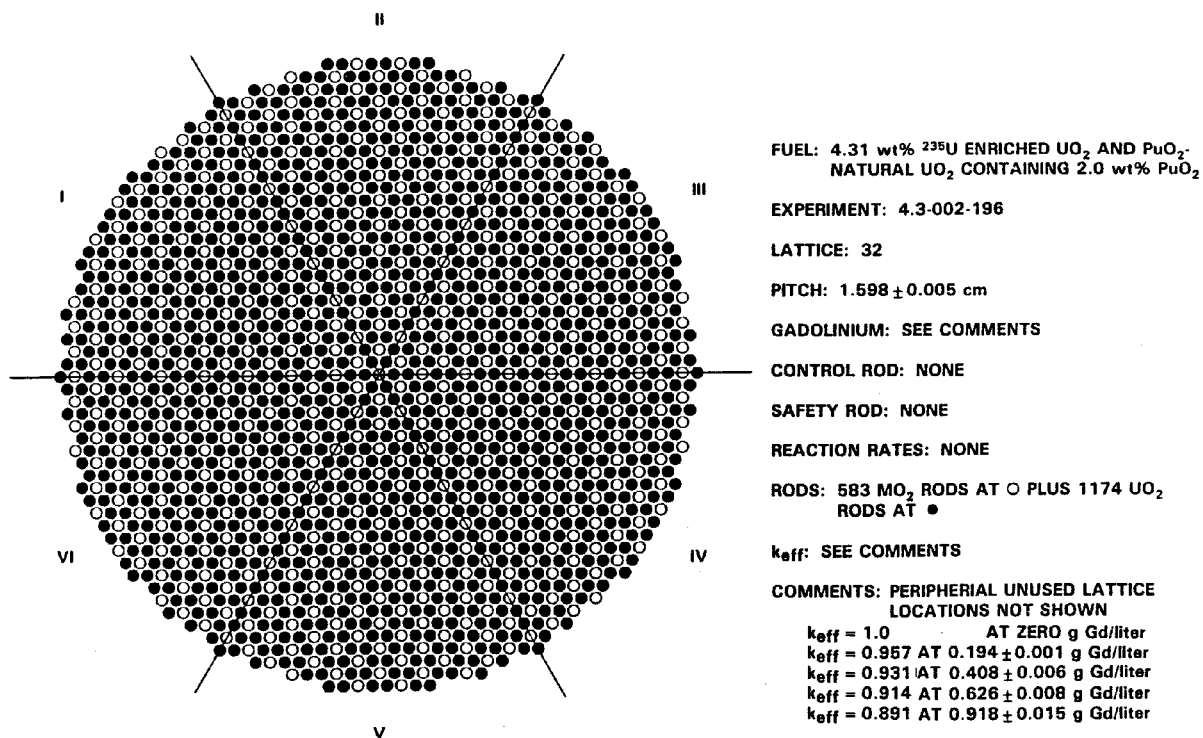


Fig. A.30. Fuel loading for experiment **pnl4976**. *Source*: ref. 14.

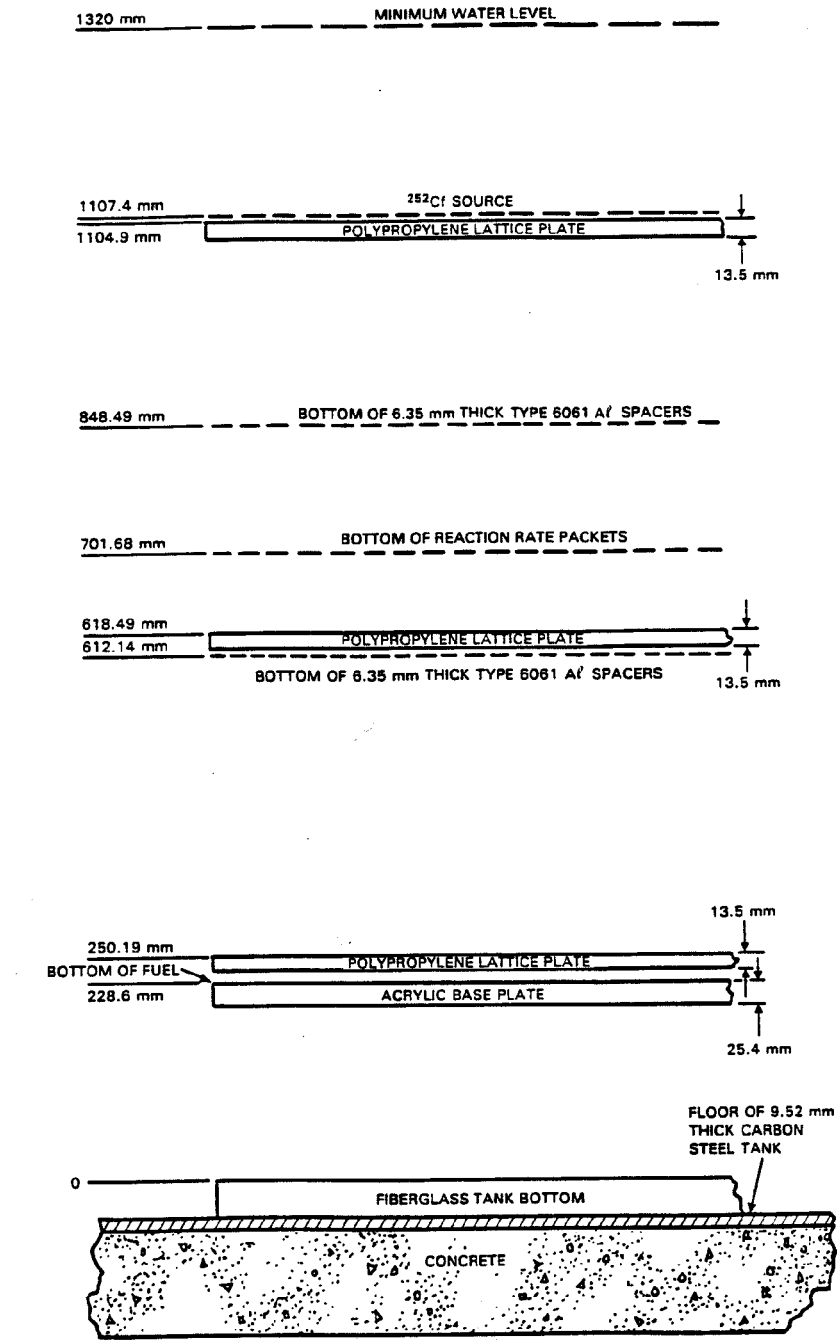


Fig. A.31. Assembly elevations for experiment **pnl4976**. *Source:* ref. 14.

APPENDIX B

SCALE-4 INPUT LISTINGS FOR THE 34 FRESH FUEL CRITICALS (Listed alphabetically by case designation)

baw1484a

```
=csas25
'
' problem id baw 1484-7 exp 2282 (core iv)
'
' 2.46% u-235 enriched uo2 rods, 1.206 cm od al clad, 1.044 cm id,
' 1.030 cm od fuel. uo2 153.34 cm long, h2o moderated and reflected.
' critical h2o height = 145.68 cm
' 9 14x14 clusters, separated by 1 pin pitch with 84 b4c rods
' reference: baw-1484-7
' scale module: csas25
'
baw 1484-7 core iv lattice cell pitch=1.636 cm fuel=2.46 w/o u235 uo2
27burnup latticecell
uo2 1 den=10.22 1.0 293 92235 2.459 92238 97.541 end
al 2 1.0 end
h2o 3 1.0 end
b4c 4 den=1.28 0.986 end
arbm2o3 1.28 2 1 1 0 5000 2 8016 3 4 0.001 end
al 5 1.0 end
h2o 6 1.0 end
end comp
squarepitch 1.636 1.030 1 3 1.206 2 1.044 0 end
baw-1484-7 core iv exp 2282 2.46 wt%u235 9 assys 14x14 w/ 84 b4c pins
read parm plt=yes run=yes gen=805 npg=600 nsk=5 tme=240
wrs=34 res=205 nub=yes rnd=6516246C6230 end parm
read geom
unit 1
com='bottom plug of fuel rod'
cylinder 2 1 .603 .3175 0.0
cuboid 3 1 4p.818 .3175 0.0
unit 2
com='bottom plug of b4c rod'
cylinder 2 1 .5565 .3175 0.0
cuboid 3 1 4p.818 .3175 0.0
unit 3
com='bottom of water hole'
cuboid 3 1 4p.818 .3175 0.0
unit 4
com='fuel rod in grid'
cylinder 1 1 .515 2.54 0.0
cylinder 0 1 .522 2.54 0.0
cylinder 2 1 .603 2.54 0.0
cuboid 3 1 4p.615 2.54 0.0
cuboid 5 1 4p.818 2.54 0.0
unit 5
com='b4c rod in grid'
cylinder 2 1 .4675 0.6345 0.0
cylinder 4 1 .4675 2.54 0.0
cylinder 2 1 .5565 2.54 0.0
cuboid 3 1 4p.615 2.54 0.0
cuboid 5 1 4p.818 2.54 0.0
unit 6
com='water hole in grid'
cuboid 3 1 4p.615 2.54 0.0
cuboid 5 1 4p.818 2.54 0.0
unit 7
com='fuel rod'
```

```

cylinder 1 1 .515      142.8225 0.0
cylinder 0 1 .522      142.8225 0.0
cylinder 2 1 .603      142.8225 0.0
cuboid 3 1 4p.818      142.8225 0.0
unit 8
com='b4c rod '
cylinder 4 1 .4675      142.8225 0.0
cylinder 2 1 .5565      142.8225 0.0
cuboid 3 1 4p.818      142.8225 0.0
unit 9
com='water hole'
cuboid 3 1 4p.818      142.8225 0.0
unit 11
com='fuel rod'
array 1 3*0.0
unit 12
com='b4c pin'
array 2 3*0.0
unit 13
com='water hole'
array 3 3*0.0
unit 14
com='fuel assy'
array 4 3*0.0
unit 15
com='bottom vertical row of b4c pins'
array 5 3*0.0
unit 16
com='middle vertical row of b4c pins'
array 6 3*0.0
unit 17
com='top vertical row of b4c pins'
array 7 3*0.0
unit 18
com='bottom row of assemblies '
array 8 3*0.0
unit 19
com='middle row of assemblies'
array 9 3*0.0
unit 20
com='top row of assemblies '
array 10 3*0.0
unit 21
com='horizontal row of b4c pins'
array 11 3*0.0
global unit 22
array 12 3*0.0
cuboid 5 1 71.984 0.0 71.984 0.0 145.68 -5.08
cuboid 6 1 71.984 0.0 71.984 0.0 145.68 -7.62
reflector 6 2 4r3 2r0 8
end geom
read bias id=500 2 9 end bias
read array
com='fuel rod' ara=1 nux=1 nuy=1 nuz=3 fill 1 4 7 end fill
com='b4c pin' ara=2 nux=1 nuy=1 nuz=3 fill 2 5 8 end fill
com='water hole' ara=3 nux=1 nuy=1 nuz=3 fill 3 6 9 end fill
com='fuel assy' ara=4 nux=14 nuy=14 nuz=1 fill f11 end fill
ara=5 nux=1 nuy=14 nuz=1 fill 12 13 6q2 end fill
ara=6 nux=1 nuy=14 nuz=1 fill 13 12 2q2 13 13 12 13 2q2 end fill
ara=7 nux=1 nuy=14 nuz=1 fill 13 12 6q2 end fill
ara=8 nux=5 nuy=1 nuz=1 fill 14 15 14 15 14 end fill
ara=9 nux=5 nuy=1 nuz=1 fill 14 16 14 16 14 end fill
ara=10 nux=5 nuy=1 nuz=1 fill 14 17 14 17 14 end fill
ara=11 nux=44 nuy=1 nuz=1
fill 13 13 12 13q2 12 12 13 6q2 end fill
ara=12 nux=1 nuy=5 nuz=1 fill 18 21 19 21 20 end fill
end array
read plot

```

```

ttl='x-y slice below grid plate'
xul=-0.5   yul=72.5   zul=0.2
xlr=72.5   ylr=-0.5   zlr=0.2
uax=1 vdn=-1 nax=260 nch=' 12 456789' end
ttl='x-y slice of grid plate'
xul=-0.5   yul=72.5   zul=2.
xlr=72.5   ylr=-0.5   zlr=2.
uax=1 vdn=-1 nax=260 nch=' 12 456789' end
ttl='x-y slice above grid plate'
xul=-0.5   yul=72.5   zul=50.
xlr=72.5   ylr=-0.5   zlr=50.
uax=1 vdn=-1 nax=260 nch=' 12 456789' end
end plot
end data
end

```

bnw1810a

```

=csas25
baw-1810 4.02 w/o u235 uo2 rods .4755 inches o.d.
27burnup latticecell
uo2 1 den=9.46 1.0 293 92235 4.02 92238 95.98 end
ss304 2 1.0 293 end
h2o 3 den=1.0 0.998101 end
boron 3 den=1.0 0.001899 end
uo2 4 den=10.24 1.0 293 92235 2.459 92238 97.541 end
al 5 1.0 293 end
end comp
squarepitch 1.636 1.128 1 3 1.208 2 end
more data
res=4 cylinder .51486 dan(4)=.189732
end more data
baw-1810 core 12 - 4.02 & 2.46 w/o uo2 1899.3 ppm; no uo2-gd2o3 rods
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes tme=60
wrs=35 end parm
read geom
unit 1
com="4.02 w/o fuel rod"
cylinder 1 1 .5639 145 5.969
cylinder 2 1 .6039 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 2
com="2.46 w/o uo2 fuel rod"
cylinder 4 1 .5149 145 .3175
cylinder 0 1 .5217 145 .3175
cylinder 5 1 .603 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 3
com="water hole"
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 4
com="inner row fuel"
array 2 -49.898 -6.544 0
unit 5
com="bottom row fuel"
array 3 -33.538 -8.180 0
unit 6
com="top row fuel"
array 4 -33.538 -8.180 0
global unit 7
array 1 -66.258 -36.81 0
cylinder 3 1 76.2 145 0.0
hole 4 0 -43.3542 0
hole 4 0 43.3542 0
hole 5 0 -58.0784 0
hole 6 0 58.0784 0
cylinder 5 1 76.2 145 -5.08
cylinder 3 1 76.2 145 -7.62
cylinder 5 1 77.47 145 -8.890
cuboid 0 1 4p77.47 145 -8.890
end geom
read array
ara=1
com="core center"
nux=81 nuy=45 loop
2 1 81 1 1 45 1 1 1 1
1 26 56 1 8 38 1 1 1 1
3 24 54 15 3 33 15 1 1 1
3 28 58 15 3 33 15 1 1 1
3 24 54 15 13 43 15 1 1 1
3 28 58 15 13 43 15 1 1 1
3 22 52 15 4 34 15 1 1 1
3 30 60 15 4 34 15 1 1 1
3 22 52 15 12 42 15 1 1 1
3 30 60 15 12 42 15 1 1 1
3 21 51 15 6 36 15 1 1 1

```

```

3  24 54 15    6 36 15    1 1 1
3  28 58 15    6 36 15    1 1 1
3  31 61 15    6 36 15    1 1 1
3  21 51 15   10 40 15    1 1 1
3  24 54 15   10 40 15    1 1 1
3  28 58 15   10 40 15    1 1 1
3  31 61 15   10 40 15    1 1 1
3  26 56 15    8 38 15    1 1 1
3   1 10 1     1  2  1    1 1 1
3  72 81 1     1  2  1    1 1 1
3   1  5 1     3 12  1    1 1 1
3  77 81 1     3 12  1    1 1 1
3   1 10 1    44 45  1    1 1 1
3  72 81 1    44 45  1    1 1 1
3   1  5 1    34 43  1    1 1 1
3  77 81 1    34 43  1    1 1 1
    end loop
ara=2
com="fuel inner outer row"
nux=61 nuy=8 fill f2  end fill
ara=3
com="fuel bottom outer row"
nux=41 nuy=10 loop
2   1 41 1     1 10 1     1 1 1
3   1 10 1     1  5  1     1 1 1
3  32 41 1     1  5  1     1 1 1  end loop
ara=4
com="fuel top outer row"
nux=41 nuy=10 loop
2   1 41 1     1 10 1     1 1 1
3   1 10 1     6 10  1     1 1 1
3  32 41 1     6 10  1     1 1 1  end loop
end array
read start
nst=0 xsm=-66.258 xsp=66.258 ysm=-66.258 ysp=66.258 zsm=0. zsp=145.
end start
read plot
ttl='x-y slice of baw1810 core 12 at z=50'
xul=-73.6092 yul= 73.6092    zul=50
xlr= 73.6092 ylr=-73.6092    zlr=50
uax=1 vdn=-1 dlx=1.63576 dld=1.63576 nch=' 12 456789abc'  end
end plot
end data
end

```

bnw1810b

```

=csas25
baw-1810 4.02 w/o u235 uo2 rods .4755 inches o.d.
27burnup latticecell
uo2 1 den=9.46 1.0 293 92235 4.02 92238 95.98 end
ss304 2 1.0 end
h2o 3 den=1.0 0.998346 end
boron 3 den=1.0 0.001654 end
uo2 4 den=10.24 1.0 293 92235 2.459 92238 97.541 end
al 5 1.0 end
uo2 6 den=10.24 0.96 293 92235 1.944 92238 98.056 end
arbmgd2o3 10.24 2 0 1 1 64000 2 8016 3 6 0.04 293 end
'The following is for use with 44GROUPNDF5
'gd-152 6 den=0.3555 0.002 end
'gd-154 6 den=0.3555 0.0218 end
'gd-155 6 den=0.3555 0.148 end
'gd-156 6 den=0.3555 0.2047 end
'gd-157 6 den=0.3555 0.1565 end
'gd-158 6 den=0.3555 0.2484 end
'gd-160 6 den=0.3555 0.2186 end
'o 6 den=0.0541 1 end
end comp
squarepitch 1.636 1.128 1 3 1.208 2 end
more data
res=4 cylinder .51486 dan(4)=.189732
res=6 cylinder .51499 dan(6)=.189958
end more data
baw-1810 core 14 - 4.02 & 2.46 w/o uo2 1654 ppm; 28 uo2-gd2o3 rods
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes tme=60
wrs=35 end parm
read geom
unit 1
com="4.02 w/o fuel rod"
cylinder 1 1 .5639 145 5.969
cylinder 2 1 .6039 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 2
com="2.46 w/o uo2 fuel rod"
cylinder 4 1 .5149 145 .3175
cylinder 0 1 .5217 145 .3175
cylinder 5 1 .603 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 3
com="water hole"
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 8
com="uo2/gd2o3 fuel rod"
cylinder 6 1 .51499 145 .3175
cylinder 0 1 .52197 145 .3175
cylinder 5 1 .60325 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 4
com="inner row fuel"
array 2 -49.898 -6.544 0
unit 5
com="bottom row fuel"
array 3 -33.538 -8.180 0
unit 6
com="top row fuel"
array 4 -33.538 -8.180 0
global unit 7
array 1 -66.258 -36.81 0
cylinder 3 1 76.2 145 0.0
hole 4 0 -43.3542 0
hole 4 0 43.3542 0
hole 5 0 -58.0784 0
hole 6 0 58.0784 0
cylinder 5 1 76.2 145 -5.08
cylinder 3 1 76.2 145 -7.62

```



```

cylinder  5 1 77.47          145  -8.890
cuboid    0 1 4p77.47       145  -8.890
end geom
read array
ara=1
com="core center"
nux=81 nuy=45 loop
2  1 81 1 1 45 1 1 1 1
1 26 56 1 8 38 1 1 1 1
3 24 54 15 3 33 15 1 1 1
3 28 58 15 3 33 15 1 1 1
3 24 54 15 13 43 15 1 1 1
3 28 58 15 13 43 15 1 1 1
3 22 52 15 4 34 15 1 1 1
3 30 60 15 4 34 15 1 1 1
3 22 52 15 12 42 15 1 1 1
3 30 60 15 12 42 15 1 1 1
3 21 51 15 6 36 15 1 1 1
3 24 54 15 6 36 15 1 1 1
3 28 58 15 6 36 15 1 1 1
3 31 61 15 6 36 15 1 1 1
3 21 51 15 10 40 15 1 1 1
3 24 54 15 10 40 15 1 1 1
3 28 58 15 10 40 15 1 1 1
3 31 61 15 10 40 15 1 1 1
3 26 56 15 8 38 15 1 1 1
3 1 10 1 1 2 1 1 1 1
3 72 81 1 1 2 1 1 1 1
3 1 5 1 3 12 1 1 1 1
3 77 81 1 3 12 1 1 1 1
3 1 10 1 44 45 1 1 1 1
3 72 81 1 44 45 1 1 1 1
3 1 5 1 34 43 1 1 1 1
3 77 81 1 34 43 1 1 1 1
8 29 53 24 8 38 30 1 1 1
8 26 56 30 11 35 24 1 1 1
8 29 53 24 11 35 24 1 1 1
8 31 51 20 13 33 20 1 1 1
8 36 46 10 18 28 10 1 1 1
8 38 44 6 20 26 6 1 1 1
8 38 44 6 23 23 1 1 1 1
8 41 41 1 20 26 6 1 1 1
end loop
ara=2
com="fuel inner outer row"
nux=61 nuy=8 fill f2 end fill
ara=3
com="fuel bottom outer row"
nux=41 nuy=10 loop
2 1 41 1 1 10 1 1 1 1
3 1 10 1 1 5 1 1 1 1
3 32 41 1 1 5 1 1 1 1 end loop
ara=4
com="fuel top outer row"
nux=41 nuy=10 loop
2 1 41 1 1 10 1 1 1 1
3 1 10 1 6 10 1 1 1 1
3 32 41 1 6 10 1 1 1 1 end loop
end array
read start
nst=0 xsm=-66.258 xsp=66.258 ysm=-66.258 ysp=66.258 zsm=0. zsp=145.
end start
read plot
ttl='x-y slice of baw1810 core 14 at z=50'
xul=-73.6092 yul= 73.6092 zul=50
xlr= 73.6092 ylr=-73.6092 zlr=50
uax=1 vdn=-1 dlx=1.63576 dld=1.63576 nch=' 12 456789abc' end
end plot
end data
end

```

bnw1810c

```

=csas25
baw-1810 4.02 w/o u235 uo2 rods .4755 inches o.d.
27burnup latticecell
uo2 1 den=9.46 1.0 293 92235 4.02 92238 95.98 end
ss304 2 1.0 end
h2o 3 den=1.0 0.998421 end
boron 3 den=1.0 0.001579 end
uo2 4 den=10.24 1.0 293 92235 2.459 92238 97.541 end
al 5 1.0 end
uo2 6 den=10.24 0.96 293 92235 1.944 92238 98.056 end
arbmgd2o3 10.24 2 0 1 1 64000 2 8016 3 6 0.04 293 end
'The following is for use with 44GROUPNDF5
'gd-152 6 den=0.3555 0.002 end
'gd-154 6 den=0.3555 0.0218 end
'gd-155 6 den=0.3555 0.148 end
'gd-156 6 den=0.3555 0.2047 end
'gd-157 6 den=0.3555 0.1565 end
'gd-158 6 den=0.3555 0.2484 end
'gd-160 6 den=0.3555 0.2186 end
'o 6 den=0.0541 1 end
end comp
squarepitch 1.636 1.128 1 3 1.208 2 end
more data
res=4 cylinder .51486 dan(4)=.189732
res=6 cylinder .51499 dan(6)=.189958
end more data
baw-1810 core 16 - 4.02 & 2.46 w/o uo2 1579 ppm; 36 uo2-gd2o3 rods
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes tme=60
wrs=35 end parm
read geom
unit 1
com="4.02 w/o fuel rod"
cylinder 1 1 .5639 145 5.969
cylinder 2 1 .6039 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 2
com="2.46 w/o uo2 fuel rod"
cylinder 4 1 .5149 145 .3175
cylinder 0 1 .5217 145 .3175
cylinder 5 1 .603 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 3
com="water hole"
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 8
com="uo2/gd2o3 fuel rod"
cylinder 6 1 .51499 145 .3175
cylinder 0 1 .52197 145 .3175
cylinder 5 1 .60325 145 0
cuboid 3 1 .818 -.818 .818 -.818 145 0
unit 4
com="inner row fuel"
array 2 -49.898 -6.544 0
unit 5
com="bottom row fuel"
array 3 -33.538 -8.180 0
unit 6
com="top row fuel"
array 4 -33.538 -8.180 0
global unit 7
array 1 -66.258 -36.81 0
cylinder 3 1 76.2 145 0.0
hole 4 0 -43.3542 0
hole 4 0 43.3542 0
hole 5 0 -58.0784 0

```

```

hole 6 0 58.0784 0
cylinder 5 1 76.2 145 -5.08
cylinder 3 1 76.2 145 -7.62
cylinder 5 1 77.47 145 -8.890
cuboid 0 1 4p77.47 145 -8.890
end geom
read array
ara=1
com="core center"
nux=81 nuy=45 loop
2 1 81 1 1 45 1 1 1 1
1 26 56 1 8 38 1 1 1 1
3 24 54 15 3 33 15 1 1 1
3 28 58 15 3 33 15 1 1 1
3 24 54 15 13 43 15 1 1 1
3 28 58 15 13 43 15 1 1 1
3 22 52 15 4 34 15 1 1 1
3 30 60 15 4 34 15 1 1 1
3 22 52 15 12 42 15 1 1 1
3 30 60 15 12 42 15 1 1 1
3 21 51 15 6 36 15 1 1 1
3 24 54 15 6 36 15 1 1 1
3 28 58 15 6 36 15 1 1 1
3 31 61 15 6 36 15 1 1 1
3 21 51 15 10 40 15 1 1 1
3 24 54 15 10 40 15 1 1 1
3 28 58 15 10 40 15 1 1 1
3 31 61 15 10 40 15 1 1 1
3 26 56 15 8 38 15 1 1 1
3 1 10 1 1 2 1 1 1 1
3 72 81 1 1 2 1 1 1 1
3 1 5 1 3 12 1 1 1 1
3 77 81 1 3 12 1 1 1 1
3 1 10 1 44 45 1 1 1 1
3 72 81 1 44 45 1 1 1 1
3 1 5 1 34 43 1 1 1 1
3 77 81 1 34 43 1 1 1 1
8 29 53 24 8 38 30 1 1 1
8 26 56 30 11 35 24 1 1 1
8 28 54 26 14 32 18 1 1 1
8 32 50 18 10 36 26 1 1 1
8 31 51 20 13 33 20 1 1 1
8 36 46 10 18 28 10 1 1 1
8 35 47 12 21 25 4 1 1 1
8 39 43 4 17 29 12 1 1 1
8 38 44 6 23 23 1 1 1 1
8 41 41 1 20 26 6 1 1 1
end loop
ara=2
com="fuel inner outer row"
nux=61 nuy=8 fill f2 end fill
ara=3
com="fuel bottom outer row"
nux=41 nuy=10 loop
2 1 41 1 1 10 1 1 1 1
3 1 10 1 1 5 1 1 1 1
3 32 41 1 1 5 1 1 1 1 end loop
ara=4
com="fuel top outer row"
nux=41 nuy=10 loop
2 1 41 1 1 10 1 1 1 1
3 1 10 1 6 10 1 1 1 1
3 32 41 1 6 10 1 1 1 1 end loop
end array
read start
nst=0 xsm=-66.258 xsp=66.258 ysm=-66.258 ysp=66.258 zsm=0. zsp=145.
end start
read plot
ttl='x-y slice of baw1810 core 16 at z=50'
```

```
xul=-73.6092 yul= 73.6092    zul=50
xlr= 73.6092 ylr=-73.6092    zlr=50
uax=1 vdn=-1 dlx=1.63576 dld=1.63576 nch=' 12 456789abc' end
end plot
end data
end
```

e196u6n

```

#csas25
epri np-196 .615 inch pitch unborated uo2
27burnup          latticecell
uo2              1 den=9.20 1.0 293
          92234 0.0137 92235 2.35 92236 0.0171 92238 97.62 end
al              3 1.0 293 end
h2o             4 1.0 293 end
pb              5 1.0 293 end
end comp
squarepitch 1.5621 1.1176 1 4 1.2700 3 end
epri np-196 .615 inch pitch unborated uo2
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!61 1/8 to 62 1/8!
cylinder 3 1 .635 2.540 2.2225
cuboid 4 1 .78105 -.78105 .78105 -.78105 2.540 2.2225
cuboid 3 1 .78105 -.78105 .78105 -.78105 2.540 0
unit 2
com=!62 1/8 to 63 1/8!
cylinder 3 1 .635 5.080 2.540
cuboid 4 1 .66675 -.66675 .66675 -.66675 5.080 2.540
cuboid 3 1 .78105 -.78105 .78105 -.78105 5.080 2.540
unit 3
com=!63 1/8 to 98 7/8!
cylinder 3 1 .5588 7.3025 5.080
cylinder 1 1 .5588 95.885 5.080
cylinder 3 1 .635 95.885 5.080
cuboid 4 1 .78105 -.78105 .78105 -.78105 95.885 5.080
unit 4
com=!98 7/8 to 99 7/8!
cylinder 1 1 .5588 98.4250 95.885
cylinder 3 1 .635 98.4250 95.885
cuboid 4 1 .74041 -.74041 .74041 -.74041 98.4250 95.885
cuboid 3 1 .78105 -.78105 .78105 -.78105 98.4250 95.885
unit 5
com=!99 7/8 to 100 7/8!
cylinder 1 1 .5588 98.7425 98.4250
cylinder 3 1 .635 100.0125 98.4250
cuboid 4 1 .78105 -.78105 .78105 -.78105 100.0125 98.4250
cuboid 5 1 .78105 -.78105 .78105 -.78105 100.965 98.4250
unit 6
com=!61 1/8 to 62 1/8 with no fuel!
cuboid 4 1 .78105 -.78105 .78105 -.78105 2.540 2.2225
cuboid 3 1 .78105 -.78105 .78105 -.78105 2.540 0
unit 7
com=!62 1/8 to 63 1/8 with no fuel!
cuboid 4 1 .66675 -.66675 .66675 -.66675 5.080 2.540
cuboid 3 1 .78105 -.78105 .78105 -.78105 5.080 2.540
unit 8
com=!63 1/8 to 98 7/8 with no fuel!
cuboid 4 1 .78105 -.78105 .78105 -.78105 95.885 5.080
unit 9
com=!98 7/8 to 99 7/8 with no fuel!
cuboid 4 1 .74041 -.74041 .74041 -.74041 98.4250 95.885
cuboid 3 1 .78105 -.78105 .78105 -.78105 98.4250 95.885
unit 10
com=!99 7/8 to 100 7/8 with no fuel!
cuboid 4 1 .78105 -.78105 .78105 -.78105 100.0125 98.4250
cuboid 5 1 .78105 -.78105 .78105 -.78105 100.965 98.4250
global unit 11
com=!reflector region!
array 1 0 0 0
replicate 4 1 30 30 30 30 15.24 30 1
end geom
read array

```

```

ara=1 nux=31 nuy=31 nuz=5
com=!epri np-196 .615 inch pitch unborated uo2 core - 708 rods!
fill
  13r6 5r1 23r6 11r1 18r6 15r1 15r6 17r1 13r6 19r1 11r6 21r1 9r6
    23r1 7r6 25r1 5r6 27r1 2r6 1q31 1r6 29r1 1r6 2q31
  154r1 1r6 155b403
  13r7 5r2 23r7 11r2 18r7 15r2 15r7 17r2 13r7 19r2 11r7 21r2 9r7
    23r2 7r7 25r2 5r7 27r2 2r7 1q31 1r7 29r2 1r7 2q31
  154r2 1r7 155b403
  13r8 5r3 23r8 11r3 18r8 15r3 15r8 17r3 13r8 19r3 11r8 21r3 9r8
    23r3 7r8 25r3 5r8 27r3 2r8 1q31 1r8 29r3 1r8 2q31
  154r3 1r8 155b403
  13r9 5r4 23r9 11r4 18r9 15r4 15r9 17r4 13r9 19r4 11r9 21r4 9r9
    23r4 7r9 25r4 5r9 27r4 2r9 1q31 1r9 29r4 1r9 2q31
  154r4 1r9 155b403
  13r10 5r5 23r10 11r5 18r10 15r5 15r10 17r5 13r10 19r5 11r10 21r5 9r10
    23r5 7r10 25r5 5r10 27r5 2r10 1q31 1r10 29r5 1r10 2q31
  154r5 1r10 155b403
end fill
end array
read plot
ttl=!x-y cross-section at z=5.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=5 xlr=60 ylr=60 zlr=5 uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 nch=' 13 5' end
end plot
end data
end

```

e196u87c

```

#csas25
epri np-196 .87 inch pitch unborated uo2
27burnup          latticecell
uo2              1 den=9.20 1.0 293
          92234 0.0137 92235 2.35 92236 0.0171 92238 97.62 end
al              3 1.0 293 end
h2o             4 1.0 293 end
pb              5 1.0 293 end
end comp
squarepitch 2.2098 1.1176 1 4 1.2700 3 end
epri np-196 .87 inch pitch unborated uo2
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!61 1/8 to 62 1/8!
cylinder 3 1 .635 2.540 2.225
cuboid 4 1 .78105 -.78105 .78105 -.78105 2.540 2.225
cuboid 3 1 .78105 -.78105 .78105 -.78105 2.540 0
unit 2
com=!62 1/8 to 63 1/8!
cylinder 3 1 .635 5.080 2.540
cuboid 4 1 .66675 -.66675 .66675 -.66675 5.080 2.540
cuboid 3 1 .78105 -.78105 .78105 -.78105 5.080 2.540
unit 3
com=!63 1/8 to 98 7/8!
cylinder 3 1 .5588 7.3025 5.080
cylinder 1 1 .5588 95.885 5.080
cylinder 3 1 .635 95.885 5.080
cuboid 4 1 .78105 -.78105 .78105 -.78105 95.885 5.080
unit 4
com=!98 7/8 to 99 7/8!
cylinder 1 1 .5588 98.4250 95.885
cylinder 3 1 .635 98.4250 95.885
cuboid 4 1 .74041 -.74041 .74041 -.74041 98.4250 95.885
cuboid 3 1 .78105 -.78105 .78105 -.78105 98.4250 95.885
unit 5
com=!99 7/8 to 100 7/8!
cylinder 1 1 .5588 98.7425 98.4250
cylinder 3 1 .635 100.0125 98.4250
cuboid 4 1 .78105 -.78105 .78105 -.78105 100.0125 98.4250
cuboid 5 1 .78105 -.78105 .78105 -.78105 100.965 98.4250
unit 6
com=!61 1/8 to 62 1/8 with no fuel!
cuboid 4 1 .78105 -.78105 .78105 -.78105 2.540 2.225
cuboid 3 1 .78105 -.78105 .78105 -.78105 2.540 0
unit 7
com=!62 1/8 to 63 1/8 with no fuel!
cuboid 4 1 .66675 -.66675 .66675 -.66675 5.080 2.540
cuboid 3 1 .78105 -.78105 .78105 -.78105 5.080 2.540
unit 8
com=!63 1/8 to 98 7/8 with no fuel!
cuboid 4 1 .78105 -.78105 .78105 -.78105 95.885 5.080
unit 9
com=!98 7/8 to 99 7/8 with no fuel!
cuboid 4 1 .74041 -.74041 .74041 -.74041 98.4250 95.885
cuboid 3 1 .78105 -.78105 .78105 -.78105 98.4250 95.885
unit 10
com=!99 7/8 to 100 7/8 with no fuel!
cuboid 4 1 .78105 -.78105 .78105 -.78105 100.0125 98.4250
cuboid 5 1 .78105 -.78105 .78105 -.78105 100.965 98.4250
global unit 11
com=!reflector region!
array 1 0 0 0
replicate 4 1 30 30 30 30 15.24 30 1
end geom
read array

```

```

ara=1 nux=29 nuy=29 nuz=5
com=!epri np-196 .87 inch pitch unborated uo2 core - 342 rods!
fill
10r6 1 6 4q2 9r6 9r6 1 6 6q2 6r6 6r6 1 6 8q2 5r6 5r6 1 6 9q2 4r6
4r6 1 6 10q2 3r6 3r6 1 6 11q2 2r6 2r6 1 6 12q2 6 1q58
6 1 13q2 6 1 6 13q2 1 4q58 261b232
9r6 1 6 5q2 8r6 10r6 1 6 4q2 9r6
10r7 2 7 4q2 9r7 9r7 2 7 6q2 6r7 6r7 2 7 8q2 5r7 5r7 2 7 9q2 4r7
4r7 2 7 10q2 3r7 3r7 2 7 11q2 2r7 2r7 2 7 12q2 7 1q58
7 2 13q2 7 2 7 13q2 2 4q58 261b232
9r7 2 7 5q2 8r7 10r7 2 7 4q2 9r7
10r8 3 8 4q2 9r8 9r8 3 8 6q2 6r8 6r8 3 8 8q2 5r8 5r8 3 8 9q2 4r8
4r8 3 8 10q2 3r8 3r8 3 8 11q2 2r8 2r8 3 8 12q2 8 1q58
8 3 13q2 8 3 8 13q2 3 4q58 261b232
9r8 3 8 5q2 8r8 10r8 3 8 4q2 9r8
10r9 4 9 4q2 9r9 9r9 4 9 6q2 6r9 6r9 4 9 8q2 5r9 5r9 4 9 9q2 4r9
4r9 4 9 10q2 3r9 3r9 4 9 11q2 2r9 2r9 4 9 12q2 9 1q58
9 4 13q2 9 4 9 13q2 4 4q58 261b232
9r9 4 9 5q2 8r9 10r9 4 9 4q2 9r9
10r10 5 10 4q2 9r10 9r10 5 10 6q2 6r10 6r10 5 10 8q2 5r10 5r10 5 10 9q2 4r10
4r10 5 10 10q2 3r10 3r10 5 10 11q2 2r10 2r10 5 10 12q2 10 1q58
10 5 13q2 10 5 10 13q2 5 4q58 261b232
9r10 5 10 5q2 8r10 10r10 5 10 4q2 9r10
end fill
end array
read plot
ttl=!x-y cross-section at z=25.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=25 xlr=50 ylr=50 zlr=25
uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 nch=' 13 5' end
end plot
end data
end

```


epri70b

```

#csas25
epri .70 inch pitch borated plutonium
27burnup          latticecell
u-234             1  0.0 1.2462-6 293 end
u-235             1  0.0 1.4891-4 293 end
u-236             1  0.0 2.0943-9 293 end
u-238             1  0.0 2.0619-2 293 end
pu-238            1  0.0 3.885-8 293 end
pu-239            1  0.0 3.9477-4 293 end
pu-240            1  0.0 3.3218-5 293 end
pu-241            1  0.0 1.6023-6 293 end
pu-242            1  0.0 1.1887-7 293 end
am-241            1  0.0 1.5024-6 293 end
o                 1  0.0 4.3763-2 293 end
zircalloy         2  1.0 293 end
al                 3  1.0 293 end
h2o                4  1.0 293 end
boron              4  den=687.9-6      end
pb                 5  1.0 293 end
end comp
squarepitch 1.778 1.2827 1  4  1.4351 2  end
epri .70inch pitch borated plutonium
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes
wrs=34 end parm
read geom
unit 1
com=!62 5/8 to 63 7/8!
cylinder  2 1 .71755 3.175 2.8575
cuboid    4 1 .889 -.889 .889 -.889 3.175 2.8575
cuboid    3 1 .889 -.889 .889 -.889 3.175 0
unit 2
com=!63 7/8 to 64 7/8!
cylinder  1 1 .64135 5.715 3.556
cylinder  2 1 .71755 5.715 3.175
cuboid    4 1 .73025 -.73025 .73025 -.73025 5.715 3.175
cuboid    3 1 .889 -.889 .889 -.889 5.715 3.175
unit 3
com=!64 7/8 to 99!
cylinder  1 1 .64135 92.3925 5.715
cylinder  2 1 .71755 92.3925 5.715
cuboid    4 1 .889 -.889 .889 -.889 92.3925 5.715
unit 4
com=!99 to 100!
cylinder  1 1 .64135 94.9325 92.3925
cylinder  2 1 .71755 94.9325 92.3925
cuboid    4 1 .73025 -.73025 .73025 -.73025 94.9325 92.3925
cuboid    3 1 .889 -.889 .889 -.889 94.9325 92.3925
unit 5
com=!100 to 100.725!
cylinder  1 1 .64135 94.996 94.9325
cylinder  2 1 .71755 95.8215 94.9325
cuboid    4 1 .889 -.889 .889 -.889 95.8215 94.9325
cuboid    5 1 .889 -.889 .889 -.889 96.774 94.9325
unit 6
com=!62 5/8 to 63 7/8 with no fuel!
cuboid    4 1 .889 -.889 .889 -.889 3.175 2.8575
cuboid    3 1 .889 -.889 .889 -.889 3.175 0
unit 7
com=!63 7/8 to 64 7/8 with no fuel!
cuboid    4 1 .73025 -.73025 .73025 -.73025 5.715 3.175
cuboid    3 1 .889 -.889 .889 -.889 5.715 3.175
unit 8
com=!64 7/8 to 99 with no fuel!
cuboid    4 1 .889 -.889 .889 -.889 92.3925 5.715
unit 9
com=!99 to 100 with no fuel!
cuboid    4 1 .73025 -.73025 .73025 -.73025 94.9325 92.3925

```

```

cuboid      3 1      .889 -.889 .889 -.889 94.9325 92.3925
unit      10
com=!100 to 100.725 with no fuel!
cuboid      4 1      .889 -.889 .889 -.889 95.8215 94.9325
cuboid      5 1      .889 -.889 .889 -.889 96.774 94.9325
global unit 11
com=!reflector region!
array      1      0 0 0
replicate  4 1 30 30 30 30 15.24 30 1
end geom
read array
ara=1 nux=31 nuy=31 nuz=5
com=!epri .70inch pitch borated plutonium!
fill
  12r6  7r1 21r6  13r1 16r6  17r1 12r6  21r1 9r6  23r1 7r6  25r1 3r6  q31
  2r6  27r1 2r6  q31 6  29r1 6  2q31 217r1 217b372
  12r7  7r2 21r7  13r2 16r7  17r2 12r7  21r2 9r7  23r2 7r7  25r2 3r7  q31
  2r7  27r2 2r7  q31 7  29r2 7  2q31 217r2 217b372
  12r8  7r3 21r8  13r3 16r8  17r3 12r8  21r3 9r8  23r3 7r8  25r3 3r8  q31
  2r8  27r3 2r8  q31 8  29r3 8  2q31 217r3 217b372
  12r9  7r4 21r9  13r4 16r9  17r4 12r9  21r4 9r9  23r4 7r9  25r4 3r9  q31
  2r9  27r4 2r9  q31 9  29r4 9  2q31 217r4 217b372
  12r10 7r5 21r10 13r5 16r10 17r5 12r10 21r5 9r10 23r5 7r10 25r5 3r10 q31
  2r10 27r5 2r10 q31 10 29r5 10 2q31 217r5 217b372      t
end fill
end array
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
read plot
ttl=!x-y cross-section at z=5.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=5 xlr=60 ylr=60 zlr=5 uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 nch=' 123 5' end
end plot
end data
end

```

epri70un

```

#csas25
epri .70 inch pitch unborated plutonium
27burnup          latticecell
u-234             1  0.0 1.2462-6 293 end
u-235             1  0.0 1.4891-4 293 end
u-236             1  0.0 2.0943-9 293 end
u-238             1  0.0 2.0619-2 293 end
pu-238            1  0.0 3.885-8 293 end
pu-239            1  0.0 3.9477-4 293 end
pu-240            1  0.0 3.3218-5 293 end
pu-241            1  0.0 1.6023-6 293 end
pu-242            1  0.0 1.1887-7 293 end
am-241            1  0.0 1.5024-6 293 end
o                 1  0.0 4.3763-2 293 end
zircalloy         2  1.0 293 end
al                 3  1.0 293 end
h2o                4  1.0 293 end
boron              4  den=0.0      end
pb                 5  1.0 293 end
end comp
squarepitch 1.778 1.2827 1  4  1.4351 2  end
epri .70inch pitch unborated plutonium
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!62 5/8 to 63 7/8!
cylinder  2 1 .71755 3.175 2.8575
cuboid    4 1      .889 -.889 .889 -.889 3.175 2.8575
cuboid    3 1      .889 -.889 .889 -.889 3.175 0
unit 2
com=!63 7/8 to 64 7/8!
cylinder  1 1 .64135 5.715 3.556
cylinder  2 1 .71755 5.715 3.175
cuboid    4 1      .73025 -.73025 .73025 -.73025 5.715 3.175
cuboid    3 1      .889 -.889 .889 -.889 5.715 3.175
unit 3
com=!64 7/8 to 99!
cylinder  1 1 .64135 92.3925 5.715
cylinder  2 1 .71755 92.3925 5.715
cuboid    4 1      .889 -.889 .889 -.889 92.3925 5.715
unit 4
com=!99 to 100!
cylinder  1 1 .64135 94.9325 92.3925
cylinder  2 1 .71755 94.9325 92.3925
cuboid    4 1      .73025 -.73025 .73025 -.73025 94.9325 92.3925
cuboid    3 1      .889 -.889 .889 -.889 94.9325 92.3925
unit 5
com=!100 to 100.725!
cylinder  1 1 .64135 94.996 94.9325
cylinder  2 1 .71755 95.8215 94.9325
cuboid    4 1      .889 -.889 .889 -.889 95.8215 94.9325
cuboid    5 1      .889 -.889 .889 -.889 96.774 94.9325
unit 6
com=!62 5/8 to 63 7/8 with no fuel!
cuboid    4 1      .889 -.889 .889 -.889 3.175 2.8575
cuboid    3 1      .889 -.889 .889 -.889 3.175 0
unit 7
com=!63 7/8 to 64 7/8 with no fuel!
cuboid    4 1      .73025 -.73025 .73025 -.73025 5.715 3.175
cuboid    3 1      .889 -.889 .889 -.889 5.715 3.175
unit 8
com=!64 7/8 to 99 with no fuel!
cuboid    4 1      .889 -.889 .889 -.889 92.3925 5.715
unit 9
com=!99 to 100 with no fuel!
cuboid    4 1      .73025 -.73025 .73025 -.73025 94.9325 92.3925

```

```

cuboid      3 1      .889 -.889 .889 -.889 94.9325 92.3925
unit      10
com=!100 to 100.725 with no fuel!
cuboid      4 1      .889 -.889 .889 -.889 95.8215 94.9325
cuboid      5 1      .889 -.889 .889 -.889 96.774 94.9325
global unit 11
com=!reflector region!
array      1 0 0 0
replicate  4 1 30 30 30 30 15.24 30 1
end geom
read array
ara=1 nux=23 nuy=23 nuz=5
com=!epri .70inch pitch unborated plutonium!
fill
    5r6 13r1 9r6      15r1 7r6      17r1 5r6      19r1 3r6      21r1 6
    299r1 299b115
    5r7 13r2 9r7      15r2 7r7      17r2 5r7      19r2 3r7      21r2 7
    299r2 299b115
    5r8 13r3 9r8      15r3 7r8      17r3 5r8      19r3 3r8      21r3 8
    299r3 299b115
    5r9 13r4 9r9      15r4 7r9      17r4 5r9      19r4 3r9      21r4 9
    299r4 299b115
    5r10 13r5 9r10    15r5 7r10      17r5 5r10      19r5 3r10      21r5 10
    299r5 299b115 t
end fill
end array
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
read plot
ttl=!x-y cross-section at z=5.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=5 xlr=45 ylr=45 zlr=5 uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 nch=' 123 5' end
end plot
end data
end

```

epri87b

```

#csas25
epri .87 inch pitch borated plutonium
27burnup          latticecell
u-234             1  0.0 1.2462-6 293 end
u-235             1  0.0 1.4891-4 293 end
u-236             1  0.0 2.0943-9 293 end
u-238             1  0.0 2.0619-2 293 end
pu-238            1  0.0 3.885-8 293 end
pu-239            1  0.0 3.9477-4 293 end
pu-240            1  0.0 3.3218-5 293 end
pu-241            1  0.0 1.6023-6 293 end
pu-242            1  0.0 1.1887-7 293 end
am-241            1  0.0 1.5024-6 293 end
o                 1  0.0 4.3763-2 293 end
zircalloy         2  1.0 293 end
al                 3  1.0 293 end
h2o                4  1.0 293 end
boron              4  den=1090.4-6      end
pb                 5  1.0 293 end
end comp
squarepitch 2.2098 1.2827 1  4  1.4351 2  end
epri .87inch pitch borated plutonium
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes
wrs=34  end parm
read geom
unit 1
com=!62 5/8 to 63 7/8!
cylinder  2 1  .71755 3.175 2.8575
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 3.175 2.8575
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 3.175 0
unit 2
com=!63 7/8 to 64 7/8!
cylinder  1 1  .64135 5.715 3.556
cylinder  2 1  .71755 5.715 3.175
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 5.715 3.175
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 5.715 3.175
unit 3
com=!64 7/8 to 99!
cylinder  1 1  .64135 92.3925 5.715
cylinder  2 1  .71755 92.3925 5.715
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 92.3925 5.715
unit 4
com=!99 to 100!
cylinder  1 1  .64135 94.9325 92.3925
cylinder  2 1  .71755 94.9325 92.3925
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 94.9325 92.3925
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 94.9325 92.3925
unit 5
com=!100 to 100.725!
cylinder  1 1  .64135 94.996 94.9325
cylinder  2 1  .71755 95.8215 94.9325
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 95.8215 94.9325
cuboid    5 1      1.1049 -1.1049 1.1049 -1.1049 96.774 94.9325
unit 6
com=!62 5/8 to 63 7/8 with no fuel!
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 3.175 2.8575
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 3.175 0
unit 7
com=!63 7/8 to 64 7/8 with no fuel!
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 5.715 3.175
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 5.715 3.175
unit 8
com=!64 7/8 to 99 with no fuel!
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 92.3925 5.715
unit 9
com=!99 to 100 with no fuel!
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 94.9325 92.3925

```

```

cuboid      3 1      1.1049 -1.1049 1.1049 -1.1049 94.9325 92.3925
unit      10
com=!100 to 100.725 with no fuel!
cuboid      4 1      1.1049 -1.1049 1.1049 -1.1049 95.8215 94.9325
cuboid      5 1      1.1049 -1.1049 1.1049 -1.1049 96.774 94.9325
global unit 11
com=!reflector region!
array      1      0 0 0
replicate  4 1 30 30 30 30 15.24 30 1
end geom
read array
ara=1 nux=31 nuy=31 nuz=5
com=!epri .87inch pitch borated plutonium!
fill
  12r6 7r1 12r6 9r6 13r1 9r6 7r6 17r1 7r6 5r6 21r1 5r6 4r6 23r1 4r6
  3r6 25r1 3r6 q31 2r6 27r1 2r6 q31 6 29r1 6 2q31 217r1 217b372
  12r7 7r2 21r7      13r2 16r7      17r2 12r7      21r2 9r7      23r2 4r7
  3r7 25r2 3r7 q31 2r7 27r2 2r7 q31 7 29r2 7 2q31 217r2 217b372
  12r8 7r3 21r8      13r3 16r8      17r3 12r8      21r3 9r8      23r3 4r8
  3r8 25r3 3r8 q31 2r8 27r3 2r8 q31 8 29r3 8 2q31 217r3 217b372
  12r9 7r4 21r9      13r4 16r9      17r4 12r9      21r4 9r9      23r4 4r9
  3r9 25r4 3r9 q31 2r9 27r4 2r9 q31 9 29r4 9 2q31 217r4 217b372
  12r10 7r5 21r10      13r5 16r10      17r5 12r10      21r5 9r10      23r5 4r10
  3r10 25r5 3r10 q31 2r10 27r5 2r10 q31 10 29r5 10 2q31 217r5 217b372 t
end fill
end array
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
read plot
ttl=!x-y cross-section at z=5.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=5 xlr=70 ylr=70 zlr=5 uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 nch=' 123 5' end
end plot
end data
end

```

epri87un

```

#csas25
epri .87 inch pitch unborated plutonium
27burnup          latticecell
u-234             1  0.0 1.2462-6 293 end
u-235             1  0.0 1.4891-4 293 end
u-236             1  0.0 2.0943-9 293 end
u-238             1  0.0 2.0619-2 293 end
pu-238            1  0.0 3.885-8 293 end
pu-239            1  0.0 3.9477-4 293 end
pu-240            1  0.0 3.3218-5 293 end
pu-241            1  0.0 1.6023-6 293 end
pu-242            1  0.0 1.1887-7 293 end
am-241            1  0.0 1.5024-6 293 end
o                 1  0.0 4.3763-2 293 end
zircalloy         2  1.0 293 end
al                 3  1.0 293 end
h2o               4  1.0 293 end
boron             4  den=0.0      end
pb                5  1.0 293 end
end comp
squarepitch 2.2098 1.2827 1  4  1.4351 2  end
epri .87inch pitch unborated plutonium
read parm gen=805 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=120
wrs=34 end parm
read geom
unit 1
com=!62 5/8 to 63 7/8!
cylinder  2 1  .71755 3.175 2.8575
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 3.175 2.8575
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 3.175 0
unit 2
com=!63 7/8 to 64 7/8!
cylinder  1 1  .64135 5.715 3.556
cylinder  2 1  .71755 5.715 3.175
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 5.715 3.175
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 5.715 3.175
unit 3
com=!64 7/8 to 99!
cylinder  1 1  .64135 92.3925 5.715
cylinder  2 1  .71755 92.3925 5.715
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 92.3925 5.715
unit 4
com=!99 to 100!
cylinder  1 1  .64135 94.9325 92.3925
cylinder  2 1  .71755 94.9325 92.3925
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 94.9325 92.3925
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 94.9325 92.3925
unit 5
com=!100 to 100.725!
cylinder  1 1  .64135 94.996 94.9325
cylinder  2 1  .71755 95.8215 94.9325
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 95.8215 94.9325
cuboid    5 1      1.1049 -1.1049 1.1049 -1.1049 96.774 94.9325
unit 6
com=!62 5/8 to 63 7/8 with no fuel!
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 3.175 2.8575
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 3.175 0
unit 7
com=!63 7/8 to 64 7/8 with no fuel!
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 5.715 3.175
cuboid    3 1      1.1049 -1.1049 1.1049 -1.1049 5.715 3.175
unit 8
com=!64 7/8 to 99 with no fuel!
cuboid    4 1      1.1049 -1.1049 1.1049 -1.1049 92.3925 5.715
unit 9
com=!99 to 100 with no fuel!
cuboid    4 1      1.06426 -1.06426 1.06426 -1.06426 94.9325 92.3925

```

```

cuboid      3 1      1.1049 -1.1049 1.1049 -1.1049 94.9325 92.3925
unit      10
com=!100 to 100.725 with no fuel!
cuboid      4 1      1.1049 -1.1049 1.1049 -1.1049 95.8215 94.9325
cuboid      5 1      1.1049 -1.1049 1.1049 -1.1049 96.774 94.9325
global unit 11
com=!reflector region!
array      1 0 0 0
replicate  4 1 30 30 30 30 5.715 30 1
end geom
read array
ara=1 nux=17 nuy=17 nuz=5
com=!epri .87inch pitch unborated plutonium!
fill
  7r6  3r1 7r6 5r6 6r1 6r6 4r6 9r1 4r6 3r6 11r1 3r6 2r6 13r1 2r6 6 15r1 6
  q17 51r1 51b119
  7r7  3r2 12r7 6r2 10r7 9r2 7r7 11r2 5r7 13r2 3r7 15r2 7
  q17 51r2 51b119
  7r8  3r3 12r8 6r3 10r8 9r3 7r8 11r3 5r8 13r3 3r8 15r3 8
  q17 51r3 51b119
  7r9  3r4 12r9 6r4 10r9 9r4 7r9 11r4 5r9 13r4 3r9 15r4 9
  q17 51r4 51b119
  7r10 3r5 12r10 6r5 10r10 9r5 7r10 11r5 5r10 13r5 3r10 15r5 10
  q17 51r5 51b119 t
end fill
end array
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
read plot
ttl=!x-y cross-section at z=5.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=5 xlr=40 ylr=40 zlr=5 uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 nch=' 123 5' end
end plot
end data
end

```


epri99b

```

#csas25
epri .99 inch pitch borated plutonium
27burnup          latticecell
u-234             1  0.0 1.2462-6 293 end
u-235             1  0.0 1.4891-4 293 end
u-236             1  0.0 2.0943-9 293 end
u-238             1  0.0 2.0619-2 293 end
pu-238            1  0.0 3.885-8 293 end
pu-239            1  0.0 3.9477-4 293 end
pu-240            1  0.0 3.3218-5 293 end
pu-241            1  0.0 1.6023-6 293 end
pu-242            1  0.0 1.1887-7 293 end
am-241            1  0.0 1.5024-6 293 end
o                 1  0.0 4.3763-2 293 end
zircalloy         2  1.0 293 end
al                 3  1.0 293 end
h2o                4  1.0 293 end
boron              4  den=767.25-6      end
pb                 5  1.0 293 end
end comp
squarepitch 2.5146 1.2827 1  4  1.4351 2  end
epri .99inch pitch borated plutonium
read parm gen=805 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes
wrs=34 tme=60 end parm
read geom
unit 1
com=!62 5/8 to 63 7/8!
cylinder  2 1  .71755 3.175 2.8575
cuboid    4 1      1.2573 -1.2573 1.2573 -1.2573 3.175 2.8575
cuboid    3 1      1.2573 -1.2573 1.2573 -1.2573 3.175 0
unit 2
com=!63 7/8 to 64 7/8!
cylinder  1 1  .64135 5.715 3.556
cylinder  2 1  .71755 5.715 3.175
cuboid    4 1      1.09855 -1.09855 1.09855 -1.09855 5.715 3.175
cuboid    3 1      1.2573 -1.2573 1.2573 -1.2573 5.715 3.175
unit 3
com=!64 7/8 to 99!
cylinder  1 1  .64135 92.3925 5.715
cylinder  2 1  .71755 92.3925 5.715
cuboid    4 1      1.2573 -1.2573 1.2573 -1.2573 92.3925 5.715
unit 4
com=!99 to 100!
cylinder  1 1  .64135 94.9325 92.3925
cylinder  2 1  .71755 94.9325 92.3925
cuboid    4 1      1.09855 -1.09855 1.09855 -1.09855 94.9325 92.3925
cuboid    3 1      1.2573 -1.2573 1.2573 -1.2573 94.9325 92.3925
unit 5
com=!100 to 100.725!
cylinder  1 1  .64135 94.996 94.9325
cylinder  2 1  .71755 95.8215 94.9325
cuboid    4 1      1.2573 -1.2573 1.2573 -1.2573 95.8215 94.9325
cuboid    5 1      1.2573 -1.2573 1.2573 -1.2573 96.774 94.9325
unit 6
com=!62 5/8 to 63 7/8 with no fuel!
cuboid    4 1      1.2573 -1.2573 1.2573 -1.2573 3.175 2.8575
cuboid    3 1      1.2573 -1.2573 1.2573 -1.2573 3.175 0
unit 7
com=!63 7/8 to 64 7/8 with no fuel!
cuboid    4 1      1.09855 -1.09855 1.09855 -1.09855 5.715 3.175
cuboid    3 1      1.2573 -1.2573 1.2573 -1.2573 5.715 3.175
unit 8
com=!64 7/8 to 99 with no fuel!
cuboid    4 1      1.2573 -1.2573 1.2573 -1.2573 92.3925 5.715
unit 9
com=!99 to 100 with no fuel!
cuboid    4 1      1.09855 -1.09855 1.09855 -1.09855 94.9325 92.3925

```

```

cuboid      3 1      1.2573 -1.2573 1.2573 -1.2573 94.9325 92.3925
unit      10
com=!100 to 100.725 with no fuel!
cuboid      4 1      1.2573 -1.2573 1.2573 -1.2573 95.8215 94.9325
cuboid      5 1      1.2573 -1.2573 1.2573 -1.2573 96.774 94.9325
global unit 11
com=!reflector region!
array      1 0 0 0
replicate  4 1 30 30 30 30 15.24 30 1
end geom
read array
ara=1 nux=29 nuy=29 nuz=5
com=!epri .99inch pitch borated plutonium!
fill
    9r6 11r1 9r6 7r6 15r1 7r6 6r6 17r1 6r6 5r6 19r1 5r6 4r6 21r1 4r6
    3r6 23r1 3r6 2r6 25r1 2r6 6 27r1 6 q29 319r1 319b261
    9r7 11r2 16r7 15r2 13r7 17r2 11r7 19r2 9r7 21r2 4r7
    3r7 23r2 5r7 25r2 3r7 27r2 7 q29 319r2 319b261
    9r8 11r3 16r8 15r3 13r8 17r3 11r8 19r3 9r8 21r3 4r8
    3r8 23r3 5r8 25r3 3r8 27r3 8 q29 319r3 319b261
    9r9 11r4 16r9 15r4 13r9 17r4 11r9 19r4 9r9 21r4 4r9
    3r9 23r4 5r9 25r4 3r9 27r4 9 q29 319r4 319b261
    9r10 11r5 16r10 15r5 13r10 17r5 11r10 19r5 9r10 21r5 4r10
    3r10 23r5 5r10 25r5 3r10 27r5 10 q29 319r5 319b261 t
end fill
end array
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
read plot
ttl=!x-y cross-section at z=5.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=5 xlr=75 ylr=75 zlr=5 uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 nch=' 123 5' end
end plot
end data
end

```

epri99un

```

#csas25
epri .99 inch pitch unborated pu
27burnup latticecell
u-234      1  0.0 1.2462-6 293 end
u-235      1  0.0 1.4891-4 293 end
u-236      1  0.0 2.0943-9 293 end
u-238      1  0.0 2.0619-2 293 end
pu-238      1  0.0 3.885-8 293 end
pu-239      1  0.0 3.9477-4 293 end
pu-240      1  0.0 3.3218-5 293 end
pu-241      1  0.0 1.6023-6 293 end
pu-242      1  0.0 1.1887-7 293 end
am-241      1  0.0 1.5024-6 293 end
o           1  0.0 4.3763-2 293 end
zircalloy   2  1.0 293 end
al           3  1.0 293 end
h2o         4  1.0 293 end
boron        4  den=0.0      end
pb           5  1.0 293 end
end comp
squarepitch 2.5146 1.2827 1  4  1.4351 2  end
epri .99inch pitch unborated plutonium
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!62 5/8 to 63 7/8!
cylinder 2 1 .71755 3.175 2.8575
cuboid 4 1 1.2573 -1.2573 1.2573 -1.2573 3.175 2.8575
cuboid 3 1 1.2573 -1.2573 1.2573 -1.2573 3.175 0
unit 2
com=!63 7/8 to 64 7/8!
cylinder 1 1 .64135 5.715 3.556
cylinder 2 1 .71755 5.715 3.175
cuboid 4 1 1.09855 -1.09855 1.09855 -1.09855 5.715 3.175
cuboid 3 1 1.2573 -1.2573 1.2573 -1.2573 5.715 3.175
unit 3
com=!64 7/8 to 99!
cylinder 1 1 .64135 92.3925 5.715
cylinder 2 1 .71755 92.3925 5.715
cuboid 4 1 1.2573 -1.2573 1.2573 -1.2573 92.3925 5.715
unit 4
com=!99 to 100!
cylinder 1 1 .64135 94.9325 92.3925
cylinder 2 1 .71755 94.9325 92.3925
cuboid 4 1 1.09855 -1.09855 1.09855 -1.09855 94.9325 92.3925
cuboid 3 1 1.2573 -1.2573 1.2573 -1.2573 94.9325 92.3925
unit 5
com=!100 to 100.725!
cylinder 1 1 .64135 94.996 94.9325
cylinder 2 1 .71755 95.8215 94.9325
cuboid 4 1 1.2573 -1.2573 1.2573 -1.2573 95.8215 94.9325
cuboid 5 1 1.2573 -1.2573 1.2573 -1.2573 96.774 94.9325
unit 6
com=!62 5/8 to 63 7/8 with no fuel!
cuboid 4 1 1.2573 -1.2573 1.2573 -1.2573 3.175 2.8575
cuboid 3 1 1.2573 -1.2573 1.2573 -1.2573 3.175 0
unit 7
com=!63 7/8 to 64 7/8 with no fuel!
cuboid 4 1 1.09855 -1.09855 1.09855 -1.09855 5.715 3.175
cuboid 3 1 1.2573 -1.2573 1.2573 -1.2573 5.715 3.175
unit 8
com=!64 7/8 to 99 with no fuel!
cuboid 4 1 1.2573 -1.2573 1.2573 -1.2573 92.3925 5.715
unit 9
com=!99 to 100 with no fuel!
cuboid 4 1 1.09855 -1.09855 1.09855 -1.09855 94.9325 92.3925

```

```

cuboid      3 1      1.2573 -1.2573 1.2573 -1.2573 94.9325 92.3925
unit      10
com=!100 to 100.725 with no fuel!
cuboid      4 1      1.2573 -1.2573 1.2573 -1.2573 95.8215 94.9325
cuboid      5 1      1.2573 -1.2573 1.2573 -1.2573 96.774 94.9325
global unit 11
com=!reflector region!
array      1      0 0 0
replicate  4 1 30 30 30 30 2.286 30 1
end geom
read array
ara=1 nux=17 nuy=17 nuz=5
com=!epri .99inch pitch unborated plutonium!
fill 8r6 1 8r6 7r6 3r1 7r6 5r6 7r1 5r6 4r6 9r1 4r6 3r6 11r1 3r6 2r6 13r1 2r6
      q17 6 15r1 6 17r1 17b136
      8r7 2 8r7 7r7 3r2 7r7 5r7 7r2 5r7 4r7 9r2 4r7 3r7 11r2 3r7 2r7 13r2 2r7
      q17 7 15r2 7 17r2 17b136
      8r8 3 8r8 7r8 3r3 7r8 5r8 7r3 5r8 4r8 9r3 4r8 3r8 11r3 3r8 2r8 13r3 2r8
      q17 8 15r3 8 17r3 17b136
      8r9 4 8r9 7r9 3r4 7r9 5r9 7r4 5r9 4r9 9r4 4r9 3r9 11r4 3r9 2r9 13r4 2r9
      q17 9 15r4 9 17r4 17b136
      8r10 5 15r10 3r5 12r10 7r5 9r10 9r5 7r10 11r5 5r10 13r5 2r10
      q17 10 15r5 10 17r5 17b136 t
end fill
end array
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
read plot
ttl=!x-y cross-section at z=5.0cm!
plt=yes pic=mixture xul=-5 yul=-5 zul=5 xlr=50 ylr=50 zlr=5 uax=1 vax=0 wax=0
udn=0 vdn=1 wdn=0 nax=130 end
end plot
end data
end

```

ft214r

```

=csas2x
' 952 fuel rods
' 4.31% u-235 enriched uo2 rods, 1.265 cm diam.; al clad, 1.283 cm id,
' 1.415 cm od. uo2 91.44 cm long, rod 96.52 cm long. h2o moderated and
' reflected, 2 x 2 array of fuel clusters, 1.891 cm square pitch.
' 0.295 cm between clusters and poison plates, 3.73 cm flux trap width.
' reference: pnl-6205
' scale module: csas2x
'
1.891 cm pitch lattice cell, 4.31 wt% enriched fuel,discrete
27burnup      latticecell
uo2  1 0.9489 293 92234 0.022 92235 4.306 92236 0.022 92238 95.650  end
al   2      end
h2o  3      end
uo2  8 0.9489 293 92234 0.022 92235 4.306 92236 0.022 92238 95.650  end
al   9      end
h2o 10      end
al   4      end
arbmboral    2.64 5 1 0 0 5000 29.22 6012 8.16 13027 62.54
              8016 0.06 26000 0.02 5 end
arbmrubber   1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
              16000 1.7 8016 22.1 14000 0.3 6 end
h2o  7      end
end comp
squarepitch 1.891 1.265 1 3 1.415 2 1.283 0 end
more data
res=8 cylinder .6325  dan(8)=.173084
end more
flux trap assembly no. 214r
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=120
      wrs=34 res=205 nub=yes  end parm
read geometry
unit 1
cylinder 8 1 .6325 2p45.72
cylinder 0 1 .6415 2p45.72
cylinder 6 1 .6415 2p48.26
cylinder 9 1 .7075 2p48.26
cuboid 10 1 4p.9455 2p48.26
unit 2
array 1 3*0.0
'16x15 cluster
cuboid 7 1 30.313 -14.013 44.269 -.057 96.52 0.0
cuboid 4 1 30.415 -14.013 44.269 -.159 96.52 0.0
cuboid 5 1 30.885 -14.013 44.269 -.629 96.52 0.0
cuboid 4 1 30.987 -14.013 44.269 -.731 96.52 0.0
unit 3
array 1 3*0.0
'16x15 cluster
cuboid 7 1 44.269 -0.057 44.269 -0.057 96.52 0.0
cuboid 4 1 44.269 -0.159 44.269 -0.159 96.52 0.0
cuboid 5 1 44.269 -0.629 44.269 -0.629 96.52 0.0
cuboid 4 1 44.269 -0.731 44.269 -0.731 96.52 0.0
unit 4
array 1 3*0.0
'16x15 cluster
cuboid 7 1 30.313 -14.013 28.422 -15.905 96.52 0.0
cuboid 4 1 30.415 -14.013 28.5235 -15.905 96.52 0.0
cuboid 5 1 30.885 -14.013 28.9935 -15.905 96.52 0.0
cuboid 4 1 30.987 -14.013 29.095 -15.905 96.52 0.0
unit 5
array 2 3*0.0
'15x15 cluster
cuboid 7 1 44.269 -0.057 28.422 -15.905 96.52 0.0
cuboid 4 1 44.269 -0.159 28.5235 -15.905 96.52 0.0
cuboid 5 1 44.269 -0.629 28.9935 -15.905 96.52 0.0
cuboid 4 1 44.269 -0.731 29.095 -15.905 96.52 0.0
unit 6

```

```

cuboid 7 1 2.18 -1.55 45.0 0.0 96.52 0.0
'flux trap
unit 7
cuboid 7 1 45.0 0.0 2.18 -1.55 96.52 0.0
'flux trap
unit 8
cuboid 7 1 2.18 -1.55 2.18 -1.55 96.52 0.0
'central moderator
unit 9
com='7 rods smeared over a row of 15'
cuboid 500 1 .8825 0 1.891 0 2p45.72
cuboid 6 1 .8825 0 1.891 0 2p48.26
cuboid 7 1 1.891 0 1.891 0 2p48.26
global unit 10
array 3 3*0.0
'3x3 array
reflector 7 2 6r3 5
end geom

read bias id=500 2 6 end bias

read array
ara=1 nux=16 nuy=15 fill f1 end fill
ara=2 nux=16 nuy=15 fill 15r1 9 14q16 end fill
ara=3 nux=3 nuy=3 fill 4 6 5 7 8 7 2 6 3 end fill
end array
read plot
ttl='x-y slice of 214r '
xul=39 yul=54.7 zul=63.26
xlr=54.7 ylr=39 zlr=63.26
uax=1 vdn=-1 nax=130 nch=' 456 89 s' end
ttl='x-y slice of 214r '
xul=-15 yul=108 zul=63.26
xlr=108 ylr=-15 zlr=63.26
uax=1 vdn=-1 nax=260 nch=' 456 89 s' end
end plot
end data
end

```

ft214v3

```

=csas2x
' 862.1 fuel rods
' 4.31% u-235 enriched uo2 rods, 1.265 cm diam.; al clad, 1.283 cm id,
' 1.415 cm od. uo2 91.44 cm long, rod 96.52 cm long. h2o moderated and
' reflected, 2 x 2 array of fuel clusters, 1.891 cm square pitch.
' 0.295 cm between clusters and poison plates, 3.73 cm flux trap width.
' three 0.63 cm x 45.0 cm x 96 cm al plates between clusters.
' reference: pnl-6205
' scale module: csas2x
'
1.891 cm pitch lattice cell, 4.31 wt% enriched fuel,discrete
27burnup latticecell
uo2 1 0.9489 293 92234 0.022 92235 4.306 92236 0.022 92238 95.650 end
al 2 end
h2o 3 end
uo2 8 0.9489 293 92234 0.022 92235 4.306 92236 0.022 92238 95.650 end
al 9 end
h2o 10 end
al 4 end
arbmboral 2.64 5 1 0 0 5000 29.22 6012 8.16 13027 62.54
8016 0.06 26000 0.02 5 end
arbmrubber 1.321 6 0 0 0 6012 58.1001 6.5 20000 11.4
16000 1.7 8016 22.1 14000 0.3 6 end
h2o 7 end
end comp
squarepitch 1.891 1.265 1 3 1.415 2 1.283 0 end
more data
res=8 cylinder .6325 dan(8)=.173084
end more
flux trap assembly no. 214v3
read parm plt=yes run=yes gen=805 npg=600 nsk=5 tme=240
wrs=34 res=205 nub=yes end parm
read geometry
unit 1
cylinder 8 1 .6325 2p45.72
cylinder 0 1 .6415 2p45.72
cylinder 6 1 .6415 2p48.26
cylinder 9 1 .7075 2p48.26
cuboid 10 1 4p.9455 2p48.26
unit 2
array 1 3*0.0
'14x15 cluster
cuboid 7 1 26.531 -17.795 44.269 -.057 96.52 0.0
cuboid 4 1 26.633 -17.795 44.269 -.159 96.52 0.0
cuboid 5 1 27.103 -17.795 44.269 -.629 96.52 0.0
cuboid 4 1 27.205 -17.795 44.269 -.731 96.52 0.0
unit 3
array 2 3*0.0
'15x15 cluster
cuboid 7 1 44.269 -0.057 44.269 -0.057 96.52 0.0
cuboid 4 1 44.269 -0.159 44.269 -0.159 96.52 0.0
cuboid 5 1 44.269 -0.629 44.269 -0.629 96.52 0.0
cuboid 4 1 44.269 -0.731 44.269 -0.731 96.52 0.0
unit 4
array 1 3*0.0
'14x15 cluster
cuboid 7 1 26.531 -17.795 28.422 -15.904 96.52 0.0
cuboid 4 1 26.633 -17.795 28.524 -15.904 96.52 0.0
cuboid 5 1 27.103 -17.795 28.994 -15.904 96.52 0.0
cuboid 4 1 27.205 -17.795 29.096 -15.904 96.52 0.0
unit 5
array 4 3*0.0
'14x15 cluster
cuboid 7 1 44.269 -0.057 28.422 -15.904 96.52 0.0
cuboid 4 1 44.269 -0.159 28.524 -15.904 96.52 0.0
cuboid 5 1 44.269 -0.629 28.994 -15.904 96.52 0.0
cuboid 4 1 44.269 -0.731 29.096 -15.904 96.52 0.0

```

```

unit 6
cuboid 7 1 0.46 0.0 45.0 0.0 96.52 0.0
cuboid 4 1 1.09 0.0 45.0 0.0 96.52 0.0
cuboid 7 1 1.55 0.0 45.0 0.0 96.52 0.0
cuboid 4 1 2.18 0.0 45.0 0.0 96.52 0.0
cuboid 7 1 2.64 0.0 45.0 0.0 96.52 0.0
cuboid 4 1 3.27 0.0 45.0 0.0 96.52 0.0
cuboid 7 1 3.73 0.0 45.0 0.0 96.52 0.0
'flux trap
unit 7
cuboid 7 1 45.0 0.0 0.46 0.0 96.52 0.0
cuboid 4 1 45.0 0.0 1.09 0.0 96.52 0.0
cuboid 7 1 45.0 0.0 1.55 0.0 96.52 0.0
cuboid 4 1 45.0 0.0 2.18 0.0 96.52 0.0
cuboid 7 1 45.0 0.0 2.64 0.0 96.52 0.0
cuboid 4 1 45.0 0.0 3.27 0.0 96.52 0.0
cuboid 7 1 45.0 0.0 3.73 0.0 96.52 0.0
'flux trap
unit 8
cuboid 7 1 2.18 -1.55 2.18 -1.55 96.52 0.0
'central moderator
unit 9
com='7.1 rods smeared over a row of 15'
cuboid 500 1 .8951 0 1.891 0 2p45.72
cuboid 6 1 .8951 0 1.891 0 2p48.26
cuboid 7 1 1.891 0 1.891 0 2p48.26
global
unit 10
array 3 3*0.0
'3x3 array
reflector 7 2 6r3 5
end geom
read array
ara=1 nux=14 nuy=15 fill f1 end fill
ara=2 nux=15 nuy=15 fill f1 end fill
ara=3 nux=3 nuy=3 fill 4 6 5 7 8 7 2 6 3 end fill
ara=4 nux=15 nuy=15 fill 14r1 9 14q15 end fill
end array
read bias id=500 2 6 end bias
read plot
ttl='x-y slice of 214rv3 '
xul=39 yul=54.7 zul=63.26
xlr=54.7 ylr=39 zlr=63.26
uax=1 vdn=-1 nax=130 nch=' 456 89 s' end
ttl='x-y slice of 214v3 '
xul=-15 yul=108 zul=63.26
xlr=108 ylr=-15 zlr=63.26
uax=1 vdn=-1 nax=260 nch=' 456 89 s' end
end plot
end data
end

```


p2438x05

```

=csas25
'
' problem id 1051024
' citation id 2094 exp. no. 005
'
' 2.35% u-235 enriched uo2 rods, 1.1176 cm diam. al clad, 1.1176 cm id,
' 1.270 cm od. uo2 91.44 cm long, rod 97.79 cm long. h2o moderated and
' reflected. no plates between clusters.
' 3 20x16 clusters, 2.032 cm square pitch.
' ---- cm between central cluster and absorbers, 8.39 cm separation
' between clusters. exp. no. 5
' reference: pnl-2438
' scale module: csas25
'
0.8 in pitch lattice cell,2.35 wt% enriched fuel.
27burn latticecell
uo2 1 0.84 293 92235 2.35 92238 97.65 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
plexiglass 4 1.0 end plexiglass
h2o 5 end
end comp
squarepitch 2.032 1.1176 1 3 1.27 2 end geometry
exp#5, 8.39 cm h2o separating 3 20x16 arrays
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=80
wrs=34 res=205 nub=yes end parm
read geom
unit 2
cylinder 1 1 0.5588 91.44 0.0
cylinder 2 1 0.635 96.52 -1.27
cuboid 3 1 1.016 -1.016 1.016 -1.016 96.52 -1.27
unit 5
array 2 3*0.0
unit 6
cuboid 5 1 8.39 0.0 32.512 0.0 97.79 0.0
global unit 7
array 3 3*0.0
reflector 4 1 5r0 2.54 1
reflector 5 2 6r3.04 5
reflector 5 7 4r3.06 0 0 5
end geometry
read bias id=500 2 11 end bias
read array
ara=2 nux=20 nuy=16 nuz=1 fill f2 end fill
ara=3 nux=5 nuy=1 nuz=1 fill 5 6 5 6 5 end fill
end array
read plot
ttl='x-y slice of m1051024 at z=50'
xul=0.0 yul=35.5 zul=50
xlr=143. ylr=0.0 zlr=50
uax=1 vdn=-1 nax=260 nch=' 12 4 67' end
end plot
end data
end

```

p2438x17

```

=csas25
'
' problem id 1171024
' citation id 2094 exp. no. 017
'
' 2.35% u-235 enriched uo2 rods, 1.1176 cm diam. al clad, 1.1176 cm id,
' 1.270 cm od. uo2 91.44 cm long, rod 97.79 cm long. h2o moderated and
' reflected. boral plates between clusters 0.713 cm thickness
' 2 22x16 clusters, with 1 20x16 central cluster, 2.032 cm square pitch.
' 0.645cm between central cluster and absorbers, 5.05 cm separation
' between clusters. exp. no. 17
' reference: pnl-2438
' scale module: csas25
'
0.8 in pitch lattice cell, 2.35 wt% enriched fuel.
27burn latticecell
uo2 1 0.84 293 92235 2.35 92238 97.65 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
plexiglass 4 1.0 end plexiglass
h2o 5 end
arbmboral 2.49 4 1 0 1 5000 28.7 13027 63.0
        6012 7.97 26000 .33 6 1 293 end boral
end comp
squarepitch 2.032 1.1176 1 3 1.27 2 end geometry
exp#017, 5.05 cm h2o/boral separating 2 22x16 arrays and 1 20x16 array
read parm plt=yes run=yes gen=805 npg=600 nsk=5 tme=240
wrs=34 res=205 nub=yes end parm
read geom
unit 2
cylinder 1 1 0.5588 91.44 0.0
cylinder 2 1 0.635 96.52 -1.27
cuboid 3 1 1.016 -1.016 1.016 -1.016 96.52 -1.27
unit 6
array 2 3*0.0
replicate 5 1 2r0.0 2r1.994 2r0.0 1
unit 7
cuboid 6 1 4.303 3.794 36.5 0.0 91.5 0.0
cuboid 2 1 4.405 3.692 36.5 0.0 91.5 0.0
cuboid 5 1 5.05 0.0 36.5 0.0 97.79 0.0
unit 8
cuboid 6 1 1.256 0.747 36.5 0.0 91.5 0.0
cuboid 2 1 1.358 0.645 36.5 0.0 91.5 0.0
cuboid 5 1 5.05 0.0 36.5 0.0 97.79 0.0
unit 9
array 4 3*0.0
replicate 5 1 2r0.0 2r1.994 2r0.0 1
global
unit 10
array 5 3*0.0
reflector 4 1 5r0 2.54 1
reflector 5 2 6r3.04 5
reflector 5 7 4r3.06 0 0 5
end geometry
read bias id=500 2 11 end bias
read array
ara=2 nux=22 nuy=16 nuz=1 fill f2 end fill
ara=4 nux=20 nuy=16 nuz=1 fill f2 end fill
ara=5 nux=5 nuy=1 nuz=1 fill 6 7 9 8 6 end fill
end array
read plot
ttl='x-y slice of m1171024 at z=50'
xul=0.0 yul=35.5 zul=50
xlr=145.6 ylr=0.0 zlr=50
uax=1 vdn=-1 nax=260 nch=' 12 467' end
end plot
end data
end

```

p2438x24

```

=csas25
'
' problem id 1241024
' citation id 2094 exp. no. 024
'
' 2.35% u-235 enriched uo2 rods, 1.1176 cm diam. al clad, 1.1176 cm id,
' 1.270 cm od. uo2 91.44 cm long, rod 97.79 cm long. h2o moderated and
' reflected. al plates between clusters 0.625 cm thickness
' 3 20x16 clusters, 2.032 cm square pitch.
' .645 cm between central cluster and absorbers, 8.67 cm separation
' between clusters. exp. no. 24
' reference: pnl-2438
' scale module: csas25
'
0.8 in pitch lattice cell,2.35 wt% enriched fuel.
27burn latticecell
uo2 1 0.84 293 92235 2.35 92238 97.65 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
plexiglass 4 1.0 end plexiglass
h2o 5 end
al 6 end
end comp
squarepitch 2.032 1.1176 1 3 1.27 2 end geometry
exp#24, 8.67 cm h2o/al separating 3 20x16 arrays
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=40
res=205 nub=yes wrs=34 end parm
read geom
unit 2
cylinder 1 1 0.5588 91.44 0.0
cylinder 2 1 0.635 96.52 -1.27
cuboid 3 1 1.016 -1.016 1.016 -1.016 96.52 -1.27
unit 6
array 2 3*0.0
cuboid 5 1 40.64 0.0 34.056 -1.544 97.79 0.0
unit 7
cuboid 5 1 7.4 0.0 35.6 0.0 91.5 0.0
cuboid 6 1 8.025 0.0 35.6 0.0 91.5 0.0
cuboid 5 1 8.67 0.0 35.6 0.0 97.79 0.0
unit 8
cuboid 5 1 0.645 0.0 35.6 0.0 91.5 0.0
cuboid 6 1 1.27 0.0 35.6 0.0 91.5 0.0
cuboid 5 1 8.67 0.0 35.6 0.0 97.79 0.0
global unit 9
array 3 3*0.0
reflector 4 1 5r0 2.54 1
reflector 5 2 6r3.04 5
reflector 5 7 4r3.06 0 0 5
end geometry
read bias id=500 2 11 end bias
read array
ara=2 nux=20 nuy=16 nuz=1 fill f2 end fill
ara=3 nux=5 nuy=1 nuz=1 fill 6 7 6 8 6 end fill
end array
read plot
ttl='x-y slice of m1241024 at z=50'
xul=0.0 yul=35.5 zul=50
xlr=139.0 ylr=0.0 zlr=50
uax=1 vdn=-1 nax=260 nch=' 12 4 67' end
end plot
end data
end

```

p2438x28

```
=csas25
'
' problem id 1281024
' citation id 2094 exp. no. 028
'
' 2.35% u-235 enriched uo2 rods, 1.1176 cm diam. al clad, 1.1176 cm id,
' 1.270 cm od. uo2 91.44 cm long, rod 97.79 cm long. h2o moderated and
' reflected. ss plates between clusters 0.485 cm thickness
' 3 20x16 clusters, 2.032 cm square pitch.
' .645 cm between central cluster and absorbers, 6.88 cm separation
' between clusters. exp. no. 28
' reference: pnl-2438
' scale module: csas25
'

0.8 in pitch lattice cell,2.35 wt% enriched fuel.
27burn latticecell
uo2 1 0.84 293 92235 2.35 92238 97.65 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
plexiglass 4 1.0 end plexiglass
h2o 5 end
ss304 6 end
end comp
squarepitch 2.032 1.1176 1 3 1.27 2 end geometry
exp#28, 6.88 cm h2o/ss separating 3 20x16 arrays
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=40
res=205 nub=yes wrs=34 end parm
read geom
unit 2
cylinder 1 1 0.5588 91.44 0.0
cylinder 2 1 0.635 96.52 -1.27
cuboid 3 1 1.016 -1.016 1.016 -1.016 96.52 -1.27
unit 6
array 2 3*0.0
cuboid 5 1 40.64 0.0 34.056 -1.544 97.79 0.0
unit 7
cuboid 5 1 5.750 0.0 35.6 0.0 91.5 0.0
cuboid 6 1 6.235 0.0 35.6 0.0 91.5 0.0
cuboid 5 1 6.88 0.0 35.6 0.0 97.79 0.0
unit 8
cuboid 5 1 0.645 0.0 35.6 0.0 91.5 0.0
cuboid 6 1 1.130 0.0 35.6 0.0 91.5 0.0
cuboid 5 1 6.88 0.0 35.6 0.0 97.79 0.0
global unit 9
array 3 3*0.0
reflector 4 1 5r0 2.54 1
reflector 5 2 6r3.04 5
reflector 5 7 4r3.06 0 0 5
end geometry
read bias id=500 2 11 end bias
read array
ara=2 nux=20 nuy=16 nuz=1 fill f2 end fill
ara=3 nux=5 nuy=1 nuz=1 fill 6 7 6 8 6 end fill
end array
read plot
ttl='x-y slice of m1281024 at z=50'
xul=0.0 yul=35.5 zul=50
xlr=138.0 ylr=0.0 zlr=50
uax=1 vdn=-1 nax=260 nch=' 12 4 6' end
end plot
end data
end
```

p3602s4

```

=csas25
1.892cm pitch lattice cell,4.31 wt% enriched fuel,b-ss plate
27burn latticecell
uo2 1 0.949 293 92235 4.31 92238 95.69 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
plexiglass 4 1.0 end plexiglass
h2o 5 end
arbmsteel 7.84 8 0 0 1 26304 96.78 6012 0.19 25055 1.28 14000 .22
28304 .79 42000 .49 24304 .12 29000 .13 6 end
arbmrubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
16000 1.7 8016 22.1 14000 0.3 7 end
boron 8 den=7.9 .0105 end
crss 8 den=7.9 .1903 end
cu 8 den=7.9 .0028 end
fess 8 den=7.9 .6804 end
mn 8 den=7.9 .0158 end
mo 8 den=7.9 .0049 end
niss 8 den=7.9 .0953 end
end comp
squarepitch 1.892 1.2649 1 3 1.4147 2 1.2827 0 end
steel refl. 9.83cm h2o separating 3 12x16 arrays w/borated ss plates
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=60
wrs=34 res=205 nub=yes end parm
read geom
unit 1
cylinder 1 1 0.63245 91.44 0.0
cylinder 0 1 0.64135 91.44 0.0
cylinder 7 1 0.64135 93.98 -2.54
cylinder 2 1 0.70735 93.98 -2.54
cuboid 3 1 4p.9460 93.98 -2.54
unit 2
array 1 3*0.0
unit 3
cuboid 5 1 9.0547 0.0 30.272 0.0 93.98 -2.54
unit 4
cuboid 8 1 0.298 0.0 2p15.1 88.96 -2.54
cuboid 5 1 0.298 0.0 2p15.136 93.98 -2.54
global unit 5
array 2 -43.4087 -15.136 0.
reflector 4 1 5r0.0 2.54 1
cuboid 5 1 2p73.65 2p17.092 104.06 -17.84
reflector 6 1 2r0.0 2r17.85 2r0.0 1
reflector 5 2 5r3.0 0 3
reflector 5 5 4r3.0 2r0 1
reflector 5 6 2r3.0 4r0 6
end geometry
read bias id=500 2 11 end bias
read array
ara=1 nux=12 nuy=16 nuz=1 fill f1 end fill
ara=2 nux=7 nuy=1 nuz=1 fill 2 3 4 2 4 3 2 end fill
end array
read plot
ttl='x-y slice at z=50'
xul=110. yul=50. zul=50
xlr=-110. ylr=-50. zlr=50
vax=-1 udn=-1 nax=130 nch='.. 4 6789' end
ttl='close up x-y slice at z=50'
xul=45. yul=16. zul=50
xlr=-45. ylr=-16. zlr=50
vax=-1 udn=-1 nax=130 nch='.. 4 6789' end
ttl='y-z slice at x=0.'
xul=.946 yul=-50. zul=120
xlr=.946 ylr=50. zlr=-20
vax=1 wdn=-1 nax=130 nch='.. 4 6789' end
end plot
end data
end

```

p3926l4a

```
=csas25
'
' problem id --
' citation id --      exp. no.  --
'
' 4.31% u-235 enriched uo2 rods, 1.4147cm od al clad, 1.2827 cm id,
' 1.2649 cm od uo2 91.44 cm long, rod 96.52 cm long.
' lead walls (10.2 x 164.0 x 123.4) on floor reflecting in h2o.
' 3-12x16 clusters, 1.892 cm square pitch. 18.18 cm separation
' between clusters. 0.66 cm from fuel clusters
' reference: pnl-3926 pg.13
' scale module: csas25
'
1.892 cm pitch lattice cell,4.31 wt% enriched fuel.
27burn latticecell
uo2  1 0.949 293 92235 4.31 92238 95.69 end uo2
al   2 1.0   end al
h2o  3 1.0   end h2o
plexiglass  4 1.0   end plexiglass
h2o        5      end
pb          6 .97533 end
arbm rubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
          16000 1.7 8016 22.1 14000 0.3 7 end
end comp
squarepitch 1.892 1.2649 1 3 1.4147 2 1.2827 0 end
lead refl. 18.18cm h2o separating 12x16 arrays
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=60
wrs=34 res=205 nub=yes end parm
read geom
unit 1
cylinder  1 1 0.63245          91.44  0.0
cylinder  0 1 0.64135          91.44  0.0
cylinder  7 1 0.64135          93.98 -2.54
cylinder  2 1 0.70735          93.98 -2.54
cuboid    3 1 4p0.946          93.98 -2.54
unit 2
array  1 3*0.0
unit 3
cuboid   5 1 17.7027 0.0 30.272  0.0  96.52  0.0
global unit 4
array 2 -51.7587 -15.136  0.
reflector  4 1 5r0.0  2.54 1
cuboid     5 1 2p82.0 2p15.796 105.56 -17.84
reflector  6 1 2r0.0 2r10.2 2r0.0  1
reflector  5 2 5r3.0  0 2
reflector  5 4 4r3.0  2r0  5
reflector  5 9 2r3.0  4r0  3
end geometry
read bias id=500 2 11 end bias
read array
ara=1 nux=12 nuy=16 nuz=1 fill f1 end fill
ara=2 nux=5 nuy=1 nuz=1 fill 2 3 2 3 2 end fill
end array
read plot
ttl='x-y slice at z=50'
xul=115. yul=45. zul=50
xlr=-115. ylr=-45. zlr=50
vax=-1 udn=-1 nax=130 nch=' .. 4 67' end
ttl='y-z slice at x=0.'
xul=0.9 yul=-45. zul=120
xlr=0.9 ylr=45. zlr=-20
vax=1 wdn=-1 nax=130 nch=' .. 4 67' end
end plot
end data
end
```

p3926u4a

```
=csas25
'
' problem id --
' citation id --      exp. no.  --
'
' 4.31% u-235 enriched uo2 rods, 1.4147cm od al clad, 1.2827 cm id,
' 1.2649 cm od uo2 91.44 cm long, rod 96.52 cm long.
' uranium walls (7.65 x 152.3 x 121.9) on floor reflecting in h2o.
' 3-12x16 clusters, 1.892 cm square pitch. 19.24 cm separation
' between clusters. , 1.956 cm from fuel clusters
' reference: pnl-3926 pg.13
' scale module: csas25
'

1.892 in pitch lattice cell,4.31 wt% enriched fuel.
27burn latticecell
uo2  1 0.949 293 92235 4.31 92238 95.69 end uo2
al   2 1.0   end al
h2o  3 1.0   end h2o
plexiglass 4 1.0   end plexiglass
h2o    5      end
uranium  6 .98163 293 92235 .199 92238 99.801 end
arbmrubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
          16000 1.7 8016 22.1 14000 0.3 7 end

end comp
squarepitch 1.892 1.2649 1 3 1.4147 2 1.2827 0 end
uranium refl. 19.24cm h2o separating 12x16 arrays
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=60
wrs=34 res=205 nub=yes end parm
read geom
unit 1
cylinder 1 1 0.63245                91.44 0.0
cylinder 0 1 0.64135                91.44 0.0
cylinder 7 1 0.64135                93.98 -2.54
cylinder 2 1 0.70735                93.98 -2.54
cuboid 3 1 4p0.946                  93.98 -2.54
unit 2
array 1 3*0.0
unit 3
cuboid 5 1 18.7627 0.0 30.272 0.0 96.52 0.0
global unit 4
array 2 -52.8187 -15.136 0.
reflector 4 1 5r0.0 2.54 1
cuboid 5 1 2p76.15 2p17.092 104.06 -17.84
reflector 6 1 2r0.0 2r7.65 2r0.0 1
reflector 5 2 5r3.0 0 3
reflector 5 5 4r3.0 2r0 5
reflector 5 10 2r3.0 4r0 2
end geometry
read bias id=500 2 11 end bias
read array
ara=1 nux=12 nuy=16 nuz=1 fill f1 end fill
ara=2 nux=5 nuy=1 nuz=1 fill 2 3 2 3 2 end fill
end array
read plot
ttl='x-y slice at z=50'
xul=110. yul=45. zul=50
xlr=-110. ylr=-45. zlr=50
vax=-1 udn=-1 nax=130 nch='.. 4 67' end
ttl='y-z slice at x=0.'
xul=0.9 yul=-45. zul=120
xlr=0.9 ylr=45. zlr=-20
vax=1 wdn=-1 nax=130 nch='.. 4 67' end
end plot
end data
end
```

p4267a

```

=csas2x
'
' problem id -- pnl-4267
' citation id -- exp. no. 173
'
' 4.31% u-235 enriched uo2 rods, 1.4147 cm od al clad, 1.2827 cm id,
' 1.2649 cm od. uo2 91.44 cm long, rod 96.52 cm long.
' single array 40x8.92 rods (357 total rods), 1.890 cm square pitch.
' no soluble boron
' reference: pnl-4267 exp. 173
' scale module: csas2x
'
1.890 cm pitch lattice cell,4.31 wt% enriched fuel.
27burn latticecell
uo2 1 0.949 293 92235 4.31 92238 95.69 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
arbmrubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
16000 1.7 8016 22.1 14000 0.3 4 end
poly(h2o) 5 den=.904 end
h2o 6 end
boron 7 den=.00255 1.0 end
h2o 7 end
plexiglass 8 1.0 end
uo2 9 0.949 293 92235 4.31 92238 95.69 end uo2
al 10 1.0 end al
h2o 11 1.0 end h2o
end comp
' pitch fod f m cod c cid g
squarepitch 1.890 1.2649 9 11 1.4147 10 1.2827 0 end
more data
res=1 cylinder .63245 dan(1)=.173084
end more
pnl-4267 exp. 173 40 x 8.92 array (357 total rods) boron = 0 g/l
read parm plt=yes run=yes gen=805 npg=600 nsk=5 tme=120
wrs=34 res=205 nub=yes rnd=65162460326C end parm
read geom
unit 1
'bottom of fuel - rubber cap in lower lattice support plate
cylinder 4 1 0.64135 2.54 0.0
cylinder 2 1 0.70735 2.54 0.0
cuboid 5 1 4p0.945 2.54 0.0
unit 2
'fuel between the two lattice support plates
cylinder 1 1 0.63245 67.29 0.0
cylinder 0 1 0.64135 67.29 0.0
cylinder 2 1 0.70735 67.29 0.0
cuboid 3 1 4p0.945 67.29 0.0
unit 3
'fuel in upper lattice support plate
cylinder 1 1 0.63245 1.27 0.0
cylinder 0 1 0.64135 1.27 0.0
cylinder 2 1 0.70735 1.27 0.0
cuboid 5 1 4p0.945 1.27 0.0
unit 4
'fuel above the upper lattice support plate
cylinder 1 1 0.63245 22.86 0.0
cylinder 0 1 0.64135 22.86 0.0
cylinder 2 1 0.70735 22.86 0.0
cuboid 3 1 4p0.945 22.86 0.0
unit 5
'bottom of smeared fuel - rubber cap
cuboid 4 1 1.7483 0 2p0.945 2.54 0.0
cuboid 5 1 1.890 0 2p0.945 2.54 0.0
unit 6
'smeared fuel between the two lattice support plates
cuboid 500 1 1.7483 0 2p0.945 67.29 0.0

```



```

cuboid    3 1 1.890  0  2p0.945                67.29  0.0
unit 7
'smeared fuel in upper lattice support plate
cuboid    500 1 1.7483 0  2p0.945                1.27  0.0
cuboid     5 1 1.890  0  2p0.945                1.27  0.0
unit 8
'smeared fuel above the upper lattice support plate
cuboid    500 1 1.7483 0  2p0.945                22.86  0.0
cuboid     3 1 1.890  0  2p0.945                22.86  0.0
unit 9
'top of fuel - rubber cap in h2o
cylinder   4 1 0.64135                2.54  0.0
cylinder   2 1 0.70735                2.54  0.0
cuboid     3 1 4p0.945                2.54  0.0
unit 10
'top of smeared fuel - rubber cap in h2o
cuboid     4 1 1.7483 0  2p0.945                2.54  0.0
cuboid     3 1 1.890  0  2p0.945                2.54  0.0
global
unit 11
array  1 -8.505  -37.80  0.0
cuboid   3 1 2p39.80  2p37.94  111.7  0.0
cuboid   8 1 2p41.705 2p39.845 111.7 -17.105
reflector 6 2 4r3 2r0 10
end geometry
read bias id=500  2 11  end bias
read array
ara=1 nux=9 nuy=40 nuz=5
fill  8r1 5  39q9  8r2 6  39q9
      8r3 7  39q9  8r4 8  39q9  8r9 10 39q9  end fill
end array
read plot
ttl='x-y slice of pnl4267a at z=50'
xul=-45.  yul=45.0  zul=50
xlr= 45.  ylr=-45.  zlr=50
uax=1 vdn=-1 nax=130  nch=' 12 45 8&'  end
end plot
end data
end

```

p4267b

```
=csas2x
'
' problem id -- pnl-4267
' citation id -- exp. no. 177
'
' 4.31% u-235 enriched uo2 rods, 1.4147 cm od al clad, 1.2827 cm id,
' 1.2649 cm od. uo2 91.44 cm long, rod 96.52 cm long.
' single array 40 x 30.92 rods (1237 total rods), 1.890 cm square pitch
' boron conc = 2.55 g/l
' reference: pnl-4267 exp. 177
' scale module: csas2x
'
1.890 cm pitch lattice cell,4.31 wt% enriched fuel.
27burn latticecell
uo2 1 0.949 293 92235 4.31 92238 95.69 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
arbmrubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
16000 1.7 8016 22.1 14000 0.3 4 end
poly(h2o) 5 den=.904 end
h2o 6 end
boron 7 den=.00255 1.0 end
h2o 7 end
plexiglass 8 1.0 end
uo2 9 0.949 293 92235 4.31 92238 95.69 end uo2
al 10 1.0 end al
h2o 11 1.0 end h2o
boron 11 den=.00255 1.0 end
end comp
'
pitch fod f m cod c cid g
squarepitch 1.890 1.2649 9 11 1.4147 10 1.2827 0 end
more data
res=1 cylinder .63245 dan(1)=.173084
end more
pnl-4267 exp.177 40 x 30.92 array 1237 total rods) boron = 2.55 g/l
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=60
wrs=34 res=205 nub=yes end parm
read geom
unit 1
'bottom of fuel - rubber cap in lower lattice support plate
cylinder 4 1 0.64135 2.54 0.0
cylinder 2 1 0.70735 2.54 0.0
cuboid 5 1 4p0.945 2.54 0.0
unit 2
'fuel between the two lattice support plates
cylinder 1 1 0.63245 67.29 0.0
cylinder 0 1 0.64135 67.29 0.0
cylinder 2 1 0.70735 67.29 0.0
cuboid 7 1 4p0.945 67.29 0.0
unit 3
'fuel in upper lattice support plate
cylinder 1 1 0.63245 1.27 0.0
cylinder 0 1 0.64135 1.27 0.0
cylinder 2 1 0.70735 1.27 0.0
cuboid 5 1 4p0.945 1.27 0.0
unit 4
'fuel above the upper lattice support plate
cylinder 1 1 0.63245 22.86 0.0
cylinder 0 1 0.64135 22.86 0.0
cylinder 2 1 0.70735 22.86 0.0
cuboid 7 1 4p0.945 22.86 0.0
unit 5
'bottom of smeared fuel - rubber cap
cuboid 4 1 1.7483 0 2p0.945 2.54 0.0
cuboid 5 1 1.890 0 2p0.945 2.54 0.0
unit 6
'smeared fuel between the two lattice support plates
```

```

cuboid 500 1 1.7483 0 2p0.945 67.29 0.0
cuboid 7 1 1.890 0 2p0.945 67.29 0.0
unit 7
'smeared fuel in upper lattice support plate
cuboid 500 1 1.7483 0 2p0.945 1.27 0.0
cuboid 5 1 1.890 0 2p0.945 1.27 0.0
unit 8
'smeared fuel above the upper lattice support plate
cuboid 500 1 1.7483 0 2p0.945 22.86 0.0
cuboid 7 1 1.890 0 2p0.945 22.86 0.0
unit 9
'top of fuel - rubber cap in h2o
cylinder 4 1 0.64135 2.54 0.0
cylinder 2 1 0.70735 2.54 0.0
cuboid 7 1 4p0.945 2.54 0.0
unit 10
'top of smeared fuel - rubber cap in h2o
cuboid 4 1 1.7483 0 2p0.945 2.54 0.0
cuboid 7 1 1.890 0 2p0.945 2.54 0.0
global
unit 11
array 1 -29.295 -37.80 0.0
cuboid 7 1 2p39.80 2p37.94 111.7 0.0
cuboid 8 1 2p41.705 2p39.845 111.7 -17.105
reflector 6 2 4r3 2r0 10
end geometry
read bias id=500 2 11 end bias
read array
ara=1 nux=31 nuy=40 nuz=5
fill 30r1 5 39q31 30r2 6 39q31
      30r3 7 39q31 30r4 8 39q31 30r9 10 39q31 end fill
end array
read plot
ttl='x-y slice of pnl4267b at z=50'
xul=-45. yul=45.0 zul=50
xlr= 45. ylr=-45. zlr=50
uax=1 vdn=-1 nax=130 nch=' 12 45 8&' end
end plot
end data
end

```

p4267c

```
=csas2x
'
' problem id -- pnl-4267
' citation id -- exp. no. 178
'
' 4.31% u-235 enriched uo2 rods, 1.4147 cm od al clad, 1.2827 cm id,
' 1.2649 cm od. uo2 91.44 cm long, rod 96.52 cm long.
' single array 44x11.57 rods(509 total rods), 1.715 cm square pitch.
' no soluble boron
' reference: pnl-4267 exp. 178
' scale module: csas2x
'
1.715 cm pitch lattice cell,4.31 wt% enriched fuel.
27burn latticecell
uo2 1 0.949 293 92235 4.31 92238 95.69 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
arbmrubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
16000 1.7 8016 22.1 14000 0.3 4 end
poly(h2o) 5 den=.904 end
h2o 6 end
boron 7 den=.00255 1.0 end
h2o 7 end
plexiglass 8 1.0 end
uo2 9 0.949 293 92235 4.31 92238 95.69 end uo2
al 10 1.0 end al
h2o 11 1.0 end h2o
end comp
' pitch fod f m cod c cid g
squarepitch 1.715 1.2649 9 11 1.4147 10 1.2827 0 end
more data
res=1 cylinder .63245 dan(1)=.269915
end more
pnl-4267 exp. 178 44 x 11.57array (509 total rods) boron = 0 g/l
read parm plt=yes run=yes gen=805 npg=600 nsk=5 tme=120
wrs=34 res=205 nub=yes end parm
read geom
unit 1
'bottom of fuel - rubber cap in lower lattice support plate
cylinder 4 1 0.64135 2.54 0.0
cylinder 2 1 0.70735 2.54 0.0
cuboid 5 1 4p0.8575 2.54 0.0
unit 2
'fuel between the two lattice support plates
cylinder 1 1 0.63245 67.29 0.0
cylinder 0 1 0.64135 67.29 0.0
cylinder 2 1 0.70735 67.29 0.0
cuboid 3 1 4p0.8575 67.29 0.0
unit 3
'fuel in upper lattice support plate
cylinder 1 1 0.63245 1.27 0.0
cylinder 0 1 0.64135 1.27 0.0
cylinder 2 1 0.70735 1.27 0.0
cuboid 5 1 4p0.8575 1.27 0.0
unit 4
'fuel above the upper lattice support plate
cylinder 1 1 0.63245 22.86 0.0
cylinder 0 1 0.64135 22.86 0.0
cylinder 2 1 0.70735 22.86 0.0
cuboid 3 1 4p0.8575 22.86 0.0
unit 5
'bottom of smeared fuel - rubber cap
cuboid 4 1 0.9744 0 2p0.8575 2.54 0.0
cuboid 5 1 1.715 0 2p0.8575 2.54 0.0
unit 6
'smeared fuel between the two lattice support plates
cuboid 500 1 0.9744 0 2p0.8575 67.29 0.0
```

```

cuboid    3 1 1.715  0  2p0.8575          67.29  0.0
unit 7
'smeared fuel in upper lattice support plate
cuboid    500 1 0.9744 0  2p0.8575          1.27  0.0
cuboid    5 1 1.715  0  2p0.8575          1.27  0.0
unit 8
'smeared fuel above the upper lattice support plate
cuboid    500 1 0.9744 0  2p0.8575          22.86  0.0
cuboid    3 1 1.715  0  2p0.8575          22.86  0.0
unit 9
'top of fuel - rubber cap in h2o
cylinder  4 1 0.64135          2.54  0.0
cylinder  2 1 0.70735          2.54  0.0
cuboid    3 1 4p0.8575          2.54  0.0
unit 10
'top of smeared fuel - rubber cap
cuboid    4 1 0.9744 0  2p0.8575          2.54  0.0
cuboid    3 1 1.715  0  2p0.8575          2.54  0.0
global
unit 11
array 1 -10.29 -37.73  0.0
cuboid    3 1 2p39.80 2p37.94  111.7  0.0
cuboid    8 1 2p41.705 2p39.845  111.7 -17.105
reflector 6 2 4r3 2r0 10
end geometry
read bias id=500  2 11  end bias
read array
ara=1 nux=12 nuy=44 nuz=5
fill 11r1 5  43q12 11r2 6  43q12
      11r3 7  43q12 11r4 8  43q12  11r9 10 43q12  end fill
end array
read plot
ttl='x-y slice of pnl4267c at z=50'
xul=-45.  yul=45.0  zul=50
xlr= 45.  ylr=-45.  zlr=50
uax=1 vdn=-1 nax=130  nch=' 12 45 8&'  end
end plot
end data
end

```

p4267d

```
=csas2x
'
' problem id -- pnl-4267
' citation id -- exp. no. 181
'
' 4.31% u-235 enriched uo2 rods, 1.4147 cm od al clad, 1.2827 cm id,
' 1.2649 cm od. uo2 91.44 cm long, rod 96.52 cm long.
' single array 44 x 27.09 rods (1192 total rods), 1.715 cm square pitch.
' boron = 2.55 g/l
' reference: pnl-4267 exp. 181
' scale module: csas2x
'
1.715 cm pitch lattice cell,4.31 wt% enriched fuel.
27burn latticecell
uo2 1 0.949 293 92235 4.31 92238 95.69 end uo2
al 2 1.0 end al
h2o 3 1.0 end h2o
arbm rubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
16000 1.7 8016 22.1 14000 0.3 4 end
poly(h2o) 5 den=.904 end
h2o 6 end
boron 7 den=.00255 1.0 end
h2o 7 end
plexiglass 8 1.0 end
uo2 9 0.949 293 92235 4.31 92238 95.69 end uo2
al 10 1.0 end al
h2o 11 1.0 end h2o
boron 11 den=.00255 1.0 end
end comp
'
pitch fod f m cod c cid g
squarepitch 1.715 1.2649 9 11 1.4147 10 1.2827 0 end
more data
res=1 cylinder .63245 dan(1)=.269915
end more
pnl-4267 exp. 181 44 x 27.09 array (1192 total rods) boron = 2.55 g/l
read parm plt=yes run=yes gen=405 npg=600 nsk=5 tme=60
wrs=34 res=205 nub=yes end parm
read geom
unit 1
'bottom of fuel - rubber cap in lower lattice support plate
cylinder 4 1 0.64135 2.54 0.0
cylinder 2 1 0.70735 2.54 0.0
cuboid 5 1 4p0.8575 2.54 0.0
unit 2
'fuel between the two lattice support plates
cylinder 1 1 0.63245 67.29 0.0
cylinder 0 1 0.64135 67.29 0.0
cylinder 2 1 0.70735 67.29 0.0
cuboid 7 1 4p0.8575 67.29 0.0
unit 3
'fuel in upper lattice support plate
cylinder 1 1 0.63245 1.27 0.0
cylinder 0 1 0.64135 1.27 0.0
cylinder 2 1 0.70735 1.27 0.0
cuboid 5 1 4p0.8575 1.27 0.0
unit 4
'fuel above the upper lattice support plate
cylinder 1 1 0.63245 22.86 0.0
cylinder 0 1 0.64135 22.86 0.0
cylinder 2 1 0.70735 22.86 0.0
cuboid 7 1 4p0.8575 22.86 0.0
unit 5
'bottom of smeared fuel - rubber cap
cuboid 4 1 0.1559 0 2p0.8575 2.54 0.0
cuboid 5 1 1.715 0 2p0.8575 2.54 0.0
unit 6
'smeared fuel between the two lattice support plates
```

```

cuboid 500 1 0.1559 0 2p0.8575 67.29 0.0
cuboid 7 1 1.715 0 2p0.8575 67.29 0.0
unit 7
'smeared fuel in upper lattice support plate
cuboid 500 1 0.1559 0 2p0.8575 1.27 0.0
cuboid 5 1 1.715 0 2p0.8575 1.27 0.0
unit 8
'smeared fuel above the upper lattice support plate
cuboid 500 1 0.1559 0 2p0.8575 22.86 0.0
cuboid 7 1 1.715 0 2p0.8575 22.86 0.0
unit 9
'top of fuel - rubber cap in h2o
cylinder 4 1 0.64135 2.54 0.0
cylinder 2 1 0.70735 2.54 0.0
cuboid 7 1 4p0.8575 2.54 0.0
unit 10
'top of smeared fuel - rubber cap
cuboid 4 1 0.1559 0 2p0.8575 2.54 0.0
cuboid 7 1 1.715 0 2p0.8575 2.54 0.0
global
unit 11
array 1 -24.01 -37.73 0.0
cuboid 7 1 2p39.80 2p37.94 111.7 0.0
cuboid 8 1 2p41.705 2p39.845 111.7 -17.105
reflector 6 2 4r3 2r0 10
end geometry
read bias id=500 2 11 end bias
read array
ara=1 nux=28 nuy=44 nuz=5
fill 27r1 5 43q28 27r2 6 43q28
27r3 7 43q28 27r4 8 43q28 27r9 10 43q28 end fill
end array
read plot
ttl='x-y slice of pnl4267d at z=50'
xul=-45. yul=45.0 zul=50
xlr= 45. ylr=-45. zlr=50
uax=1 vdn=-1 nax=130 nch=' 12 45 8&' end
end plot
end data
end

```

pnl4976

```

=csasn
infinite lattice of mox rods @ actual pitch; this is for natural uo2 xs in mox
27burn latticecell
uo2 1 den=9.54 0.98 293 end
puo2 1 den=9.54 0.02 293 94238 0.01 94239 91.806 94240 7.876
      94241 0.277 94242 0.031 end
am-241 1 den=9.54 0.000076 293 end
zircalloy 2 end
h2o 3 end
end comp
triangpitch 1.598 1.283 1 3 1.415 2 end
end
=scommand
mv ft04f001 tmp1
end
=csasn
mox rods @ wider pitch of mox rods w/ 4.31 w/o uo2 in mod(vol.wt'd);for puo2 xs
27burn latticecell
uo2 1 den=9.54 0.98 293 end
puo2 1 den=9.54 0.02 293 94238 0.01 94239 91.806 94240 7.876
      94241 0.277 94242 0.031 end
am-241 1 den=9.54 0.000076 293 end
zircalloy 2 end
h2o 3 .379 end
end comp
triangpitch 2.768 1.283 1 3 1.415 2 end
end
=scommand
mv ft04f001 tmp2
end
=csasn
pnl-4976 exp196 4.31 w/o uo2 rods in infinite lattice, actual pitch
27burn latticecell
'4.31 w/o uo2
uo2 1 den=10.4 1.0 293 92234 0.022 92235 4.306 92236 0.022 92238 95.65 end
'aluminum clad
al 2 end
'moderator
h2o 3 end
'rubber end caps
arbmrubber 1.321 6 0 0 0 6012 58. 1001 6.5 20000 11.4
            16000 1.7 8016 22.1 14000 0.3 4 end
poly(h2o) 5 den=.904 end
plexiglass 6 1.0 end
'natural uo2 powder (in bottom .2 cm of mox rods)
uo2 8 den=9.54 1.0 end
end comp
triangpitch 1.598 1.265 1 3 1.415 2 1.283 0 end
end
=scommand
mv tmp1 ft33f001
mv tmp2 ft34f001
mv ft04f001 ft35f001
end
=wax
'write final library to unit 4
0$$ 4 35
'input xsec's from 3 libs
1$$ 3 t
'input xsec's for natural uo2 in mox rods and zirc clad mat'ls
2$$ 33 5 t
3$$ 92234 92235 92238 8016 40302
4$$ 234 235 238 8116 40302 t
'input xsec's for puo2 in mox rods
2$$ 34 6 t
3$$ 94238 94239 94240 94241 94242 95241
4$$ 94238 94239 94240 94241 94242 95241 t

```



```

'input all other xsec's from third lib (4.31 w/o)
2$$ 35 0 t
end
=kenov
pnl4976 exp196 1174 uo2 & 583 mo2 rods to approx. 20,000 mwd/mtu assy
read param tme=60 plt=yes npg=600 gen=505 nsk=5 run=yes lib=4
wrs=44 res=205 nub=yes end param
read mixt
sct=2
mix=1
'4.31 w/o uo2
92234      5.18950e-06
92235      1.01139e-03
92236      5.14542e-06
92238      2.21824e-02
8016       4.64083e-02
mix=2
'al clad
13027      6.02374e-02
mix=3
'h2o moderator
1001       6.67514e-02
308016     3.33757e-02
mix=4
'rubber end caps
401001     5.13089e-02
408016     1.09913e-02
6012       3.84503e-02
20000      2.26270e-03
16000      4.21784e-04
14000      8.49759e-05
mix=5
'polypropylene lattice plates
501001     7.76850e-02
506012     3.88425e-02
mix=6
'acrylic plates
601001     5.68187e-02
608016     1.42047e-02
606012     3.55117e-02
mix=7
'mixed oxide = natural uo2 + puo2
234        1.18851e-06
235        1.48879e-04
238        2.07010e-02
94238      4.25437e-08
94239      3.89206e-04
94240      3.32505e-05
94241      1.16460e-06
94242      1.29791e-07
95241      1.81131e-06
8116       4.25498e-02
mix=8
'natural uo2 powder
892234     1.21277e-06
892235     1.51917e-04
892238     2.11235e-02
808016     4.25533e-02
mix=9
'zirc clad
40302      4.25156e-02
end mixt
read geom
unit 1
zhemicyl-y 1 1 .6325      42.774  0.0
zhemicyl-y 0 1 .6415      42.774  0.0
zhemicyl-y 2 1 .7075      42.774  0.0
unit 2
zhemicyl-x 1 1 .6325      42.774  0.0

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zhemicyl-x	0	1	.6415	42.774	0.0
zhemicyl-x	2	1	.7075	42.774	0.0
unit 3					
zhemicyl+x	1	1	.6325	42.774	0.0
zhemicyl+x	0	1	.6415	42.774	0.0
zhemicyl+x	2	1	.7075	42.774	0.0
unit 4					
zhemicyl+y	1	1	.6325	42.774	0.0
zhemicyl+y	0	1	.6415	42.774	0.0
zhemicyl+y	2	1	.7075	42.774	0.0
unit 5					
zhemicyl-y	7	1	.6415	42.774	0.0
zhemicyl-y	9	1	.7175	42.774	0.0
unit 6					
zhemicyl-x	7	1	.6415	42.774	0.0
zhemicyl-x	9	1	.7175	42.774	0.0
unit 7					
zhemicyl+x	7	1	.6415	42.774	0.0
zhemicyl+x	9	1	.7175	42.774	0.0
unit 8					
zhemicyl+y	7	1	.6415	42.774	0.0
zhemicyl+y	9	1	.7175	42.774	0.0
unit 11					
zhemicyl-y	4	1	.6415	2.54	0.0
zhemicyl-y	2	1	.7075	2.54	0.0
unit 12					
zhemicyl-x	4	1	.6415	2.54	0.0
zhemicyl-x	2	1	.7075	2.54	0.0
unit 13					
zhemicyl+x	4	1	.6415	2.54	0.0
zhemicyl+x	2	1	.7075	2.54	0.0
unit 14					
zhemicyl+y	4	1	.6415	2.54	0.0
zhemicyl+y	2	1	.7075	2.54	0.0
unit 15					
zhemicyl-y	8	1	.6415	0.898	0.698
zhemicyl-y	7	1	.6415	2.540	0.698
zhemicyl-y	9	1	.7175	2.540	0.0
unit 16					
zhemicyl-x	8	1	.6415	0.898	0.698
zhemicyl-x	7	1	.6415	2.540	0.698
zhemicyl-x	9	1	.7175	2.540	0.0
unit 17					
zhemicyl+x	8	1	.6415	0.898	0.698
zhemicyl+x	7	1	.6415	2.540	0.698
zhemicyl+x	9	1	.7175	2.540	0.0
unit 18					
zhemicyl+y	8	1	.6415	0.898	0.698
zhemicyl+y	7	1	.6415	2.540	0.698
zhemicyl+y	9	1	.7175	2.540	0.0
unit 21					
zhemicyl-y	1	1	.6325	1.35	0.0
zhemicyl-y	0	1	.6415	1.35	0.0
zhemicyl-y	2	1	.7075	1.35	0.0
unit 22					
zhemicyl-x	1	1	.6325	1.35	0.0
zhemicyl-x	0	1	.6415	1.35	0.0
zhemicyl-x	2	1	.7075	1.35	0.0
unit 23					
zhemicyl+x	1	1	.6325	1.35	0.0
zhemicyl+x	0	1	.6415	1.35	0.0
zhemicyl+x	2	1	.7075	1.35	0.0
unit 24					
zhemicyl+y	1	1	.6325	1.35	0.0
zhemicyl+y	0	1	.6415	1.35	0.0
zhemicyl+y	2	1	.7075	1.35	0.0
unit 25					
zhemicyl-y	7	1	.6415	1.35	0.0
zhemicyl-y	9	1	.7175	1.35	0.0

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unit 26
zhemicyl-x 7 1 .6415      1.35    0.0
zhemicyl-x 9 1 .7175      1.35    0.0
unit 27
zhemicyl+x 7 1 .6415      1.35    0.0
zhemicyl+x 9 1 .7175      1.35    0.0
unit 28
zhemicyl+y 7 1 .6415      1.35    0.0
zhemicyl+y 9 1 .7175      1.35    0.0
unit 31
zhemicyl-y 1 1 .6325      2.477   0.0
zhemicyl-y 0 1 .6415      2.477   0.0
zhemicyl-y 4 1 .6415      5.017   0.0
zhemicyl-y 2 1 .7075      5.017   0.0
unit 32
zhemicyl-x 1 1 .6325      2.477   0.0
zhemicyl-x 0 1 .6415      2.477   0.0
zhemicyl-x 4 1 .6415      5.017   0.0
zhemicyl-x 2 1 .7075      5.017   0.0
unit 33
zhemicyl+x 1 1 .6325      2.477   0.0
zhemicyl+x 0 1 .6415      2.477   0.0
zhemicyl+x 4 1 .6415      5.017   0.0
zhemicyl+x 2 1 .7075      5.017   0.0
unit 34
zhemicyl+y 1 1 .6325      2.477   0.0
zhemicyl+y 0 1 .6415      2.477   0.0
zhemicyl+y 4 1 .6415      5.017   0.0
zhemicyl+y 2 1 .7075      5.017   0.0
unit 35
zhemicyl-y 2 1 .7175      0.825   0.0
unit 36
zhemicyl-x 2 1 .7175      0.825   0.0
unit 37
zhemicyl+x 2 1 .7175      0.825   0.0
unit 38
zhemicyl+y 2 1 .7175      0.825   0.0
unit 90
cuboid      3 1 2p.799 2p1.384 42.774 0.0
unit 91
cuboid      3 1 2p.799 2p1.384 2.54 0.0
unit 92
cuboid      3 1 2p.799 2p1.384 1.35 0.0
unit 93
cuboid      3 1 2p.799 2p1.384 5.017 0.0
unit 110
zhemicyl+y 1 1 .6325      42.774 0.0
zhemicyl+y 0 1 .6415      42.774 0.0
zhemicyl+y 2 1 .7075      42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        6 .799 1.384 0.0
hole        3 -.799 1.384 0.0
hole        1 0.0 2.768 0.0
unit 111
zhemicyl+y 7 1 .6415      42.774 0.0
zhemicyl+y 9 1 .7175      42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        2 .799 1.384 0.0
hole        3 -.799 1.384 0.0
hole        5 0.0 2.768 0.0
unit 112
zhemicyl-y 7 1 .6415      42.774 0.0
zhemicyl-y 9 1 .7175      42.774 0.0
cuboid      3 1 2p.799 0.0 -2.768 42.774 0.0
unit 113
zhemicyl-y 7 1 .6415      42.774 0.0
zhemicyl-y 9 1 .7175      42.774 0.0
cuboid      3 1 2p.799 0.0 -2.768 42.774 0.0
hole        3 -.799 -1.384 0.0

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unit 114
zhemicyl-y 7 1 .6415      42.774  0.0
zhemicyl-y 9 1 .7175      42.774  0.0
cuboid      3 1 2p.799  0.0 -2.768  42.774  0.0
hole        2 .799 -1.384  0.0
unit 115
zhemicyl-y 7 1 .6415      42.774  0.0
zhemicyl-y 9 1 .7175      42.774  0.0
cuboid      3 1 2p.799  0.0 -2.768  42.774  0.0
hole        3 -.799 -1.384  0.0
hole        2 .799 -1.384  0.0
unit 116
zhemicyl+y 7 1 .6415      42.774  0.0
zhemicyl+y 9 1 .7175      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
unit 117
zhemicyl+y 7 1 .6415      42.774  0.0
zhemicyl+y 9 1 .7175      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        2 .799 1.384  0.0
unit 118
zhemicyl+y 7 1 .6415      42.774  0.0
zhemicyl+y 9 1 .7175      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        2 .799 1.384  0.0
hole        3 -.799 1.384  0.0
unit 119
zhemicyl+y 7 1 .6415      42.774  0.0
zhemicyl+y 9 1 .7175      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        3 -.799 1.384  0.0
unit 120
zhemicyl+y 7 1 .6415      42.774  0.0
zhemicyl+y 9 1 .7175      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        2 .799 1.384  0.0
hole        5 0.0  2.768  0.0
unit 121
zhemicyl+y 1 1 .6325      42.774  0.0
zhemicyl+y 0 1 .6415      42.774  0.0
zhemicyl+y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        7 -.799 1.384  0.0
hole        2 .799 1.384  0.0
hole        1 0.0  2.768  0.0
unit 122
zhemicyl+y 1 1 .6325      42.774  0.0
zhemicyl+y 0 1 .6415      42.774  0.0
zhemicyl+y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        2 .799 1.384  0.0
hole        1 0.0  2.768  0.0
unit 123
zhemicyl+y 1 1 .6325      42.774  0.0
zhemicyl+y 0 1 .6415      42.774  0.0
zhemicyl+y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        6 .799 1.384  0.0
hole        1 0.0  2.768  0.0
unit 124
zhemicyl+y 1 1 .6325      42.774  0.0
zhemicyl+y 0 1 .6415      42.774  0.0
zhemicyl+y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  2.768  0.0  42.774  0.0
hole        3 -.799 1.384  0.0
hole        6 .799 1.384  0.0
unit 125
zhemicyl+x 7 1 .6415      42.774  0.0
zhemicyl+x 9 1 .7175      42.774  0.0

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cuboid      3 1 1.598 0.0 2p1.384 42.774 0.0
unit 126
zhemicyl-x 7 1 .6415          42.774 0.0
zhemicyl-x 9 1 .7175          42.774 0.0
cuboid      3 1 0.0 -1.598 2p1.384 42.774 0.0
unit 127
zhemicyl+y 1 1 .6325          42.774 0.0
zhemicyl+y 0 1 .6415          42.774 0.0
zhemicyl+y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        3 -.799 1.384 0.0
hole        1 0.0 2.768 0.0
unit 128
zhemicyl+y 1 1 .6325          42.774 0.0
zhemicyl+y 0 1 .6415          42.774 0.0
zhemicyl+y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        2 .799 1.384 0.0
unit 129
zhemicyl+y 1 1 .6325          42.774 0.0
zhemicyl+y 0 1 .6415          42.774 0.0
zhemicyl+y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        2 .799 1.384 0.0
hole        7 -.799 1.384 0.0
unit 130
zhemicyl+y 1 1 .6325          42.774 0.0
zhemicyl+y 0 1 .6415          42.774 0.0
zhemicyl+y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
unit 131
zhemicyl+y 1 1 .6325          42.774 0.0
zhemicyl+y 0 1 .6415          42.774 0.0
zhemicyl+y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        7 -.799 1.384 0.0
unit 132
zhemicyl+y 1 1 .6325          42.774 0.0
zhemicyl+y 0 1 .6415          42.774 0.0
zhemicyl+y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        3 -.799 1.384 0.0
unit 133
zhemicyl+y 1 1 .6325          42.774 0.0
zhemicyl+y 0 1 .6415          42.774 0.0
zhemicyl+y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 2.768 0.0 42.774 0.0
hole        6 .799 1.384 0.0
unit 134
zhemicyl-y 1 1 .6325          42.774 0.0
zhemicyl-y 0 1 .6415          42.774 0.0
zhemicyl-y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 0.0 -2.768 42.774 0.0
hole        6 .799 -1.384 0.0
hole        3 -.799 -1.384 0.0
unit 135
zhemicyl-y 1 1 .6325          42.774 0.0
zhemicyl-y 0 1 .6415          42.774 0.0
zhemicyl-y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 0.0 -2.768 42.774 0.0
hole        2 .799 -1.384 0.0
hole        7 -.799 -1.384 0.0
unit 136
zhemicyl-y 1 1 .6325          42.774 0.0
zhemicyl-y 0 1 .6415          42.774 0.0
zhemicyl-y 2 1 .7075          42.774 0.0
cuboid      3 1 2p.799 0.0 -2.768 42.774 0.0
hole        3 -.799 -1.384 0.0
unit 137

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zhemicyl-y 1 1 .6325      42.774  0.0
zhemicyl-y 0 1 .6415      42.774  0.0
zhemicyl-y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  0.0 -2.768  42.774 0.0
hole        7 -.799 -1.384 0.0
unit 138
zhemicyl-y 1 1 .6325      42.774  0.0
zhemicyl-y 0 1 .6415      42.774  0.0
zhemicyl-y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  0.0 -2.768  42.774 0.0
hole        6 .799 -1.384 0.0
unit 139
zhemicyl-y 1 1 .6325      42.774  0.0
zhemicyl-y 0 1 .6415      42.774  0.0
zhemicyl-y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  0.0 -2.768  42.774 0.0
hole        2 .799 -1.384 0.0
unit 140
zhemicyl-y 1 1 .6325      42.774  0.0
zhemicyl-y 0 1 .6415      42.774  0.0
zhemicyl-y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  0.0 -2.768  42.774 0.0
unit 141
zhemicyl-x 1 1 .6325      42.774  0.0
zhemicyl-x 0 1 .6415      42.774  0.0
zhemicyl-x 2 1 .7075      42.774  0.0
cuboid      3 1 0.0 -1.598  2p1.384  42.774 0.0
unit 142
zhemicyl+x 1 1 .6325      42.774  0.0
zhemicyl+x 0 1 .6415      42.774  0.0
zhemicyl+x 2 1 .7075      42.774  0.0
cuboid      3 1 1.598  0.0 2p1.384  42.774 0.0
unit 143
zhemicyl+y 1 1 .6325      42.774  0.0
zhemicyl+y 0 1 .6415      42.774  0.0
zhemicyl+y 2 1 .7075      42.774  0.0
cuboid      3 1 2p.799  2.768 0.0 42.774 0.0
hole        7 -.799 1.384 0.0
hole        1 0.0 2.768 0.0
unit 144
array 1 3*0.0
unit 210
zhemicyl+y 4 1 .6415      2.54  0.0
zhemicyl+y 2 1 .7075      2.54  0.0
cuboid      3 1 2p.799  2.768 0.0 2.54 0.0
hole       16 .799 1.384 0.0
hole       13 -.799 1.384 0.0
hole       11 0.0 2.768 0.0
unit 211
zhemicyl+y 8 1 .6415      0.898 0.698
zhemicyl+y 7 1 .6415      2.540 0.698
zhemicyl+y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799  2.768 0.0 2.54 0.0
hole       12 .799 1.384 0.0
hole       13 -.799 1.384 0.0
hole       15 0.0 2.768 0.0
unit 212
zhemicyl-y 8 1 .6415      0.898 0.698
zhemicyl-y 7 1 .6415      2.540 0.698
zhemicyl-y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799  0.0 -2.768  2.54 0.0
unit 213
zhemicyl-y 8 1 .6415      0.898 0.698
zhemicyl-y 7 1 .6415      2.540 0.698
zhemicyl-y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799  0.0 -2.768  2.54 0.0
hole       13 -.799 -1.384 0.0
unit 214
zhemicyl-y 8 1 .6415      0.898 0.698

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zhemicyl-y 7 1 .6415      2.540 0.698
zhemicyl-y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799 0.0 -2.768 2.54 0.0
hole        12 .799 -1.384 0.0
unit 215
zhemicyl-y 8 1 .6415      0.898 0.698
zhemicyl-y 7 1 .6415      2.540 0.698
zhemicyl-y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799 0.0 -2.768 2.54 0.0
hole        13 -.799 -1.384 0.0
hole        12 .799 -1.384 0.0
unit 216
zhemicyl+y 8 1 .6415      0.898 0.698
zhemicyl+y 7 1 .6415      2.540 0.698
zhemicyl+y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
unit 217
zhemicyl+y 8 1 .6415      0.898 0.698
zhemicyl+y 7 1 .6415      2.540 0.698
zhemicyl+y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        12 .799 1.384 0.0
unit 218
zhemicyl+y 8 1 .6415      0.898 0.698
zhemicyl+y 7 1 .6415      2.540 0.698
zhemicyl+y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        12 .799 1.384 0.0
hole        13 -.799 1.384 0.0
unit 219
zhemicyl+y 8 1 .6415      0.898 0.698
zhemicyl+y 7 1 .6415      2.540 0.698
zhemicyl+y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        13 -.799 1.384 0.0
unit 220
zhemicyl+y 8 1 .6415      0.898 0.698
zhemicyl+y 7 1 .6415      2.540 0.698
zhemicyl+y 9 1 .7175      2.540 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        12 .799 1.384 0.0
hole        15 0.0 2.768 0.0
unit 221
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        17 -.799 1.384 0.0
hole        12 .799 1.384 0.0
hole        11 0.0 2.768 0.0
unit 222
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        12 .799 1.384 0.0
hole        11 0.0 2.768 0.0
unit 223
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        16 .799 1.384 0.0
hole        11 0.0 2.768 0.0
unit 224
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        13 -.799 1.384 0.0
hole        16 .799 1.384 0.0
unit 225
zhemicyl+x 8 1 .6415      0.898 0.698

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zhemicyl+x 7 1 .6415      2.540 0.698
zhemicyl+x 9 1 .7175      2.540 0.0
cuboid      3 1 1.598 0.0 2p1.384 2.54 0.0
unit 226
zhemicyl-x 8 1 .6415      0.898 0.698
zhemicyl-x 7 1 .6415      2.540 0.698
zhemicyl-x 9 1 .7175      2.540 0.0
cuboid      3 1 0.0 -1.598 2p1.384 2.54 0.0
unit 227
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        13 -.799 1.384 0.0
hole        11 0.0 2.768 0.0
unit 228
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        12 .799 1.384 0.0
unit 229
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        12 .799 1.384 0.0
hole        17 -.799 1.384 0.0
unit 230
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
unit 231
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        17 -.799 1.384 0.0
unit 232
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        13 -.799 1.384 0.0
unit 233
zhemicyl+y 4 1 .6415      2.54 0.0
zhemicyl+y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 2.768 0.0 2.54 0.0
hole        16 .799 1.384 0.0
unit 234
zhemicyl-y 4 1 .6415      2.54 0.0
zhemicyl-y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 0.0 -2.768 2.54 0.0
hole        16 .799 -1.384 0.0
hole        13 -.799 -1.384 0.0
unit 235
zhemicyl-y 4 1 .6415      2.54 0.0
zhemicyl-y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 0.0 -2.768 2.54 0.0
hole        12 .799 -1.384 0.0
hole        17 -.799 -1.384 0.0
unit 236
zhemicyl-y 4 1 .6415      2.54 0.0
zhemicyl-y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 0.0 -2.768 2.54 0.0
hole        13 -.799 -1.384 0.0
unit 237
zhemicyl-y 4 1 .6415      2.54 0.0
zhemicyl-y 2 1 .7075      2.54 0.0
cuboid      3 1 2p.799 0.0 -2.768 2.54 0.0
hole        17 -.799 -1.384 0.0
unit 238
zhemicyl-y 4 1 .6415      2.54 0.0
zhemicyl-y 2 1 .7075      2.54 0.0

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cuboid      3 1 2p.799  0.0 -2.768    2.54  0.0
hole        16 .799 -1.384 0.0
unit 239
zhemicyl-y 4 1 .6415      2.54  0.0
zhemicyl-y 2 1 .7075      2.54  0.0
cuboid      3 1 2p.799  0.0 -2.768    2.54  0.0
hole        12 .799 -1.384 0.0
unit 240
zhemicyl-y 4 1 .6415      2.54  0.0
zhemicyl-y 2 1 .7075      2.54  0.0
cuboid      3 1 2p.799  0.0 -2.768    2.54  0.0
unit 241
zhemicyl-x 4 1 .6415      2.54  0.0
zhemicyl-x 2 1 .7075      2.54  0.0
cuboid      3 1 0.0 -1.598 2p1.384    2.54  0.0
unit 242
zhemicyl+x 4 1 .6415      2.54  0.0
zhemicyl+x 2 1 .7075      2.54  0.0
cuboid      3 1 1.598  0.0 2p1.384    2.54  0.0
unit 243
zhemicyl+y 4 1 .6415      2.54  0.0
zhemicyl+y 2 1 .7075      2.54  0.0
cuboid      3 1 2p.799  2.768 0.0    2.54  0.0
hole        17 -.799 1.384 0.0
hole        11 0.0  2.768 0.0
unit 244
array 2 3*0.0
unit 310
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0    1.350 0.0
hole        26 .799 1.384 0.0
hole        23 -.799 1.384 0.0
hole        21 0.0  2.768 0.0
unit 311
zhemicyl+y 7 1 .6415      1.350  0.0
zhemicyl+y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0    1.350 0.0
hole        22 .799 1.384 0.0
hole        23 -.799 1.384 0.0
hole        25 0.0  2.768 0.0
unit 312
zhemicyl-y 7 1 .6415      1.350  0.0
zhemicyl-y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768    1.350 0.0
unit 313
zhemicyl-y 7 1 .6415      1.350  0.0
zhemicyl-y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768    1.350 0.0
hole        23 -.799 -1.384 0.0
unit 314
zhemicyl-y 7 1 .6415      1.350  0.0
zhemicyl-y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768    1.350 0.0
hole        22 .799 -1.384 0.0
unit 315
zhemicyl-y 7 1 .6415      1.350  0.0
zhemicyl-y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768    1.350 0.0
hole        23 -.799 -1.384 0.0
hole        22 .799 -1.384 0.0
unit 316
zhemicyl+y 7 1 .6415      1.350  0.0
zhemicyl+y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0    1.350 0.0
unit 317
zhemicyl+y 7 1 .6415      1.350  0.0
zhemicyl+y 9 1 .7175      1.350  0.0

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cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        22 .799 1.384  0.0
unit 318
zhemicyl+y 7 1 .6415      1.350  0.0
zhemicyl+y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        22 .799 1.384  0.0
hole        23 -.799 1.384  0.0
unit 319
zhemicyl+y 7 1 .6415      1.350  0.0
zhemicyl+y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        23 -.799 1.384  0.0
unit 320
zhemicyl+y 7 1 .6415      1.350  0.0
zhemicyl+y 9 1 .7175      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        22 .799 1.384  0.0
hole        25 0.0  2.768 0.0
unit 321
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        27 -.799 1.384  0.0
hole        22 .799 1.384  0.0
hole        21 0.0  2.768 0.0
unit 322
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        22 .799 1.384  0.0
hole        21 0.0  2.768 0.0
unit 323
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        26 .799 1.384  0.0
hole        21 0.0  2.768 0.0
unit 324
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        23 -.799 1.384  0.0
hole        26 .799 1.384  0.0
unit 325
zhemicyl+x 7 1 .6415      1.350  0.0
zhemicyl+x 9 1 .7175      1.350  0.0
cuboid      5 1 1.598 0.0 2p1.384 1.350 0.0
unit 326
zhemicyl-x 7 1 .6415      1.350  0.0
zhemicyl-x 9 1 .7175      1.350  0.0
cuboid      5 1 0.0 -1.598 2p1.384 1.350 0.0
unit 327
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        23 -.799 1.384  0.0
hole        21 0.0  2.768 0.0
unit 328
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        22 .799 1.384  0.0

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unit 329
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        22 .799 1.384 0.0
hole        27 -.799 1.384 0.0
unit 330
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
unit 331
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        27 -.799 1.384 0.0
unit 332
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        23 -.799 1.384 0.0
unit 333
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0  1.350 0.0
hole        26 .799 1.384 0.0
unit 334
zhemicyl-y 1 1 .6325      1.350  0.0
zhemicyl-y 0 1 .6415      1.350  0.0
zhemicyl-y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768  1.350 0.0
hole        26 .799 -1.384 0.0
hole        23 -.799 -1.384 0.0
unit 335
zhemicyl-y 1 1 .6325      1.350  0.0
zhemicyl-y 0 1 .6415      1.350  0.0
zhemicyl-y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768  1.350 0.0
hole        22 .799 -1.384 0.0
hole        27 -.799 -1.384 0.0
unit 336
zhemicyl-y 1 1 .6325      1.350  0.0
zhemicyl-y 0 1 .6415      1.350  0.0
zhemicyl-y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768  1.350 0.0
hole        23 -.799 -1.384 0.0
unit 337
zhemicyl-y 1 1 .6325      1.350  0.0
zhemicyl-y 0 1 .6415      1.350  0.0
zhemicyl-y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768  1.350 0.0
hole        27 -.799 -1.384 0.0
unit 338
zhemicyl-y 1 1 .6325      1.350  0.0
zhemicyl-y 0 1 .6415      1.350  0.0
zhemicyl-y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768  1.350 0.0
hole        26 .799 -1.384 0.0
unit 339
zhemicyl-y 1 1 .6325      1.350  0.0
zhemicyl-y 0 1 .6415      1.350  0.0
zhemicyl-y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768  1.350 0.0
hole        22 .799 -1.384 0.0
unit 340

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zhemicyl-y 1 1 .6325      1.350  0.0
zhemicyl-y 0 1 .6415      1.350  0.0
zhemicyl-y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  0.0 -2.768  1.350 0.0
unit 341
zhemicyl-x 1 1 .6325      1.350  0.0
zhemicyl-x 0 1 .6415      1.350  0.0
zhemicyl-x 2 1 .7075      1.350  0.0
cuboid      5 1 0.0 -1.598  2p1.384  1.350 0.0
unit 342
zhemicyl+x 1 1 .6325      1.350  0.0
zhemicyl+x 0 1 .6415      1.350  0.0
zhemicyl+x 2 1 .7075      1.350  0.0
cuboid      5 1 1.598  0.0 2p1.384  1.350 0.0
unit 343
zhemicyl+y 1 1 .6325      1.350  0.0
zhemicyl+y 0 1 .6415      1.350  0.0
zhemicyl+y 2 1 .7075      1.350  0.0
cuboid      5 1 2p.799  2.768 0.0 1.350 0.0
hole        27 -.799 1.384 0.0
hole        21 0.0  2.768 0.0
unit 344
array 3 3*0.0
unit 410
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  2.768 0.0 5.017 0.0
hole        36 .799 1.384 0.0
hole        33 -.799 1.384 0.0
hole        31 0.0  2.768 0.0
unit 411
zhemicyl+y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  2.768 0.0 5.017 0.0
hole        32 .799 1.384 0.0
hole        33 -.799 1.384 0.0
hole        35 0.0  2.768 0.0
unit 412
zhemicyl-y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
unit 413
zhemicyl-y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        33 -.799 -1.384 0.0
unit 414
zhemicyl-y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        32 .799 -1.384 0.0
unit 415
zhemicyl-y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        33 -.799 -1.384 0.0
hole        32 .799 -1.384 0.0
unit 416
zhemicyl+y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  2.768 0.0 5.017 0.0
unit 417
zhemicyl+y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  2.768 0.0 5.017 0.0
hole        32 .799 1.384 0.0
unit 418
zhemicyl+y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  2.768 0.0 5.017 0.0
hole        32 .799 1.384 0.0
hole        33 -.799 1.384 0.0
unit 419
zhemicyl+y 2 1 .7175      0.825  0.0
cuboid      3 1 2p.799  2.768 0.0 5.017 0.0

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hole      33 -.799 1.384 0.0
unit 420
zhemicyl+y 2 1 .7175      0.825  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      32 .799 1.384 0.0
hole      35 0.0  2.768 0.0
unit 421
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      37 -.799 1.384 0.0
hole      32 .799 1.384 0.0
hole      31 0.0  2.768 0.0
unit 422
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      32 .799 1.384 0.0
hole      31 0.0  2.768 0.0
unit 423
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      36 .799 1.384 0.0
hole      31 0.0  2.768 0.0
unit 424
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      33 -.799 1.384 0.0
hole      36 .799 1.384 0.0
unit 425
zhemicyl+x 2 1 .7175      0.825  0.0
cuboid     3 1 1.598 0.0 2p1.384 5.017 0.0
unit 426
zhemicyl-x 2 1 .7175      0.825  0.0
cuboid     3 1 0.0 -1.598 2p1.384 5.017 0.0
unit 427
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      33 -.799 1.384 0.0
hole      31 0.0  2.768 0.0
unit 428
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      32 .799 1.384 0.0
unit 429
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0 5.017 0.0
hole      32 .799 1.384 0.0
hole      37 -.799 1.384 0.0
unit 430

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zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  2.768 0.0  5.017 0.0
unit 431
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  2.768 0.0  5.017 0.0
hole        37 -.799 1.384 0.0
unit 432
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  2.768 0.0  5.017 0.0
hole        33 -.799 1.384 0.0
unit 433
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  2.768 0.0  5.017 0.0
hole        36 .799 1.384 0.0
unit 434
zhemicyl-y 1 1 .6325      2.477  0.0
zhemicyl-y 0 1 .6415      2.477  0.0
zhemicyl-y 4 1 .6415      5.017  0.0
zhemicyl-y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        36 .799 -1.384 0.0
hole        33 -.799 -1.384 0.0
unit 435
zhemicyl-y 1 1 .6325      2.477  0.0
zhemicyl-y 0 1 .6415      2.477  0.0
zhemicyl-y 4 1 .6415      5.017  0.0
zhemicyl-y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        32 .799 -1.384 0.0
hole        37 -.799 -1.384 0.0
unit 436
zhemicyl-y 1 1 .6325      2.477  0.0
zhemicyl-y 0 1 .6415      2.477  0.0
zhemicyl-y 4 1 .6415      5.017  0.0
zhemicyl-y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        33 -.799 -1.384 0.0
unit 437
zhemicyl-y 1 1 .6325      2.477  0.0
zhemicyl-y 0 1 .6415      2.477  0.0
zhemicyl-y 4 1 .6415      5.017  0.0
zhemicyl-y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        37 -.799 -1.384 0.0
unit 438
zhemicyl-y 1 1 .6325      2.477  0.0
zhemicyl-y 0 1 .6415      2.477  0.0
zhemicyl-y 4 1 .6415      5.017  0.0
zhemicyl-y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0
hole        36 .799 -1.384 0.0
unit 439
zhemicyl-y 1 1 .6325      2.477  0.0
zhemicyl-y 0 1 .6415      2.477  0.0
zhemicyl-y 4 1 .6415      5.017  0.0
zhemicyl-y 2 1 .7075      5.017  0.0
cuboid      3 1 2p.799  0.0 -2.768  5.017 0.0

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hole      32 .799 -1.384 0.0
unit 440
zhemicyl-y 1 1 .6325      2.477  0.0
zhemicyl-y 0 1 .6415      2.477  0.0
zhemicyl-y 4 1 .6415      5.017  0.0
zhemicyl-y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  0.0 -2.768  5.017 0.0
unit 441
zhemicyl-x 1 1 .6325      2.477  0.0
zhemicyl-x 0 1 .6415      2.477  0.0
zhemicyl-x 4 1 .6415      5.017  0.0
zhemicyl-x 2 1 .7075      5.017  0.0
cuboid     3 1 0.0 -1.598  2p1.384  5.017 0.0
unit 442
zhemicyl+x 1 1 .6325      2.477  0.0
zhemicyl+x 0 1 .6415      2.477  0.0
zhemicyl+x 4 1 .6415      5.017  0.0
zhemicyl+x 2 1 .7075      5.017  0.0
cuboid     3 1 1.598  0.0 2p1.384  5.017 0.0
unit 443
zhemicyl+y 1 1 .6325      2.477  0.0
zhemicyl+y 0 1 .6415      2.477  0.0
zhemicyl+y 4 1 .6415      5.017  0.0
zhemicyl+y 2 1 .7075      5.017  0.0
cuboid     3 1 2p.799  2.768 0.0  5.017 0.0
hole      37 -.799 1.384 0.0
hole      31 0.0  2.768 0.0
unit 444
array 4    3*0.0
global unit 445
array 5    3*0.0
cuboid     6 1 73.508 0.0 74.736 0.0  97.155 -2.54
replicate  3  2 6r3.0      4
replicate  3  6 4r3.0  0.0  3.0  3
end geom
read bias id=500 2 8 end bias
read array
ara=1 nux=46 nuy=27 nuz=1
fill 19r90 2r140 112 2r140 112 2r140 19r90
14r90 140 112 138 135 115 110 121 111 1q3 110 121 115 134 135 113 140
  14r90
11r90 139 115 134 121 111      110 5q3 135 115 136 11r90
8r90  140 114 134 121 111      110 7q3 135 113 9r90
7r90  138 121 111 110      8q3  121 111 134 137 7r90
5r90  139 115 110 121 111 9q3  110 121 115 136 5r90
4r90  138 121 111 110      11q3  137      4r90
3r90  114 110 121 111      11q3  110 121 113      3r90
2r90  139 111 110 121      12q3  111 136      2r90
2r90  122 111 110 121      12q3  111 127      2r90
90    126 121 111 110      13q3  125      90
90    138 121 111 110      13q3  137      90
90    123 121 111 110      13q3  143      90
      141 110 121 111      13q3  110 121 142
90    123 121 111 110      13q3  143      90
90    123 121 111 110      13q3  131      90
90    133 121 111 110      13q3  125      90
2r90  122 111 110 121      12q3  111 127      2r90
2r90  128 111 110 121      12q3  111 132      2r90
3r90  117 110 121 111      11q3  110 121 119      3r90
4r90  133 121 111 110      11q3  131      4r90
5r90  128 118 110 121 111 9q3  110 121 118 132 5r90
7r90  133 129 111 110 121 8q3  111 110 131      7r90
9r90  117 124 121 111 110 7q3  129 119 130      8r90
11r90 128 118 124 121 111 110 5q3 129 118 132 11r90
14r90 130 116 133 129 118 110 121 111 1q3 110 121 118 124 131 116 130
  14r90
19r90 2r130 116 2r130 116 2r130 19r90      end fill
ara=2 nux=46 nuy=27 nuz=1
fill 19r91 2r240 212 2r240 212 2r240 19r91

```

```

14r91 240 212 238 235 215 210 221 211 1q3 210 221 215 234 235 213 240
14r91
11r91 239 215 234 221 211          210 5q3 235 215 236 11r91
8r91  240 214 234 221 211          210 7q3 235 213 9r91
7r91  238 221 211 210          8q3  221 211 234 237 7r91
5r91  239 215 210 221 211 9q3  210 221 215 236 5r91
4r91  238 221 211 210          11q3 237          4r91
3r91  214 210 221 211          11q3 210 221 213 3r91
2r91  239 211 210 221          12q3 211 236          2r91
2r91  222 211 210 221          12q3 211 227          2r91
91    226 221 211 210          13q3 225          91
91    238 221 211 210          13q3 237          91
91    223 221 211 210          13q3 243          91
      241 210 221 211          13q3 210 221 242
91    223 221 211 210          13q3 243          91
91    223 221 211 210          13q3 231          91
91    233 221 211 210          13q3 225          91
2r91  222 211 210 221          12q3 211 227          2r91
2r91  228 211 210 221          12q3 211 232          2r91
3r91  217 210 221 211          11q3 210 221 219 3r91
4r91  233 221 211 210          11q3 231          4r91
5r91  228 218 210 221 211 9q3  210 221 218 232 5r91
7r91  233 229 211 210 221 8q3  211 210 231 7r91
9r91  217 224 221 211 210 7q3  229 219 230 8r91
11r91 228 218 224 221 211 210 5q3 229 218 232 11r91
14r91 230 216 233 229 218 210 221 211 1q3 210 221 218 224 231 216 230
14r91
19r91 2r230 216 2r230 216 2r230 19r91          end fill
ara=3  nux=46 nuy=27 nuz=1
fill 19r92 2r340 312 2r340 312 2r340 19r92
14r92 340 312 338 335 315 310 321 311 1q3 310 321 315 334 335 313 340
14r92
11r92 339 315 334 321 311          310 5q3 335 315 336 11r92
8r92  340 314 334 321 311          310 7q3 335 313 9r92
7r92  338 321 311 310          8q3  321 311 334 337 7r92
5r92  339 315 310 321 311 9q3  310 321 315 336 5r92
4r92  338 321 311 310          11q3 337          4r92
3r92  314 310 321 311          11q3 310 321 313 3r92
2r92  339 311 310 321          12q3 311 336          2r92
2r92  322 311 310 321          12q3 311 327          2r92
92    326 321 311 310          13q3 325          92
92    338 321 311 310          13q3 337          92
92    323 321 311 310          13q3 343          92
      341 310 321 311          13q3 310 321 342
92    323 321 311 310          13q3 343          92
92    323 321 311 310          13q3 331          92
92    333 321 311 310          13q3 325          92
2r92  322 311 310 321          12q3 311 327          2r92
2r92  328 311 310 321          12q3 311 332          2r92
3r92  317 310 321 311          11q3 310 321 319 3r92
4r92  333 321 311 310          11q3 331          4r92
5r92  328 318 310 321 311 9q3  310 321 318 332 5r92
7r92  333 329 311 310 321 8q3  311 310 331 7r92
9r92  317 324 321 311 310 7q3  329 319 330 8r92
11r92 328 318 324 321 311 310 5q3 329 318 332 11r92
14r92 330 316 333 329 318 310 321 311 1q3 310 321 318 324 331 316 330
14r92
19r92 2r330 316 2r330 316 2r330 19r92          end fill
ara=4  nux=46 nuy=27 nuz=1
fill 19r93 2r440 412 2r440 412 2r440 19r93
14r93 440 412 438 435 415 410 421 411 1q3 410 421 415 434 435 413 440
14r93
11r93 439 415 434 421 411          410 5q3 435 415 436 11r93
8r93  440 414 434 421 411          410 7q3 435 413 9r93
7r93  438 421 411 410          8q3  421 411 434 437 7r93
5r93  439 415 410 421 411 9q3  410 421 415 436 5r93
4r93  438 421 411 410          11q3 437          4r93
3r93  414 410 421 411          11q3 410 421 413 3r93
2r93  439 411 410 421          12q3 411 436          2r93

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2r93  422 411 410 421      12q3      411 427      2r93
93    426 421 411 410      13q3      425          93
93    438 421 411 410      13q3      437          93
93    423 421 411 410      13q3      443          93
      441 410 421 411      13q3      410 421 442
93    423 421 411 410      13q3      443          93
93    423 421 411 410      13q3      431          93
93    433 421 411 410      13q3      425          93
2r93  422 411 410 421      12q3      411 427      2r93
2r93  428 411 410 421      12q3      411 432      2r93
3r93  417 410 421 411      11q3      410 421 419    3r93
4r93  433 421 411 410      11q3      431          4r93
5r93  428 418 410 421 411 9q3      410 421 418 432 5r93
7r93  433 429 411 410 421 8q3      411 410 431      7r93
9r93  417 424 421 411 410 7q3      429 419 430      8r93
11r93 428 418 424 421 411 410 5q3 429 418 432      11r93
14r93 430 416 433 429 418 410 421 411 1q3 410 421 418 424 431 416 430
14r93
19r93 2r430 416 2r430 416 2r430 19r93      end fill
ara=5  nux=1  nuy=1  nuz=7
fill   244 344 144 344 144 344 444
end fill
end array
read plot
ttl='x-y slice of pnl4976 at z=2.0 '
xul=-1.  yul=37.5      zul=2.0
xlr=37.5  ylr=-1.0      zlr=2.0
uax=1 vdn=-1 nax=130 nch=' 1. 4567 .      '      end
ttl='x-y slice of pnl4976 at z=3.5 '
xul=-1.  yul=37.5      zul=3.5
xlr=37.5  ylr=-1.0      zlr=3.5
uax=1 vdn=-1 nax=130 nch=' 1. 4567 .      '      end
ttl='x-y slice of pnl4976 at z=30. '
xul=36.5  yul=75.0      zul=30.
xlr=75.0  ylr=36.5      zlr=30.
uax=1 vdn=-1 nax=130 nch=' 1. 4567 .      '      end
ttl='x-y slice of pnl4976 at z=47. '
xul=-1.  yul=75.0      zul=47.
xlr=37.5  ylr=36.5      zlr=47.
uax=1 vdn=-1 nax=130 nch=' 1. 4567 .      '      end
ttl='x-y slice of pnl4976 at z=60. '
xul=36.5  yul=37.5      zul=60.
xlr=75.0  ylr=-1.0      zlr=60.
uax=1 vdn=-1 nax=130 nch=' 1. 4567 .      '      end
ttl='x-y slice of pnl4976 at z=91. '
xul=-1.  yul=37.5      zul=91.
xlr=37.5  ylr=-1.0      zlr=91.
uax=1 vdn=-1 nax=130 nch=' 1. 4567 .      '      end
ttl='x-y slice of pnl4976 at z=92.3'
xul=-1.  yul=37.5      zul=92.3
xlr=37.5  ylr=-1.0      zlr=92.3
uax=1 vdn=-1 nax=130 nch=' 1. 4567 .      '      end
end plot
end data
end

```

saxtn104

```

#csas25
saxton puo2-uo2 critical exp. 01.04 inch pitch (wcap-3385-54)
27burn          latticecell
uo2              1 den=10.19 .934 292.9 end
puo2             1 den=10.19 .066 292.9 94239 90.49 94240 8.57 94241 .89
94242 .04 end
zircalloy       2 1.0 293 end
h2o             3 1.0 292.9 end
al              4 1.0 292.9 end
end comp
squarepitch 2.6416 .857 1 3 .9931 2 .875 0 end
saxton puo2-uo2 critical exp. 01.04 inch pitch (wcap-3385-54)
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 1.3208 -1.3208 1.3208 -1.3208 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4285 47.625 1.905
cylinder 0 1 .4375 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 1.3208 -1.3208 1.3208 -1.3208 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4285 48.26 47.625
cylinder 0 1 .4375 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 1.3208 -1.3208 1.3208 -1.3208 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 31.96 inches!
cylinder 1 1 .4285 81.17 48.26
cylinder 0 1 .4375 81.17 48.26
cylinder 2 1 .4966 81.17 48.26
cuboid 3 1 1.3208 -1.3208 1.3208 -1.3208 81.17 48.26
unit 5
com=!fuel pin above water, 31.96 to 37.35 inches!
cylinder 1 1 .4285 94.869 81.17
cylinder 0 1 .4375 94.869 81.17
cylinder 2 1 .4966 94.869 81.17
cuboid 0 1 1.3208 -1.3208 1.3208 -1.3208 94.869 81.17
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 1.3208 -1.3208 1.3208 -1.3208 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 1.3208 -1.3208 1.3208 -1.3208 97.155 95.885
unit 8
com=!11 x 11 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!11 x 11 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom
read array

```

```

ara=1 nux=11 nuy=11 nuz=4
com=!11 x 11 fuel pin array (in water)!
fill 121r1 121r2 121r3 121r4 end fill
ara=2 nux=11 nuy=11 nuz=3
com=!11 x 11 fuel pin array (above water)!
fill 121r5 121r6 121r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=28 yul=45 zul=62 xlr=45 ylr=28 zlr=62 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12.- ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=28 yul=34 zul=113 xlr=44 ylr=34 zlr=0 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```

saxtn56b

```

#csas25
saxton puo2-uo2 critical exp. 0.56 inch pitch with boron (wcap-3385-54)
27burn          latticecell
uo2              1 den=10.19 .934 291.0 end
puo2             1 den=10.19 .066 291.0 94239 90.49 94240 8.57 94241 .89
94242 .04 end
zircalloy       2 1.0 293 end
h2o             3 1.0 291.0 end
boron           3 den=337e-6 1 291.0 end
al             4 1.0 291.0 end
end comp
squarepitch 1.4224 .857 1 3 .9931 2 .875 0 end
saxton puo2-uo2 critical exp. 0.56 inch pitch with boron (wcap-3385-54)
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes
wrs=34 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 .7112 -.7112 .7112 -.7112 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4285 47.625 1.905
cylinder 0 1 .4375 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 .7112 -.7112 .7112 -.7112 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4285 48.26 47.625
cylinder 0 1 .4375 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 .7112 -.7112 .7112 -.7112 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 35.31 inches!
cylinder 1 1 .4285 89.70 48.26
cylinder 0 1 .4375 89.70 48.26
cylinder 2 1 .4966 89.70 48.26
cuboid 3 1 .7112 -.7112 .7112 -.7112 89.70 48.26
unit 5
com=!fuel pin above water, 35.31 to 37.35 inches!
cylinder 1 1 .4285 94.869 89.70
cylinder 0 1 .4375 94.869 89.70
cylinder 2 1 .4966 94.869 89.70
cuboid 0 1 .7112 -.7112 .7112 -.7112 94.869 89.70
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 .7112 -.7112 .7112 -.7112 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 .7112 -.7112 .7112 -.7112 97.155 95.885
unit 8
com=!21 x 21 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!21 x 21 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom

```

```

read array
ara=1 nux=21 nuy=21 nuz=4
com=!21 x 21 fuel pin array (in water)!
fill 441r1 441r2 441r3 441r4 end fill
ara=2 nux=21 nuy=21 nuz=3
com=!21 x 21 fuel pin array (above water)!
fill 441r5 441r6 441r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=28 yul=46 zul=62 xlr=46 ylr=28 zlr=62 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12.- ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=28 yul=35 zul=113 xlr=46 ylr=35 zlr=65 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```

saxtn735

```

#csas25
saxton puo2-uo2 critical exp. 0.735 inch pitch (wcap-3385-54)
27burn          latticecell
uo2              1 den=10.19 .934 297.1 end
puo2             1 den=10.19 .066 297.1 94239 90.49 94240 8.57 94241 .89
94242 .04 end
zircalloy       2 1.0 293 end
h2o             3 1.0 297.1 end
al              4 1.0 297.1 end
end comp
squarepitch 1.8669 .857 1 3 .9931 2 .875 0 end
saxton puo2-uo2 critical exp. 0.735 inch pitch (wcap-3385-54)
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 .93345 -.93345 .93345 -.93345 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4285 47.625 1.905
cylinder 0 1 .4375 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 .93345 -.93345 .93345 -.93345 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4285 48.26 47.625
cylinder 0 1 .4375 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 .93345 -.93345 .93345 -.93345 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 27.60 inches!
cylinder 1 1 .4285 70.11 48.26
cylinder 0 1 .4375 70.11 48.26
cylinder 2 1 .4966 70.11 48.26
cuboid 3 1 .93345 -.93345 .93345 -.93345 70.11 48.26
unit 5
com=!fuel pin above water, 27.60 to 37.35 inches!
cylinder 1 1 .4285 94.869 70.11
cylinder 0 1 .4375 94.869 70.11
cylinder 2 1 .4966 94.869 70.11
cuboid 0 1 .93345 -.93345 .93345 -.93345 94.869 70.11
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 .93345 -.93345 .93345 -.93345 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 .93345 -.93345 .93345 -.93345 97.155 95.885
unit 8
com=!13 x 13 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!13 x 13 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom
read array

```

```

ara=1 nux=13 nuy=13 nuz=4
com=!13 x 13 fuel pin array (in water)!
fill 169r1 169r2 169r3 169r4 end fill
ara=2 nux=13 nuy=13 nuz=3
com=!13 x 13 fuel pin array (above water)!
fill 169r5 169r6 169r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=28 yul=42 zul=62 xlr=42 ylr=28 zlr=62 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12.- ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=28 yul=44 zul=113 xlr=42 ylr=44 zlr=0 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```

saxtn792

```

#csas25
saxton puo2-uo2 critical exp. 0.792 inch pitch (wcap-3385-54)
27burn          latticecell
uo2              1 den=10.19 .934 289.1 end
puo2             1 den=10.19 .066 289.1 94239 90.49 94240 8.57 94241 .89
94242 .04 end
zircalloy        2 1.0 293 end
h2o              3 1.0 289.1 end
al               4 1.0 289.1 end
end comp
squarepitch 2.01168 .857 1 3 .9931 2 .875 0 end
saxton puo2-uo2 critical exp. 0.792 inch pitch (wcap-3385-54)
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 1.00584 -1.00584 1.00584 -1.00584 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4285 47.625 1.905
cylinder 0 1 .4375 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 1.00584 -1.00584 1.00584 -1.00584 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4285 48.26 47.625
cylinder 0 1 .4375 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 1.00584 -1.00584 1.00584 -1.00584 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 30.88 inches!
cylinder 1 1 .4285 78.43 48.26
cylinder 0 1 .4375 78.43 48.26
cylinder 2 1 .4966 78.43 48.26
cuboid 3 1 1.00584 -1.00584 1.00584 -1.00584 78.43 48.26
unit 5
com=!fuel pin above water, 30.88 to 37.35 inches!
cylinder 1 1 .4285 94.869 78.43
cylinder 0 1 .4375 94.869 78.43
cylinder 2 1 .4966 94.869 78.43
cuboid 0 1 1.00584 -1.00584 1.00584 -1.00584 94.869 78.43
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 1.00584 -1.00584 1.00584 -1.00584 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 1.00584 -1.00584 1.00584 -1.00584 97.155 95.885
unit 8
com=!12 x 12 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!12 x 12 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom
read array

```



```

ara=1 nux=12 nuy=12 nuz=4
com=!12 x 12 fuel pin array (in water)!
fill 144r1 144r2 144r3 144r4 end fill
ara=2 nux=12 nuy=12 nuz=3
com=!12 x 12 fuel pin array (above water)!
fill 144r5 144r6 144r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=28 yul=42 zul=60 xlr=42 ylr=28 zlr=60 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12.- ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=28 yul=31 zul=113 xlr=42 ylr=31 zlr=0 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```

saxton52

```

#csas25
saxton puo2-uo2 critical exp .52 inch pitch (wcap-3385-54)
27burn          latticecell
uo2              1 den=10.19 .934 298.8 end
puo2             1 den=10.19 .066 298.800 94239 90.49 94240 8.57 94241 .89
94242 .04 end
zircalloy       2 1.0 293 end
h2o             3 1.0 298.800 end
al              4 1.0 298.800 end
end comp
squarepitch 1.3208 .857 1 3 .9931 2 .875 0 end
saxton puo2-uo2 critical exp. 0.52 inch pitch (wcap-3385-54)
read parm gen=805 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=120
wrs=34 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 .6604 -.6604 .6604 -.6604 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4285 47.625 1.905
cylinder 0 1 .4375 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 .6604 -.6604 .6604 -.6604 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4285 48.26 47.625
cylinder 0 1 .4375 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 .6604 -.6604 .6604 -.6604 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 33.29 inches!
cylinder 1 1 .4285 84.56 48.26
cylinder 0 1 .4375 84.56 48.26
cylinder 2 1 .4966 84.56 48.26
cuboid 3 1 .6604 -.6604 .6604 -.6604 84.56 48.26
unit 5
com=!fuel pin above water, 33.29 to 37.35 inches!
cylinder 1 1 .4285 94.869 84.56
cylinder 0 1 .4375 94.869 84.56
cylinder 2 1 .4966 94.869 84.56
cuboid 0 1 .6604 -.6604 .6604 -.6604 94.869 84.56
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 .6604 -.6604 .6604 -.6604 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 .6604 -.6604 .6604 -.6604 97.155 95.885
unit 8
com=!22 x 23 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!22 x 23 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom
read array

```

```

ara=1 nux=22 nuy=23 nuz=4
com=!22 x 23 fuel pin array (in water)!
fill 506r1 506r2 506r3 506r4 end fill
ara=2 nux=22 nuy=23 nuz=3
com=!22 x 23 fuel pin array (above water)!
fill 506r5 506r6 506r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=29 yul=47 zul=62 xlr=47 ylr=29 zlr=62 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12 - ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=29 yul=45 zul=113 xlr=47 ylr=45 zlr=-1 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```

saxton56

```

#csas25
saxton puo2-uo2 critical exp. 0.56 inch pitch (wcap-3385-54)
27burn          latticecell
uo2              1 den=10.19 .934 289.4 end
puo2             1 den=10.19 .066 289.4 94239 90.49 94240 8.57 94241 .89
94242 .04 end
zircalloy        2 1.0 293 end
h2o              3 1.0 289.4 end
al               4 1.0 289.4 end
end comp
squarepitch 1.4224 .857 1 3 .9931 2 .875 0 end
saxton puo2-uo2 critical exp. 0.56 inch pitch (wcap-3385-54)
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=34 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 .7112 -.7112 .7112 -.7112 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4285 47.625 1.905
cylinder 0 1 .4375 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 .7112 -.7112 .7112 -.7112 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4285 48.26 47.625
cylinder 0 1 .4375 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 .7112 -.7112 .7112 -.7112 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 32.66 inches!
cylinder 1 1 .4285 82.96 48.26
cylinder 0 1 .4375 82.96 48.26
cylinder 2 1 .4966 82.96 48.26
cuboid 3 1 .7112 -.7112 .7112 -.7112 82.96 48.26
unit 5
com=!fuel pin above water, 32.66 to 37.35 inches!
cylinder 1 1 .4285 94.869 82.96
cylinder 0 1 .4375 94.869 82.96
cylinder 2 1 .4966 94.869 82.96
cuboid 0 1 .7112 -.7112 .7112 -.7112 94.869 82.96
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 .7112 -.7112 .7112 -.7112 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 .7112 -.7112 .7112 -.7112 97.155 95.885
unit 8
com=!19 x 19 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!19 x 19 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom
read array

```

```

ara=1 nux=19 nuy=19 nuz=4
com=!19 x 19 fuel pin array (in water)!
fill 361r1 361r2 361r3 361r4 end fill
ara=2 nux=19 nuy=19 nuz=3
com=!19 x 19 fuel pin array (above water)!
fill 361r5 361r6 361r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=28 yul=44 zul=62 xlr=44 ylr=28 zlr=62 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12.- ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=28 yul=35 zul=113 xlr=44 ylr=35 zlr=65 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```

saxu56

```

#csas25
saxton uo2 5.742 wt% u-235 critical exp. 0.56 inch pitch (wcap-3385-54)
27burn latticecell
uo2          1 den=10.065 1.0 291.0 92235 5.742 92238 94.258 end
ss304        2 1.0 291.0 end
h2o          3 1.0 291.0 end
al           4 1.0 291.0 end
uo2          5 den=10.065 1.0 291.0 92235 5.742 92238 94.258 end
end comp
squarepitch 1.4224 .9068 1 3 .9931 2 .9169 0 end
more data
res=5 cyl .4534 dan(5)=.922095 end
saxton uo2 5.742 wt% u-235 critical exp. 0.56 inch pitch (wcap-3385-54)
read parm gen=405 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=60
wrs=35 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 .7112 -.7112 .7112 -.7112 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4534 47.625 1.905
cylinder 0 1 .4585 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 .7112 -.7112 .7112 -.7112 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4534 48.26 47.625
cylinder 0 1 .4585 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 .7112 -.7112 .7112 -.7112 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 32.96 inches!
cylinder 1 1 .4534 83.71 48.26
cylinder 0 1 .4585 83.71 48.26
cylinder 2 1 .4966 83.71 48.26
cuboid 3 1 .7112 -.7112 .7112 -.7112 83.71 48.26
unit 5
com=!fuel pin above water, 32.96 to 37.35 inches!
cylinder 5 1 .4534 94.869 83.71
cylinder 0 1 .4585 94.869 83.71
cylinder 2 1 .4966 94.869 83.71
cuboid 0 1 .7112 -.7112 .7112 -.7112 94.869 83.71
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 .7112 -.7112 .7112 -.7112 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 .7112 -.7112 .7112 -.7112 97.155 95.885
unit 8
com=!19 x 19 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!19 x 19 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom

```

```

read array
ara=1 nux=19 nuy=19 nuz=4
com=!19 x 19 fuel pin array (in water)!
fill 361r1 361r2 361r3 361r4 end fill
ara=2 nux=19 nuy=19 nuz=3
com=!19 x 19 fuel pin array (above water)!
fill 361r5 361r6 361r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=28 yul=44 zul=62 xlr=44 ylr=28 zlr=62 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12.- ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=28 yul=35 zul=113 xlr=44 ylr=35 zlr=0 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```

saxu792

```

#csas25
saxton uo2 5.742 wt% u-235 critical exp. 0.792inch pitch (wcap-3385-54)
27burn          latticecell
uo2              1  den=10.065 1.0 290.3  92235 5.742  92238 94.258  end
ss304            2  1.0 290.3  end
h2o              3  1.0 290.3  end
al               4  1.0 290.3  end
uo2              5  den=10.065 1.0 290.3  92235 5.742  92238 94.258  end
end comp
squarepitch 2.01168 .9068 1 3  .9931 2  .9169 0  end
more data
res=5 cyl .4534 dan(5)=.945902  end
saxton uo2 5.742 wt% u-235 critical exp. 0.792inch pitch (wcap-3385-54)
read parm gen=805 npg=600 nsk=5 res=205 nub=yes run=yes plt=yes tme=190
wrs=35 end parm
read geom
unit 1
com=!fuel pin (no fuel) in bottom plate, 0 to .25 inches!
cylinder 2 1 .4966 .635 0
cylinder 3 1 .5042 .635 0
cuboid 4 1 1.00584 -1.00584 1.00584 -1.00584 .635 0
unit 2
com=!fuel pin between lower plates, .25 to 18.75 inches!
cylinder 1 1 .4534 47.625 1.905
cylinder 0 1 .4585 47.625 1.905
cylinder 2 1 .4966 47.625 .635
cuboid 3 1 1.00584 -1.00584 1.00584 -1.00584 47.625 .635
unit 3
com=!fuel pin in middle plate, 18.75 to 19.0 inches!
cylinder 1 1 .4534 48.26 47.625
cylinder 0 1 .4585 48.26 47.625
cylinder 2 1 .4966 48.26 47.625
cylinder 3 1 .5042 48.26 47.625
cuboid 4 1 1.00584 -1.00584 1.00584 -1.00584 48.26 47.625
unit 4
com=!fuel pin above middle plate, 19.0 to 35.67 inches!
cylinder 1 1 .4534 90.60 48.26
cylinder 0 1 .4585 90.60 48.26
cylinder 2 1 .4966 90.60 48.26
cuboid 3 1 1.00584 -1.00584 1.00584 -1.00584 90.60 48.26
unit 5
com=!fuel pin above water, 35.67 to 37.35 inches!
cylinder 5 1 .4534 94.869 90.60
cylinder 0 1 .4585 94.869 90.60
cylinder 2 1 .4966 94.869 90.60
cuboid 0 1 1.00584 -1.00584 1.00584 -1.00584 94.869 90.60
unit 6
com=!top of fuel pin (no fuel), 37.35 to 37.75 inches!
cylinder 2 1 .4966 95.885 94.869
cuboid 0 1 1.00584 -1.00584 1.00584 -1.00584 95.885 94.869
unit 7
com=!fuel pin (no fuel) in top plate, 37.75 to 38.25 inch!
cylinder 2 1 .4966 97.155 95.885
cylinder 0 1 .5042 97.155 95.885
cuboid 4 1 1.00584 -1.00584 1.00584 -1.00584 97.155 95.885
unit 8
com=!13 x 14 core (in water)!
array 1 0 0 0
replicate 3 2 3 3 3 3 0 0 10
replicate 4 1 0 0 0 0 0 2.54 1
replicate 3 1 0 0 0 0 0 6.35 1
replicate 4 1 0 0 0 0 0 5.08 1
unit 9
com=!13 x 14 core (above water)!
array 2 0 0 0
replicate 0 1 30 30 30 30 0 0 1
end geom

```



```

read array
ara=1 nux=13 nuy=14 nuz=4
com=!13 x 14 fuel pin array (in water)!
fill 182r1 182r2 182r3 182r4 end fill
ara=2 nux=13 nuy=14 nuz=3
com=!13 x 14 fuel pin array (above water)!
fill 182r5 182r6 182r7 end fill
ara=3 gbl=3 nux=1 nuy=1 nuz=2
com=!complete fuel core!
fill 8 9 end fill
end array
read bias id=500 2 11 end bias
read plot
ttl=!x-y view of core!
plt=yes pic=mixture xul=28 yul=44 zul=62 xlr=44 ylr=28 zlr=62 uax=1 vax=0
wax=0 udn=0 vdn=-1 wdn=0 nax=130
nch=! 12.- ! end
ttl=!x-z view of core!
plt=yes pic=mixture xul=28 yul=35 zul=113 xlr=44 ylr=35 zlr=0 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=! 12./ ! end
end plot
end data
end

```


APPENDIX C

RESULTS OF ADDITIONAL CRITICAL CALCULATIONS

In addition to the 34 fresh fuel criticals described in this report, numerous other critical calculations have been performed and may be considered in reducing calculational biases and uncertainties. Such additional experiments are described in Sect. 4.3 of this report. This appendix provides the results of calculations for two sets of related experiments: seven reactor critical experiments (Table C.1) and 59 fresh fuel experiments (Table C.2). All calculations were performed using SCALE-4.2 and the SCALE 27-group burnup cross-section library, consistent with the results of the 34 fresh fuel criticals.

Table C.1. Results of reactor critical calculations

Designation	k_{eff}	$\pm\sigma$	AEG
Sequoyah BZ	1.0039	0.0005	20.49
Sequoyah BF	1.0067	0.0005	20.38
Sequoyah MF	1.0046	0.0005	20.44
Surry BZ	1.0014	0.0005	21.02
Surry EF	1.0113	0.0005	20.97
TMI BZ	0.9978	0.0004	20.78
North Anna BZ	1.0040	0.0005	20.38

Source: ref. 29.

Table C.2. Results of additional fresh fuel calculations

Designation	k_{eff}	$\pm\sigma$	AEG
ans33bb2 ^a	1.0055	0.0012	22.47
ans33bh2 ^a	1.0083	0.0012	22.54
ans33bp2 ^a	0.9975	0.0013	22.34
ans33h2 ^a	0.9929	0.0012	22.54
baw1231a ^a	0.989	0.0009	20.64
baw1231b ^a	0.9901	0.0007	19.93
baw1273m ^a	0.9912	0.001	21.25
baw1484b ^a	0.9905	0.0013	23.07
baw1484c ^a	0.9919	0.0013	22.58
baw1484d ^a	0.9876	0.0013	22.93
baw1645s ^a	0.9891	0.0012	19.85
baw1645t ^a	0.9905	0.0009	19.25
bw1645so ^a	0.9911	0.0011	21.53
cr1071as	1.0149	0.0011	21.36
cr1653as	1.0059	0.0011	21.56
cr1653b	1.0068	0.0012	19.17
cr2500s	1.011	0.0011	21.83
epru615b ^a	0.9914	0.0014	21.91
epru75 ^a	0.9921	0.001	23.34
epru75b ^a	0.9949	0.0009	23.02
epru87b ^a	0.9986	0.0011	23.62
or260901	1.0053	0.0014	24.94
or260906	1.0049	0.0012	24.99
or2968al	1.0067	0.0011	24.4
or2968s1	0.9877	0.0016	24.29

Table C.2 (continued)

Designation	k_{eff}	$\pm\sigma$	AEG
or2968s2	0.9967	0.0009	24.73
p2615x14 ^a	0.9966	0.0015	23.31
p2615x23 ^a	0.9948	0.0015	23.31
p2615x31 ^a	0.9964	0.0016	23.3
p2827l2a ^a	1.0005	0.0013	23.56
p2827l2b ^a	1.0077	0.0008	23.27
p2827non ^a	0.9943	0.0014	23.59
p2827u2a ^a	0.9971	0.0013	22.85
p2827u2b ^a	0.9969	0.0014	22.25
p3314a ^a	0.9941	0.0016	21.85
p3314b ^a	0.9966	0.0011	21.85
p3602b4 ^a	0.9983	0.0016	21.91
p3602c4 ^a	0.9968	0.0011	21.92
p3602n2 ^a	0.9953	0.0014	23.52
p3602non ^a	0.9986	0.0016	21.99
p3926l2a ^a	0.995	0.0014	22.79
p3926n2 ^a	0.9901	0.0015	22.87
p3926nob ^a	0.9928	0.0016	22.06
p3926u2a ^a	0.9894	0.0013	21.93
p5803x21	1.0117	0.0011	20.22
p5803x32	1.0109	0.0015	23.27
p5803x43	1.0117	0.0011	21.87
p5803x67	1.0063	0.0011	18.55
p5803x68r	1.0066	0.0016	22.71

Table C.2 (continued)

Designation	k_{eff}	$\pm\sigma$	AEG
pnl194	0.9944	0.0015	18.47
rfp2710r	1.0099	0.0021	22.02
rfp2710u	1.0154	0.002	23.61
w3269a ^a	1.0002	0.0009	20.77
w3269b ^a	0.9994	0.0013	21.41
w3269c ^a	0.9901	0.001	22.2
ydr14pl2	0.996	0.0013	23.68
ydr14pl3	1.0062	0.0014	22.2
ydr14un2	0.9956	0.0013	23.04
ydr14un3	1.0102	0.0015	21.78

^a UO₂-only criticals.

Source: ref. 30.

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