Scale 4.4 Validation for the DFS System at SRS

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WSMS

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Prologue

WSRC SCALE 4.4 Validation

SCALE 4.4 has been validated on the WSMS DEC Alpha machines in the Centennial Complex. As this same version of the code will be run at WSRC on their RS/6000 workstations under the Distributed File System (DFS), it was desirable to determine if the validation that was performed for SCALE 4.4 on the WSMS platform could be used for the WSRC platform as well. In order to determine if the WSMS SCALE 4.4 validation could be used to efficiently document the WSRC SCALE 4.4 validation, a comparison of results was performed. Representative samples of input files from each of the major fissile types and forms were run under the SRS certified SCALE 4.4 code (Ref. 26, 27), and outputs subsequently compared to their WSMS counterparts. The results of these comparisons confirm that the two platforms provide statistically similar k_{eff} and uncertainty values, without the introduction of an additional bias. This outcome provides sufficient certification that the WSMS SCALE 4.4 validation is directly comparable as the SRS validation for SCALE 4.4 on DFS. Appendices D and E contain discussion detailing the validity of this argument, and present the results of this comparison. The results of this comparison confirm that it is appropriate and logical to use the bias and bias uncertainties calculated in the WSMS SCALE 4.4 Validation for analysis with SCALE 4.4 performed on the WSRC system.

The input files for the SRS SCALE 4.4 validation experiments can be found in the */raid1/packages/crit/Validation/Scale4.x* directory on the WSMS DEC Alpha workstation platform. Output files have been saved to a compact disk, held by the owner of the SCALE 4.4 CTF notebook (Ref. 26). The remainder of this document (with the exception of Appendices D and E, and formatting such as page numbering) is identical to the WSMS SCALE 4.4 validation document.

Contents

1. Introduction	4
2. Calculation Methodology	5
3. Bias and Uncertainty Calculations	6
Summary of Results	6
4. Plutonium Systems	8
4.1 Metal	8
4.1.1 Area of Applicability	
4.1.2 System Descriptions	
4.1.3 Bias and Uncertainty	
4.1.4 Limitations	
4.2 Solution	16
4.2.1 Area of Applicability	
4.2.2 System Descriptions	
4.2.3 Bias and Uncertainty	
4.2.4 Limitations	
5. Uranium Systems	27
5.1 Metal	27
5.1.1 Area of Applicability	
5.1.2 System Descriptions	
5.1.3 Bias and Uncertainty	
5.1.4 Limitations	
5.2 Solution	40
5.2.1 Area of Applicability	
5.2.2 System Descriptions	
5.2.3 Bias and Uncertainty	
5.2.4 Limitations	
5.3 RBOF Fuels	52
5.3.1 Explicitly Modeled MTR Type Fuel	52
5.3.1.1 Area of Applicability	
5.3.1.2 System Descriptions	
5.3.1.3 Bias and Uncertainty	
5.3.1.4 Limitations	
5.3.2 Homogenously Modeled MTR Type Fuel	55
5.3.2.1 Area of Applicability	
5.3.2.2 System Descriptions	
5.3.2.3 Bias and Bias Uncertainty	
5.3.2.4 Limitations	
6. Acknowledgments	57
7. References	58
Appendix A: Validation Results and Parameters	60
Appendix B: Tally Information by Benchmark Experiment	70
Appendix C: Sample Input Files	71
Appendix D: 27 Group Comparison Results	96
Appendix E: 238 Group Comparison Results	98

ABSTRACT

This document is a compilation of the work to date dealing with the validation of the CSAS25 sequence in SCALE 4.4 using the 27-group ENDF/B-IV and the 238-group ENDF/B-V cross section libraries, executed on the Digital Equipment Alpha Processors workstation cluster at WSMS. Revisions to this document will be made as new validation information is generated; therefore, this document should be used as the reference point for bias and bias uncertainties for SCALE 4.4-related work. This initial issue of the report (Revision 0) contains bias and bias uncertainty for plutonium and highly enriched uranium solutions and metal systems, including MTR type fuel.

1.0 Introduction

ANSI/ANS Standard 8.1[1] requires that computer codes and methods used to determine limits for criticality safety be validated against experiments. This document provides the work to date on the validation of the WSMS certified [2, 25] SCALE 4.4 code, and is the last stage of the Validation Plan [3], which was drafted to guide the validation effort.

This validation utilized the CSAS25 control sequence, with the 27-group ENDF/B-IV and the 238-group ENDF/B-V cross section libraries, running on a Digital Equipment Alpha Processors workstation platform under UNIX 4.0B. The values of bias and bias uncertainty are presented for plutonium and uranium systems, including MTR Type fuel. For each fissile system, the area of applicability of the validation is presented, followed by a brief description of the benchmarks that were used in the determination of the bias. Following this is a discussion of the bias and bias uncertainty, presented as either a lower tolerance band (LTB), a lower tolerance limit (LTL), or an Upper Subcritical Limit (USL), and the limitations of the validation.

This document does not present values of k-safe, as these are system dependent. The LTBs, LTLs, or USLs presented in this document include the bias, the uncertainty due to reported experimental parameters, statistical uncertainties in the calculation of the experiments, and the uncertainty associated with geometric or modeling uncertainties in the computational method. When used with a margin for Area of Applicability, and an appropriate subcritical margin, the value of k-safe for a particular application can be determined. A system's sensitivity to controlled parameters (e.g., concentration, mass, geometry, etc.) should be considered when determining the subcritical margin [22].

Section 2 provides an overview of the calculation methods used in computing the Keffective values for the critical benchmarks and the CSAS25 analytical sequence. Section 3 provides an overview of the methodology used in the validation and in the generation of the bias and uncertainty. Sections 4 and 5 provide detailed discussions of bias and uncertainty for each fissile material, Appendix A provides the calculated Keffective and statistical deviation, as well as validation parameters for each critical experiment, and Appendix C provides sample input files from each of the major fissile materials.

2.0 Calculation Methodology

The CSAS25 criticality control sequence in SCALE 4.3 consists of the modules BONAMI, NITAWL and KENO Va. The module BONAMI selects the required material cross sections and creates a master cross section library to be processed by NITAWL. There is no data processing performed for either the 27-group or 238-group libraries in BONAMI.

The NITAWL module treats the resonance region cross sections for resonance absorbers based on the Nordheim Integral Transform method. Several options are available to the analyst in terms of the treatment of the resonance parameters. These options include INFHOMMEDIUM, LATTICECELL and MULTIREGION. In this validation, the treatment was chosen which was most appropriate for each specific problem. Appendix C provides sample input files for many of the fissile systems; these can be reviewed to determine the method used for a particular application.

KENO Va is a 3-D Monte Carlo based code which allows modeling of a wide variety of complex geometries. Outputs from the KENO Va module include estimates of the neutron multiplication of the system, the statistical uncertainty, the average energy of the neutrons causing fissions, and other parameters. Many input options exist in KENO Va including reflection, biasing, albedos, and holes. In the current validation, no use has been made of the biasing or albedo options, and thus they cannot be said to be validated.

Cross section input and atom density input to KENO Va are handled by the CSAS25 sequence. For this validation, the CSASIN input processor was used to generate input parameters for the CSAS25 sequence. CSASIN utilizes a standard composition library, which was provided with the code. CSASIN uses engineering parameters, density and weight-percent, to determine appropriate atom densities. Where possible, standard pre-mixed materials were selected from the standard composition library for use in the validation. This practice is recommended in the development of criticality analyses to ensure that atom densities are computed using the same methodology as was used in the validation.

Two libraries were used in this validation: the ENDF/B-IV 27-group library, and the ENDF/B-V 238-group library. The 238-group library is generally felt to be more accurate, however its fine group structure leads to longer running times than the 27-group. With appropriate validation, and within a defined area of applicability, either library may be used confidently by the criticality safety analyst to predict neutron multiplication of a system.

Detailed guidance used in the selection of experiments, and the generation of Keffective values for those experiments is contained in Chapters 5 and 7 of the Criticality Methods Manual [4]. For this validation, the number of generations (GEN) and neutrons per generation (NPG) were chosen such that the Keffective values appeared to have converged, and such that the statistical deviation was about 0.0015. Due to the complexity of some of the problems, this led to varying values for GEN and NPG,

depending on the particular configuration. Appendix B provides information concerning GEN, NPG, and NSK, while Appendix C provides sample input files, which can be used for reference.

3.0 Bias and Uncertainty Methodology

The methods used in this document to determine the value of bias and bias uncertainty for a particular area of applicability are given in Chapter 6 of the Criticality Methods Manual [4]. In Chapter 6, the bias methodology is subdivided into different approaches depending on the amount of data and its characteristics. In this report, the Lower Tolerance Band, Lower Tolerance Limit, and Upper Subcritical Limit are used. A tolerance band provides a curve, as a function of an independent variable, above which some specified percent of the data will fall with some confidence. Because of the nature of a LTB, values outside of the range of the experimental values can often be extrapolated (with caution).

A lower tolerance limit, on the other hand, assumes that the distribution of the data is normal, and thus a single value of $K_{\text{effective}}$ can be determined, above which a specified percent of the data will fall with some confidence. A LTL cannot be extrapolated, and thus is only valid within the range of the experimental data. A LTL is typically used when a good fit (or correlation) cannot be found between an independent parameter and the calculated $K_{\text{effective}}$ values. For instances when a curve fit does not exist and the data is not normally distributed, non-parametric methods are utilized, namely an Upper Subcritical Limit (USL). Table 1 provides a summary of the results of this report.

For all LTB and LTL values in this report, a confidence and population level have been set at 95%. Thus the LTB and LTL represent values that 95% of the population will lie above with 95% confidence.

Table 1, Summary of Results

Data Set	Cross-section Library	Type of Limit	Value
Plutonium Metals	27-group	LTL	0.980
	238-group	LTB	See 4.1.3
Plutonium Solutions	27-group	LTB	See 4.2.3
	238-group	LTB	See 4.2.3
HEU Metals	27-group	USL	0.994
	238-group	USL	0.981
HEU Solutions (Bare and Water-Reflected)	27-group	LTL	0.997
	238-group	LTL	0.992
(Concrete Reflected)*	27-group	LTL	1.001
	238-group	LTL	0.995
(Plexiglas Reflected)	27-group	USL	0.984
	238-group	LTL	0.988
Explicit MTR Fuel	27-group	LTL	0.977

	238-group	LTL	0.978
Homogenous MTR	27-group	LTL	0.997
	238-group	LTL	0.992

*See Section 5.2.4

4.0 Plutonium Systems

4.1 Plutonium Metal

4.1.1 Area of Applicability

This section presents the SCALE validation analysis for plutonium metal systems. The result from this analysis is a weighted lower tolerance limit for SCALE with the 27-group cross sections and a single-sided lower tolerance band for the 238-group cross sections. Benchmark experiments selected for validation have been previously evaluated and are documented in SRT-EMS-96-0017 [5] and N-CLC-H-0178 [6]. Key areas of applicability for these experiments include:

1. Fuel:	Plutonium Metal Systems
2. Moderation:	H/Pu-239 -- 0 - 0.63
3. Pu-240 Content:	4.5 - 20.2 wt% Pu-240 ¹
4. Moderating Material:	None or Slight (Polymer Mock Explosive)
5. Reflecting Material	None or Hydrogenous
6. Geometry	Single Spheres and Arrays of Cylinders
$4.2 < 4 V/S < 16.6$
7. Neutron Spectrum	Fast; $4.4 < AEG (27) < 7.4$
$21.3 < AEG (238) < 50.7$

4.1.2 System Description

4.1.2.1 Single Unit Plutonium Spheres

Six benchmark experiments have been evaluated and documented in SRT-EMS-96-0017 [5]. These experiments were extracted from the International Handbook of Evaluated Criticality Safety Benchmark Experiments [7]. These experiments utilized spheres of plutonium metal with different compositions and reflectors. A summary of the experiment parameters reported in Reference 5 are provided in Table 2.

¹ Please note limitations in Section 4.1.4 before use.

Table 2, Reported Pu Metal Sphere Experiment Parameters

Benchmark Descriptor	Fuel Alloy	Pu Isotopic Composition (Wt %)				Sphere Radius (cm)	Reflector & Thickness (cm)
		239	240	241	242		
PU-MET-FAST-001	98.98 % δ -phase Pu, 1.02 % Ga	95.18	4.52	0.30	0.00	6.3849	None
PU-MET-FAST-002	98.99 % δ -phase Pu, 1.01 % Ga	76.31	20.16	3.12	0.41	6.6595	None
PU-MET-FAST-005 ²	99.00 % δ -phase Pu, 1.00 % Ga	94.77	4.92	0.31	0.00	5.0419	W, 4.699
PU-MET-FAST-008 ²	98.99 % δ -phase Pu, 1.01 % Ga	94.55	5.15	0.30	0.00	5.310	Th, 24.57
PU-MET-FAST-010 ²	99.00 % δ -phase Pu, 1.00 % Ga	94.77	4.92	0.31	0.00	5.0419	U, 4.1274
PU-MET-FAST-011	100 % α -phase Pu	94.48	5.20	0.30	0.02	4.1217	H ₂ O, 25.4

4.1.2.2 Arrays of Plutonium Metal Cylinders

Three sets of benchmark experiments have been evaluated and documented in N-CLC-H-0178 [6]. Nineteen experiments were extracted from the International Handbook of Evaluated Criticality Safety Benchmark Experiments [7]. Experimental arrays were constructed from canned plutonium metal cylinders. Alpha phase plutonium with the composition specified in Table 3 was used for these experiments. Specific details on the experiments are provided in the following sections.

Table 3, Plutonium Isotopic Composition, Arrays Of Cylinders

Benchmark Descriptor	Isotopic Composition (Wt %)			
	239	240	241	242
PU-MET-FAST-003	93.56	5.97	0.46	0.01
PU-MET-FAST-004	93.56	5.97	0.46	0.01
PU-MET-FAST-017	93.56	5.97	0.46	0.01

4.1.2.2.1 PU-MET-FAST-003 [7]

Five experiments involving arrays of plutonium metal cylinders were evaluated [6]. Plutonium cylinders were contained within aluminum cans with steel lids.

Square pitched arrays were constructed using single (3 kg) and double (6 kg) parts. Spacing between arrays was maintained by use of aluminum support tubes and spacers fastened to an experimental table by means of a support shoe. Benchmark specifications for these experiments did not include an experimental room. Specific details on the

² This experiment has been omitted from the validation results due to the scarcity of data for this type of reflector.

benchmark specifications for these experiments can be found in Reference 7. A summary of the experimental parameters for these experiments is provided in Table 4.

Table 4, Reported Parameters for PU-MET-FAST-003

Experiment Descriptor	Array & Unit Size	Vertical CTC ³ Spacing (cm)	Horizontal CTC ³ Spacing (cm)	Reflector
101	2x2x2 3 kg Cyl.	5.40	7.30	None
102	2x2x2 3 kg Cyl.	5.74	7.64	Polyethylene ⁴
103	3x3x3 3 kg Cyl.	7.71	9.60	None
104	3x3x3 3 kg Cyl.	8.24	10.15	Polyethylene ⁴
105	2x2x1 6 kg Cyl.	N/A	7.59	None

4.1.2.2.2 PU-MET-FAST-004 [7]

Nine experiments involving unreflected three-dimensional arrays of plutonium metal cylinders were evaluated [6]. These experiments are similar to the experiments described in section 2.2.1 with the exceptions noted in the following paragraphs.

Larger square-pitched arrays were constructed using single (3 kg) and double (6 kg) parts. The support tubes, spacers, and split table used for these experiments were designed to permit the construction of larger experimental arrays than the previous experimental set.

The experimental table is modeled in a cubic concrete room 914.4 cm on a side with 152.4 cm thick walls, 91.44 cm thick floors, and a 60.96 cm thick ceiling. The table was horizontally centered in the room and had its top surface 360.342 cm from the floor. A summary of the experimental parameters for these experiments is provided in Table 5.

³ Center to center of spacing is measured from the centers of the double and single parts.

⁴ Reflection was from a 20 cm thick polyethylene slab on one side of the arrays.

Table 5, Reported Parameters for PU-MET-FAST-004

Experiment Descriptor	Array & Unit Size	Vertical CTC ⁵ Spacing (cm)	Horizontal CTC ⁵ Spacing (cm)
207	4x4x4 3 kg Cyl.	7.86	12.51
208	4x4x4 6 kg Cyl.	17.12	17.28
209	4x4x4 6 kg Cyl.	32.12	13.09
210	4x4x4 6 kg Cyl.	47.12	11.93
211	4x4x4 6 kg Cyl.	22.12	15.23
212	4x4x4 6 kg Cyl.	13.12	20.19
213	4x4x1 6 kg Cyl.	N/A	10.91
214	3x3x3 6 kg Cyl.	13.68	14.51
215	2x2x2 6 kg Cyl.	11.98	9.76

4.1.2.2.3 PU-MET-FAST-017 [7]

Five experiments involving unreflected arrays of moderated plutonium metal cylinders were evaluated [6]. These experiments were conducted using the same experimental apparatus and facility as the experiments in section 4.1.2.2.2. Moderator jackets and end disks were added to the outside of the support tube and above or below Pu parts, respectively. These disks were made of a mock explosive material (density = 1.559 g/cm³) consisting primarily of carbon (30.56 wt %), hydrogen (3.14 wt %), nitrogen (31.57 wt %) and oxygen (34.73 wt %). Three sizes of moderator jackets and end disks were used. A summary of the experimental parameters for these experiments is provided in Table 6.

Table 6, Reported Parameters for PU-MET-FAST-017

Experiment Descriptor	Array & Unit Size	Vertical CTC ⁵ Spacing (cm)	Horizontal CTC ⁵ Spacing (cm)
201	4x4x4 6 Kg Cyl.	25.79	17.50
202	4x4x4 6 Kg Cyl.	25.82	21.24
203	4x4x4 6 Kg Cyl.	25.82	24.52
204	4x4x4 3 Kg Cyl.	9.63	14.19
205	4x4x4 3 Kg Cyl.	13.64	14.55

⁵ Center to center of spacing is measured from the centers of the double and single parts.

4.1.3 Bias and Uncertainty

Table 7 presents the outcome of the normalcy tests performed on the information provided in Appendix A, Table A.1. Weighted and unweighted means are also included as part of this table.

Table 7, Normalcy Results

Cross Sections	Normal (Y/N)	Kmean	Weighted (Y/N)
27-group	Y	0.9938	Y
		0.9923	N
238-group	N	0.9923	Y
		0.9916	N

Figures 1 and 2 provide the plots used to analyze trends. $K_{\text{effective}}$ was plotted against energy group for the 27-group and 238-group results to identify trends. $K_{\text{effective}}$ increases by 1.7% (27 gr.) and 1.1% (238 gr.) over the energy group ranges. The data used to construct these plots is provided in Appendix A, Table A.1.

**Figure 1, Energy Group vs. $K_{\text{effective}}$ (27-group)
(Pu Metal Systems)**

Figure 2, Energy Group vs. Keffective (238-group)
(Pu Metal Systems)

A set of benchmark experiments for single units and arrays of Pu metal has been evaluated. These experiments cover bare and water reflected Pu metal systems with both the 27 and 238-group cross sections in SCALE 4.4 on the DEC Alpha workstation cluster. A Lower tolerance limit of 0.980 has been calculated for the 27-group library.

Table 8 LTL Calculation Results (27 group)

Weighted Data	27 group
One-sided Lower Tolerance Factor (U)	2.350
Average k_{eff}	0.9938
Sqrt. of Pooled Variance (S_p)	5.849E-05
Variance about the Mean (S^2)	2.525E-05
Average Uncertainty (σ^2)	8.958E-06
Lower Tolerance Limit	0.980

The 238-group had a non-normal distribution. However, a linear trendline could be fit to the array data. Figure 3 shows the linear fit to the Pu metal array data. The result of the regression gives a linear correlation coefficient of 0.5028. Due to this fit, a Lower Tolerance Band may be calculated for the Pu metal array data. The LTB for 238 group Pu metal arrays is shown in Figure 4. The data used in this calculation is given in Appendix A, Table A.1.

Figure 3 Pu Metal Array Data Linear Fit **Figure 4 Pu Metal Lower Tolerance Band**

The 238 group Pu metal Lower Tolerance Band within the area of applicability for a given 238 group average energy may be represented by the equation:

$$LTB = 4.7794E-07 (x^3) - 5.8752E-05 (x^2) + 2.3446E-03 (x) + 9.4937E-01$$

where x is the supplied average energy group. This equation only represents the LTB within the evaluated area of applicability and may not be used to extrapolate beyond the range of the area of applicability.

Bias and bias uncertainty for Pu metal single units may also be obtained from this Pu metal array lower tolerance band. Due to the fact that the single unit experiments all

calculate high relative to the array cases, the array bias is judged acceptable and conservative for use with single unit cases.

The data used in this validation covers a broad spectrum of materials, therefore a subcritical margin as low as 0.02 may be appropriate for those systems with Pu-240 contents near 5%. For systems with significantly different Pu-240 contents, a larger subcritical margin would be necessary.

4.1.4 Limitations

These results are applicable to bare and hydrogenously reflected Pu-239 (Pu-240 wt% = 4.5-20%) metal systems with average neutron fission groups from 4.4 - 7.4 (27gr.) and 21.3 - 50.7 (238 gr.) from SCALE Version 4.4 running on the Digital Equipment Alpha Processors Workstation Cluster. The results are not applicable to thermal [avg. energy gr. > 7.4 (27 gr.), > 50.7 (238 gr.)] systems, systems containing significant interstitial moderation (i.e., H/Pu-239 ratio $\neq$ 0) and systems with non-hydrogenous reflectors.

As can be seen in the tables in this section, the majority of the evaluated experiments have Pu-240 content near 5%. As discussed in 4.1.3, use of this bias with cases having Pu-240 content significantly different from 5% requires an increase in the subcritical margin.

Again, the equation supplied in Section 4.1.3 to determine the 238 group Pu metal lower tolerance band may not be used to extrapolate beyond the area of applicability. This is due to the fact that the polynomial fit to the data was evaluated using power series theory, which may lead to unrealistic shapes for the fit determination (oscillations) outside of the data region. Limited extrapolation would be allowed through evaluation of the data by alternate methods, such as orthogonal Legendre polynomials.

4.2 Plutonium Solutions

4.2.1 Area of Applicability

This section presents the SCALE validation analysis for plutonium nitrate solution systems. The results of this analysis present weighted (including statistical and experimental uncertainties) lower tolerance bands as a function of H/Pu-239 for the SCALE code system with the 27-group ENDF/B-IV and 238-group ENDF/B-V cross section libraries. Benchmark experiments selected for validation have been previously evaluated and are documented in N-CLC-F-00060 [9] and SRT-EMS-95-0084 [10]. Key areas of applicability for these experiments include:

1. Fuel:	Plutonium Nitrate ($\text{Pu}(\text{NO}_3)_4$) Solution
2. Moderation:	H/Pu-239 -- 90 - 2800 ⁶
3. Pu-240 Content:	Weight % (0.54 - 18.91 % Pu-240)
4. Moderating Material:	No Interspersed Heterogeneous Moderators
5. Reflecting Material	Bare or Water Reflected
6. Geometry	Single Spheres or Slabs
19.3 < 4 V/S < 81.3
7. Neutron Spectrum	Thermal; 21.4 < AEG (27) < 24.6
195.7 < AEG (238) < 219.8

4.2.2 System Description

Eighty-two critical experiments involving unreflected and water-reflected spheres and slabs were extracted from the International Handbook of Evaluated Criticality Benchmark Experiments [7] for this evaluation. Thirty-six experiments have been evaluated and documented in N-CLC-F-00060 [9]. Forty-six Benchmark experiments have been evaluated and documented in SRT-EMS-95-0084 [10]. The experimental configurations for these experiments are described in the following sections.

4.2.2.1 Unreflected Spheres

Three sets of experiments, dealing with unreflected 48-inch, 16-inch, and 18-inch spheres were evaluated. Details on each type of experiment are provided below.

Unreflected 48-Inch Diameter Spheres [8]

Three of the experiments utilized a single unreflected 48-inch diameter sphere of plutonium nitrate ($\text{Pu}(\text{NO}_3)_4$) solution. A summary of the experiment parameters reported in Reference 8 are provided in Table 9. The isotopic composition of the plutonium used in the experiments is provided in Table 10.

⁶ Please note limitations listed in Section 4.2.4 before use.

Table 9, Reported 48-Inch Sphere Experiment Parameters

Benchmark Descriptor	Pu Density (g/l)	Molarity
PU-SOL-THERM-009/1	10.02	1.119
PU-SOL-THERM-009/2	9.539	1.118
PU-SOL-THERM-009/3	9.457	1.123

Table 10, Plutonium Isotopic Composition

Isotope	Weight %
Pu-238	0.004
Pu-239	97.386
Pu-240	2.521
Pu-241	0.075
Pu-242	0.014

Unreflected 16-Inch Diameter Spheres [9]

Four of the experiments utilized a single unreflected 16-inch diameter sphere of plutonium nitrate ($\text{Pu}(\text{NO}_3)_4$) solution. A summary of the reported experimental parameters is provided in Table 11. The plutonium used in these experiments was 95.83 wt. % Pu-239 and 4.17 wt. % Pu-240.

Table 11, Reported 16-Inch Sphere Experiment Parameters

Experiment Descriptor	Pu Density (g/l)	Molarity
PU-SOL-THERM-011/16-1	35.59	1.123
PU-SOL-THERM-011/16-2	38.13	1.984
PU-SOL-THERM-011/16-3	38.16	2.255
PU-SOL-THERM-011/16-4	43.43	3.808

Unreflected 18-Inch Diameter Spheres (Cadmium Shell) [9]

Six of the experiments utilized a single unreflected 18-inch diameter sphere of plutonium nitrate ($\text{Pu}(\text{NO}_3)_4$) solution. A thin cadmium shell (0.02 inches thick) was placed on the outside of the spherical reactor tank. A summary of the reported experimental parameters is provided in Table 12. The plutonium used in these experiments was 95.8 wt.% Pu-239 and 4.2 wt.% Pu-240.

Table 12, Reported 18-Inch Sphere Experiment Parameters

Experiment Descriptor	Pu Density (g/l)	Molarity
PU-SOL-THERM-011/18-1	22.35	0.847
PU-SOL-THERM-011/18-2	23.18	1.263
PU-SOL-THERM-011/18-3	23.82	1.988
PU-SOL-THERM-011/18-4	25.20	2.783
PU-SOL-THERM-011/18-5	27.49	4.141
PU-SOL-THERM-011/18-6	23.94	1.623

4.2.2.2 Water Reflected Spheres [10]

Experiments were conducted with aluminum or stainless steel tanks of various sizes. These tanks were filled with various plutonium nitrate ($\text{Pu}(\text{NO}_3)_4$) solutions and reflected by 30 cm of water. A summary of the experimental parameters for these experiments is provided in Table 13.

Table 13, Reported Sphere Parameters

Experiment Descriptor	Pu Density (g/l)	Isotopic Composition (wt %)		Molarity	Radius (cm)
PU-SOL-THERM-001⁷		Pu-239	Pu-240		
1	73.0	95.011	4.669	0.199	14.5151
2	96.0	95.011	4.669	1.669	14.5377
3	119.0	95.011	4.669	1.999	14.5113
4	132.0	95.011	4.669	2.299	14.5302
5	140.0	95.011	4.669	2.199	14.5302
6	268.7	95.011	4.669	1.099	14.5189
PU-SOL-THERM-002					
1	49.84	96.88	3.12	1.390	15.3399
2	51.42	96.88	3.12	1.754	15.3399
3	56.09	96.88	3.12	2.387	15.3399
4	59.64	96.88	3.12	2.814	15.3399
5	63.33	96.88	3.12	3.284	15.3399
6	70.11	96.88	3.12	4.008	15.3399
7	77.09	96.88	3.12	4.487	15.3399
PU-SOL-THERM-003					
1	33.32	98.24	1.76	0.834	16.5156
2	34.32	98.24	1.76	1.298	16.5156
3	37.43	99.46	0.54	1.465	16.5156
4	38.12	99.46	0.54	1.871	16.5156
5	40.65	99.46	0.54	2.612	16.5156
6	44.09	99.46	0.54	1.982	16.5156
7	35.98	99.46	0.54	0.807	16.2487
8	36.81	99.46	0.54	1.277	16.2487

⁷ Plutonium isotopic composition also contains 0.006 % Pu-238, 0.305 % Pu-241 and 0.009 % Pu-242.

**Table 13, Reported Sphere Parameters
(continued)**

Experiment Descriptor	Pu Density (g/l)	Isotopic Composition (wt %)		Molarity	Radius (cm)
PU-SOL-THERM-004		Pu-239	Pu-240		
1	26.27	99.46	0.54	1.754	17.7865
2	26.31	99.46	0.54	2.545	17.7865
3	27.20	99.46	0.54	1.299	17.7865
4	28.09	99.46	0.54	0.925	17.7865
5	27.58	98.24	1.76	1.264	17.7865
6	28.6	98.24	1.76	1.799	17.7865
7	29.57	98.24	1.76	2.819	17.7865
8	29.95	98.24	1.76	4.392	17.7865
9	31.6	98.24	1.76	5.913	17.7865
10	35.36	98.24	1.76	1.356	17.7865
11	39.38	98.24	1.76	1.298	17.7865
12	29.44	98.24	1.76	0.908	17.7865
13	29.27	98.24	1.76	1.409	17.7865
PU-SOL-THERM-005					
1	29.65	95.95	4.05	1.837	17.7865
2	30.54	95.95	4.05	2.832	17.7865
3	31.43	95.95	4.05	3.785	17.7865
4	33.54	95.95	4.05	4.755	17.7865
5	36.04	95.95	4.05	3.903	17.7865
6	38.49	95.95	4.05	1.523	17.7865
7	40.91	95.95	4.05	2.010	17.7865
8	30.58	95.60	4.40	1.451	17.7865
9	31.85	95.60	4.40	1.938	17.7865
PU-SOL-THERM-006					
1	24.80	96.88	3.12	2.963	19.0416
2	25.56	96.88	3.12	0.893	19.0416
3	26.97	96.88	3.12	1.393	19.0416

4.2.2.3 Reflected And Unreflected Slabs [9]

Twenty-three of these experiments were conducted in a stainless steel slab tank with a 130 cm x 130 cm square base. Critical solution heights were determined for various plutonium nitrate ($\text{Pu}(\text{NO}_3)_4$) solution compositions. The plutonium isotopic composition is provided in Table 14. A summary of the reported experimental parameters is provided in Table 15.

Table 14, Plutonium Isotopic Composition

Isotope	Weight %
Pu-239	74.3189
Pu-240	18.9102
Pu-241	5.629
Pu-242	1.1418
Am-241	0.61 (% of Pu)

Table 15, Reported Slab Parameters

Experiment Descriptor	Pu Density (g/l)	Molarity	Critical Height (cm)	Reflector
PU-SOL-THERM-012/1	19.7	2.02	28.17	Water
PU-SOL-THERM-012/2	17.7	2.01	32.35	Water
PU-SOL-THERM-012/3	16.7	2.02	35.44	Water
PU-SOL-THERM-012/4	14.7	2.03	45.68	Water
PU-SOL-THERM-012/5	13.2	2.05	66.15	Water
PU-SOL-THERM-012/6	105.0	2.43	16.32	Water, 5 Sides
PU-SOL-THERM-012/7	84.0	2.04	16.32	Water, 5 Sides
PU-SOL-THERM-012/8	52.7	2.09	17.63	Water, 5 Sides
PU-SOL-THERM-012/9	31.9	2.07	21.31	Water, 5 Sides
PU-SOL-THERM-012/10	26.9	2.09	23.11	Water, 5 Sides
PU-SOL-THERM-012/11	21.7	1.99	27.15	Water, 5 Sides
PU-SOL-THERM-012/12	19.7	2.02	29.90	Water, 5 Sides
PU-SOL-THERM-012/13	13.2	2.06	67.46	Water, 5 Sides
PU-SOL-THERM-012/14	52.7	2.09	19.43	Unreflected
PU-SOL-THERM-012/15	31.9	2.07	22.98	Unreflected
PU-SOL-THERM-012/16	26.9	2.09	24.76	Unreflected
PU-SOL-THERM-012/17	21.7	1.99	28.80	Unreflected
PU-SOL-THERM-012/18	19.7	2.02	31.52	Unreflected
PU-SOL-THERM-012/19	17.7	2.01	35.53	Water, 1 Side
PU-SOL-THERM-012/20	16.7	2.02	38.60	Water, 1 Side
PU-SOL-THERM-012/21	14.7	2.03	49.09	Water, 1 Side
PU-SOL-THERM-012/22	13.2	2.05	69.57	Water, 1 Side
PU-SOL-THERM-012/23	13.2	2.05	70.00	Unreflected

4.2.3 Bias and Uncertainty

Table 16 presents the results of the normalcy tests performed on the data in Appendix A, Table A.2. Additionally, weighted and unweighted means have been provided in this table. A discussion of data acceptability follows this table.

Table 16, Normalcy Test Results

Group	Kmean	Weighted (Y/N)
27-group		
1	1.0289	
(48" unreflected spheres)		
2	1.0086	Y
(18" spheres with Cd shell)	1.0085	N
3	1.0159	Y
(Pu slabs, reflected and unreflected)	1.0169	N
4	1.0142	Y
(water reflected spheres)	1.0143	N
5	1.0154	Y
Compilation	1.0152	N
(all experiments)		
238-group		
1	1.0225	
(48" unreflected spheres)		
2	1.0054	Y
(18" Cd reflected spheres)	1.0054	N
3	1.0113	Y
(Pu slabs, reflected and unreflected)	1.0128	N
4	1.0079	Y
(water reflected spheres)	1.0078	N
5	1.0101	Y
Compilation	1.0097	N
(all experiments)		

Normalcy tests and tolerance limit calculations are not applicable to the 48" sphere set due to the lack of sufficient data points. In addition, the 16" set was calculated but not included in this validation, as there was some uncertainty in values used in the input files. The solutions in these cases were designed using CSASIN, and some of the Handbook values were altered in order to preserve the number densities. Specifically, the Pu densities given in the inputs did not match the Handbook values. Since the details of this alteration were not documented, the 16" set was excluded.

The 48-inch spheres calculate significantly higher than other experiments. Similar results have been previously documented [12]. Slab experiments approaching the H/Pu-239 ratios represented by the spheres calculate lower, but their higher Pu-240 content may cloud the comparison. Caution should be used when using bias results with H/Pu-239 greater than 2000 until the number of data points in this region has been increased.

Several of the 18-inch cadmium reflected spheres calculate lower than the polynomial fitted value. The average $K_{\text{effective}}$ for these spheres is lower than the polynomial fitted values for the 27 and 238-group data, respectively. This difference does not appear to be the result of the cadmium shell around the spheres. Removal of the shell from the experimental models results in a statistically insignificant change in $K_{\text{effective}}$. These experiments were retained because their net effect would be to reduce the positive bias (conservative). The inclusion of the cadmium-reflected spheres in this validation should not be considered an adequate test of the cadmium cross sections, as Cd presence is not statistically significant.

Several independent variables were evaluated to determine if any trends existed in the data. H/Pu-239 ratios produced the best data fits. Reference 11 provides a discussion of the other independent variables that were tested for a correlation with $K_{\text{effective}}$.

H/Pu-239 ratios were plotted against $K_{\text{effective}}$ for the 27-group and 238-group data⁸. The resulting plots (Figures 4 & 5) have well-defined negative inflections in the center of the H/Pu-239 range (1,000 - 1,500). A polynomial regression was selected for evaluation because of this inflection. The data appears to be well correlated but a reason for the correlation is not apparent. For this reason, weighted single sided lower tolerance bands were developed from the polynomials fits to the 27 and 238-group data.

Polynomial fit statistics were significantly better than those for regressions defined in Reference 4. Table 17 summarizes the values of R^2 for weighted polynomial regression fits performed during this analysis.

Table 17, Polynomial Regression Fit Test Results

Parameters	R^2
27-group	0.5312
238-group	0.5357

A weighted polynomial fit was performed on the data, and provided the basis for the tolerance band. Tolerance bands, reported as a function of H/Pu-239, represent the bias and bias uncertainty for plutonium nitrate solutions. Figures 5 & 6 provide the plots used to perform validation calculations and have the lower tolerance band displayed on them. The data used to construct these plots is provided in Appendix A, Table A-2. The value of the lower tolerance band for a specific H/Pu-239 value can be read off the graph or determined from Table 18 and its corresponding equation.

⁸ H/Pu-239 ratios were calculated from the archived output files for References 1 and 2.

The experiments involved in this validation covered a broad spectrum of material contents, and were performed at multiple critical facilities, therefore the use of a subcritical margin as low as 0.02 may be appropriate as long as the H/Pu-239 ratio is between 250 and 1200. If the ratio is larger than 1200, the scarcity of data requires that a larger value of margin be used. Since the data varies by a substantial amount at the upper end of the curve (H/Pu-239 ~ 2500), a margin of at least 0.04 may be appropriate.

The positive bias associated with the 27-group ENDF/B-IV Library may be the result of the cross section collapsing methodology. Section M4.B.3 of the SCALE 4.3 Manual describes a problem with the 0.3 ev resonance (Pu-239) and the Maxwellian used to collapse the cross sections that could cause the positive bias. Justification for suspecting the collapsing problem can be observed by comparing the 27-group and 238-group results. The positive bias is reduced when using the 238-group cross sections. The positive bias evident from the 238-group results may be the result of problems with the ENDF/B-V cross sections. A comparison of the ENDF/B-V results from SCALE to those from MCNP produces similar results.

The K-fit is expressed with the following equation. Similarly, the equation may be utilized to represent the LTB within the area of applicability, however, the equation *cannot be used to extrapolate beyond the range of the area of applicability*. The K-Limit constants must be used when determining the bias. Alternate data evaluation methods would allow limited extrapolation, if required.

$$LTB = B_0 + B_1 * (H/^{239}\text{Pu}) + B_2 * (H/^{239}\text{Pu})^2 + B_3 * (H/^{239}\text{Pu})^3$$

Table 18, Tolerance Band, Average Energy Group vs. Keffective

	B₀	B₁	B₂	B₃
27-group				
K-Fit	1.0203	-1.3161E-05	5.5335E-09	0
K-Limit (LTB)	1.0082	-8.2348E-06	2.4486E-09	4.5562E-13
238-group				
K-Fit	1.0115	-7.8695E-06	4.0821E-09	0
K-Limit (LTB)	0.9997	-3.0461E-06	1.0617E-19	4.4611E-13

Figure 3, H/Pu-239 vs. Keffective (27-group)

Figure 4, H/Pu-239 vs. Keffective (238-group)

**Figure 5, Lower Tolerance Band - H/Pu-239 vs. Keffective
(27-group bias & bias uncertainty)**

Note: 1.0022 is the lowest point on the lower tolerance band. This corresponds to a H/Pu-239 ratio of 1,209-1,254.

**Figure 6, Lower Tolerance Band - H/Pu-239 vs. Keffective
(238-group bias and bias uncertainty)**

Note: 0.9979 is the lowest point on the lower tolerance band. This corresponds to a H/Pu-239 ratio of ~987-1,254.

4.2.4 Limitations

The tolerance bands developed are applicable to unreflected and water reflected systems of plutonium nitrate solutions modeled using SCALE Version 4.4 on the Digital Equipment Alpha Processors Workstation Cluster. These results are not applicable to plutonium metal systems or to plutonium solution systems with significant non-water reflectors. Use of these results with systems containing different reflectors requires additional analysis and justification. Care should also be taken in extrapolating these results to arrays of Pu solutions.

Use of the results with H/Pu-239 Ratios above 2000 is strongly cautioned. The results in this region are based on two sets of experiments that span a range of 1.4% of $K_{\text{effective}}$. Additional analysis and justification is recommended prior to using the results from this region.

Extrapolation outside of the area of applicability for these experiments is not recommended, for several reasons. The polynomial fits used in the validation calculations were evaluated using power series theory. This can lead to unrealistic shapes for the fit determination (oscillations) outside of the data region.

5.0 Uranium Systems

5.1 Uranium Metal

5.1.1 Area of Applicability

This section presents the SCALE validation analysis for uranium metal systems. The results from this analysis are non-parametric upper subcritical margins for the 27-group and 238-group cross sections. Benchmark experiments selected for validation have been previously evaluated and are documented in SRT-EMS-96-0017 [5] and N-CLC-H-0178 [6]. Key areas of applicability for these experiments include:

1. Fuel:	Uranium Metal Systems
2. Moderation:	H/U-235 ~ 0
3. Enrichment:	93.5 wt% ²³⁵ U
4. Moderating Material:	Polyethylene, Plexiglas, Teflon
5. Reflecting Material	Bare, water, natural uranium, Polyethylene,
Paraffin, Lucite, Tungsten-Carbide, Tuballoy, steel,
and aluminum
6. Geometry	Single spheres, slabs, and cylinders; arrays
cylinders and slabs
$6.4 < 4 V/S < 28.6$
7. Neutron Spectrum	Fast; $4.8 < \text{AEG (27)} < 15.8$
$24.3 < \text{AEG (238)} < 136.9$

5.1.2 System Descriptions

5.1.2.1 Unreflected HEU Spheres [7]

Two experiments involved unreflected uranium spheres. The first, referred to as Godiva, was a bare ²³⁵U sphere. The second was a Shell Model that consisted of layers of uranium with gaps of air. Both consisted of two identical sets of nested or alloy hemispheres. For each, the upper hemisphere was supported by a 0.015-inch-thick diaphragm of stainless steel, and the lower hemisphere rested on a thin-wall aluminum cylinder. The lower stack was raised by remote control to contact the steel diaphragm for each measurement of the multiplication of neutrons from a near-central source. Specific details on the benchmark specifications for these experiments can be found in Reference 7. A summary of the experimental parameters for these experiments is provided in Table 19.

Table 19, Reported Parameters for HEU-MET-FAST-001

Benchmark Descriptor	Composition	U Isotopic Composition (Wt %)			Sphere Radius (cm)
		234	235	238	
Godiva	HEU	1.02	93.71	5.27	8.7407
Shell Model:					
Shell1	HEU	1.02	93.26	5.72	1.0216
Shell2	Air gap	-	-	-	1.0541
Shell3	HEU	1.02	93.90	5.08	6.2809
Shell4	Air gap	-	-	-	6.2937
Shell5	HEU	1.02	93.95	5.03	7.7525
Shell6	Air gap	-	-	-	7.7620
Shell7	HEU	1.02	93.58	5.40	8.2527
Shell8	Air gap	-	-	-	8.2610
Shell9	HEU	1.02	93.89	5.09	8.7062
Shell10	HEU	1.02	93.86	5.12	8.7499

5.1.2.2 Natural Uranium-Reflected Pseudosphere, Pseudocylinder, and Parallelepipeds [7]

Six experiments involving tuballoy-reflected critical assemblies were run on the Topsy machine. This set of oralloy assemblies includes a pseudosphere, a pseudocylinder, and four parallelepipeds. The density of oralloy in all six assemblies is 18.75 g/cm^3 , and it is composed of 93.5 wt% ^{235}U , 1.02 wt% ^{234}U , and 5.48 wt% ^{238}U . The tuballoy reflector has a density of 18.90 g/cm^3 , and is composed of 0.0055 at.% ^{234}U , 0.72 at.% ^{235}U , and 99.2745 at.% ^{238}U . All assemblies were taken to critical and used to demonstrate the effect of geometry on critical mass. A summary of the experimental parameters for these experiments is provided in Table 20.

Table 20, Reported Parameters for HEU-MET-FAST-002

Configuration	Region	Width (cm)	Depth (cm)	Height (cm)	Radius (cm)	Material
Sphere	1	-	-	-	6.0509	Oralloy
	2	-	-	-	26.3709	Tuballoy
Cylinder	1	-	-	11.43	5.1706	Oralloy
	2	-	-	52.07 ^(a)	25.4906	Tuballoy
4x4x3.66 Inch Parallelepiped	1	10.16	10.16	9.3	-	Oralloy
	2	50.80	50.80	49.94	-	Tuballoy
5x5x2.53 Inch Parallelepiped	1	12.70	12.70	6.415	-	Oralloy
	2	53.34	53.34	47.0550	-	Tuballoy
3x3x7.56 Inch Parallelepiped	1	7.62	7.62	19.1970	-	Oralloy
	2	48.26	48.26	59.8370	-	Tuballoy
3x3.5x6 Inch Parallelepiped	1	7.62	8.89	15.2344	-	Oralloy
	2	48.26	49.53	55.8744	-	Tuballoy

(a) 20.32 cm above and below region 1.

5.1.2.3 Unmoderated, Reflected HEU Spheres [7]

Twelve experiments involved unmoderated, reflected spherical assemblies. Included were seven spherical oralloy assemblies reflected by tuballoy, four spherical oralloy assemblies reflected by tungsten carbide, and one spherical oralloy assembly reflected by nickel. The acceptability of the nickel-reflected sphere for a benchmark experiment was deemed "marginal" in the Handbook, and so it was not included in this validation. The density of the oralloy was 18.75 g/cm^3 , with constituents of 1.02 wt% ^{234}U , 93.5 wt% ^{235}U , and 5.48 wt% ^{238}U . The density of the tuballoy was 18.90 g/cm^3 , and included 99.2745 at.% ^{238}U , 0.0055 at.% ^{234}U , and 0.72 at.% ^{235}U . Table 21 contains the isotopic abundance for Tungsten.

Table 21, Isotopic Abundance (at.%) for Tungsten

Isotope	Abundance (at.%)
^{180}W	0.12
^{182}W	26.3
^{183}W	14.28
^{184}W	30.7
^{186}W	28.6

The tuballoy-reflected experiments with reflectors less than five inches thick were not brought to critical and were either "hand-held" or run on the Elsie machine. Three tungsten carbide-reflected experiments were run on the Elsie machine, and one (with the two-inch reflector) was "hand-held." None were brought to critical. All assemblies run on the Topsy machine with tuballoy reflectors of 5 inches or greater were brought to critical. A summary of the experimental parameters for these experiments is provided in Table 22, where region 1 is the spherical oralloy, and region 2 is the reflector.

Table 22, Reported Parameters for HEU-MET-FAST-003

Reflector Thickness (in.)	Region	Outer Radius (cm)	Material
2.0	1	6.7820	Oralloy
	2	11.8620	Tuballoy
3.0	1	6.4423	Oralloy
	2	14.0623	Tuballoy
4.0	1	6.2851	Oralloy
	2	16.4451	Tuballoy
5.0	1	6.1535	Oralloy
	2	18.8535	Tuballoy
7.0	1	6.0740	Oralloy
	2	23.8540	Tuballoy
8.0	1	6.0509	Oralloy
	2	26.3709	Tuballoy
11.0	1	6.0276	Oralloy
	2	33.9676	Tuballoy
1.9	1	6.6020	Oralloy
	2	11.4280	Tungsten Carbide
2.9	1	6.2527	Oralloy
	2	13.6187	Tungsten Carbide
4.5	1	6.0509	Oralloy
	2	17.4809	Tungsten Carbide
6.5	1	6.0159	Oralloy
	2	22.5259	Tungsten Carbide
8.0	1	6.4627	Oralloy
	2	26.7827	Nickel

5.1.2.4 Water-Reflected HEU Sphere [7]

One experiment involved a water-reflected uranium sphere consisting of two hemispheres of highly enriched uranium. The hemispheres were joined together using a small HEU pin to form a very nearly uniform sphere with a radius of 6.5537 cm. The sphere was placed on a three-legged Plexiglas stand inside an aluminum tank, which was then filled with water until the system became slightly supercritical, but considerably less than prompt supercritical. The effect was to estimate the critical mass of a sphere of HEU with an effectively infinite water reflector. A summary of the constituents of the sphere is provided in Table 23.

Table 23, Components of the HEU Sphere

Item	Hemisphere 1	Hemisphere 2	Pin
Net Mass (kg)	11.335	11.336	0.013
Uranium Mass (kg)	11.328	11.331	0.013
²³⁵ U (wt.%)	< 0.01	< 0.01	< 0.01
²³⁴ U (wt.%)	1.17	1.05	1.04
²³⁵ U (wt.%)	97.67	97.68	97.67
²³⁶ U (wt.%)	0.20	0.20	0.21
²³⁸ U (wt.%)	0.95	1.06	1.07

Input files were designed to perform calculations on both one-dimensional and three-dimensional idealizations of this system. The one-dimensional idealization omits the Plexiglas stand, and uses a spherical water reflector that preserves the volume of the actual cylindrical reflector. This idealization was not included in the validation, as there was no experimental result with which to compare it against. A summary of the dimensions for the experiment is provided in Tables 24.

Table 24, Dimensions for Three-dimensional Idealization of HEU-MET-FAST-004

Item	Length (cm)
Radius of sphere of HEU	6.5537
Thickness of seat of stand	2.54
Outer diameter of seat of stand	25.4
Inner diameter of seat of stand	7.948
Outer diameter of cylinder of water	60.0
Distance from center of sphere to top of stand	5.212
Distance from center of sphere to bottom of water	32.5
Distance from center of sphere to top of water	23.054

5.1.2.5 Moderated, Reflected and Unreflected HEU Slabs [7]

Forty-three experiments involved moderated slabs of highly enriched uranium metal (1.07 wt% ^{234}U , 93.15 wt% ^{235}U , 0.68 wt% ^{236}U , and 5.10 wt% ^{238}U). The unreflected experiments consisted of uranium metal slabs interleaved with Polyethylene, Plexiglas, or Teflon. Some of the Polyethylene-moderated experiments also had a Polyethylene reflector. Table 25 provides the densities of the moderators.

Table 25, Densities of Moderators in HEU-MET-FAST-007

Moderator	Density (g/cm ³)
Polyethylene (CH ₂)	0.92
Plexiglas (C ₅ O ₂ H ₈)	1.18
Teflon (CF ₂)	2.17

The experiments were performed on the Split Table Apparatus, which consists of two cast iron bench plates, one stationary and one movable. Table 26 provides the parameters for these forty-three experiments.

Table 26, Experimental Parameters for HEU-MET-FAST-007

Case Number	Height (cm)	Number of Cells	Cell Layer Thickness		Basic Assembly Features
			Uranium (cm)	Plastic (cm)	
1	8.722	1	4.3610	-	Unreflected, Polyethylene Moderated, Base Dimensions 25.4 x 25.4 cm
2	9.545	4	1.04144	0.30340	
3	9.771	3	1.36267	0.53176	
4	9.898	5	0.80032	0.37908	
5	10.251	7	0.56137	0.34174	
6	10.401	3	1.27965	0.90778	
7	10.401	6	0.63962	0.45432	
8	10.424	8	0.48077	0.34146	
9	10.427	4	0.96169	0.68328	
10	11.689	5	0.64219	1.05342	
11	12.921	8	0.33717	0.94076	
12	13.007	8	0.32268	0.98056	
13	13.000	4	0.64497	1.95998	
14	13.165	8	0.32277	1.00006	
15	12.715	4	0.64024	1.89830	
16	12.758	4	0.64050	1.90856	
17	14.211	6	0.32152	1.72550	
18	14.328	6	0.32156	1.74488	
19	12.355	1	6.1775	-	Unreflected, Polyethylene Moderated, Base Dimensions 12.7 x 25.4 cm
20	15.730	5	1.19605	0.75392	
21	15.931	5	1.19640	0.79334	
22	16.132	5	1.19675	0.83278	
23	17.750	4	1.43819	1.56098	
24	17.915	4	1.43886	1.60094	
25	19.759	5	1.11882	1.71404	
26	19.964	5	1.11935	1.75414	
27	10.140	4	1.04059	0.45372	Unreflected, Plexiglas Moderated, Base Dimensions 25.4 x 25.4 cm
28	10.996	5	0.79891	0.60130	
29	11.831	6	0.63780	0.69628	
30	14.514	5	0.63719	1.62832	
31	18.395	8	0.31899	1.66134	Unreflected, Teflon Moderated, Base Dimensions 25.4 x 25.4 cm
32	11.908	6	0.75962	0.46534	
33	14.709	6	0.80546	0.84060	
34	17.770	6	0.84775	1.26612	
35	5.362	1	2.681	-	Polyethylene Reflected and Moderated, Base Dimensions 12.7 x 25.4 cm
36	6.307	4	0.63837	0.30056	
37	7.120	6	0.40219	0.38222	
38	7.351	12	0.20074	0.21108	
39	7.427	12	0.19982	0.21666	
40	7.242	5	0.47836	0.49158	
41	8.674	6	0.32105	0.80356	
42	8.809	6	0.32165	0.82482	
43	10.688	11	0.12003	0.73160	

5.1.2.5 HEU-MET-FAST-012 [24,7]

This critical experiment, conducted at the Russian Federal Nuclear Center Institute of Technical Physics (VNIITF), was a two-unit assembly consisting of twelve spherical layers of highly enriched uranium and an aluminum reflector. The bottom reflector has one shell; the reflector on the top hemisphere has three shells. In the experiment, the top part of the assembly rested on a steel diaphragm while the lower part was raised into a critical configuration.

5.1.2.6 HEU-MET-FAST-013 [24,7]

This critical experiment, conducted at VNIITF, was a two-unit assembly consisting of nine spherical layers of highly enriched uranium and a four-layer aluminum reflector. The top part of the assembly rested on a steel diaphragm, while the lower part was raised into a critical configuration. The material compositions and dimensions for this benchmark experiment are given in Table 27 [# , 7].

5.1.2.7 HEU-MET-FAST-021 [24,7]

This critical experiment, conducted at VNIITF, was a two-unit assembly consisting of seven spherical layers of highly enriched uranium with a central cavity and a steel reflector. The upper unit consisted of a hemispherical steel shell resting on a steel diaphragm, and the moveable lower unit incorporated the remainder of the core and reflector. The material compositions and dimensions for this benchmark experiment are given in Table 27.

5.1.2.8 HEU-MET-FAST-022 [24,7]

This critical experiment, conducted at VNIITF, consisted of two units: an upper unit composed of a hemispherical shell of highly enriched uranium and three hemispherical shells of the Duralumin reflector, and a moveable lower unit containing the remainder of the core and reflector. An aluminum diaphragm supported the upper unit. The material compositions and dimensions for this benchmark experiment are given in Table 27

5.1.2.9 HEU-MET-FAST-024 [24,7]

This experiment performed at VNIITF, was a two-unit assembly consisting of ten spherical layers of highly enriched uranium, a single-layer steel reflector , and a three-layer polyethylene reflector. The material compositions and dimensions for this benchmark experiment are given in Table 27

5.1.2.10 HEU-MET-FAST-033 [24,7]

These two critical experiments, conducted at VNIITF, consisted of two hemicylinders of alternating HEU, steel, and polyethylene disks separated by a gap that yielded a critical configuration. The top hemicylinder rested on a steel diaphragm supported by a

Duralumin tripod, and the moveable bottom half rested in a Duralumin cone. The material compositions and dimensions for this benchmark experiment are given in Table 27

5.1.2.11 HEU-MET-FAST-034 [24,7]

These three critical experiments, conducted at VNIITF, consisted of two hemicylinders of alternating HEU, polyethylene, and either steel, titanium, or aluminum disks separated by a gap that yielded a critical configuration. The top hemicylinder rested on a steel diaphragm supported by a Duralumin tripod, and the moveable bottom half rested in a Duralumin cone. The material compositions and dimensions for this benchmark experiment are given in Table 27

5.1.2.12 HEU-MET-FAST-035 [24,7]

This critical experiment, conducted at VNIITF, consisted of two hemicylinders of alternating HEU, polyethylene, and titanium disks, separated by a gap that yielded a critical configuration, and reflected on all sides by polyethylene. The top hemicylinder rested on a steel diaphragm, and the moveable bottom half rested on a steel disk. The material compositions and dimensions for this benchmark experiment are given in Table 27

Table 27. HEU-MET-FAST-012, 013, 021, 022, 024, 033, 034, 035 Compositions and Dimensions

Handbook I.D.	Core Material Composition and Density (wt%, g/cc)	Uranium Isotopic Composition (wt%)	Core Material	Core Radius (cm)	Reflector Material	Reflector Thickness (cm)
HEU-MET-FAST-012	U=99.2626 C=0.0428 Fe=0.0698 W=0.0211 Cu=0.4277 Ni=0.1811 Density=17.9924	²³⁴ U=1.1369 ²³⁵ U=89.5982 ²³⁶ U=0.1931 ²³⁸ U=9.0772	Uranium Metal	9.15	Aluminum	Top=2.85 Bottom=1.7
HEU-MET-FAST-013	U=99.2538 C=0.0443 Fe=0.0698 W=0.0211 Cu=0.4277 Ni=0.1833 Density=17.9924	²³⁴ U=1.1362 ²³⁵ U=89.6324 ²³⁶ U=0.1941 ²³⁸ U=9.0730	Uranium Metal	8.38	steel	3.65
HEU-MET-FAST-021 (average values used in the simplified benchmark model)	U=99.6921 C=0.1185 Fe=0.098 W=0.0914 Density=18.38	²³⁴ U=1.1045 ²³⁵ U=89.6324 ²³⁸ U=9.4064	Uranium Metal	7.55	steel	9.7
HEU-MET-FAST-022	U=99.7072 C=0.1137 Fe=0.0933 W=0.0858 Density=18.4	²³⁴ U=1.104 ²³⁵ U=89.4927 ²³⁸ U=9.403	Uranium Metal	8.35	Duralumin	3.9
HEU-MET-FAST-024	U=99.2144	²³⁴ U=1.1298	Uranium	7.55	Steel and	0.8 and 9.65

	C=0.0447 Fe=0.0733 W=0.0210 Cu=0.4525 Ni=0.1939 Density=18.0044	^{235}U =89.5252 ^{236}U =0.1970 ^{238}U =9.0502	Metal		polyethylene	respectively
HEU-MET-FAST-033	U=99.9896 C=0.008 Fe=0.009 W=0.0015 Density=18.5892	^{234}U =1.18 ^{235}U =95.95 ^{238}U =2.84	Uranium Metal with polyethylene and steel	9.995	None	N/A
HEU-MET-FAST-034	U=99.9815 C=0.008 Fe=0.009 W=0.021 Density=18.5887	^{234}U =1.18 ^{235}U =95.96 ^{238}U =2.84	Uranium Metal with polyethylene and Al, Ti, and steel	9.995	None	N/A
HEU-MET-FAST-035	U=99.9815 C=0.008 Fe=0.009 W=0.021 Density=18.5887	^{234}U =1.1798 ^{235}U =95.9603 ^{238}U =2.8395	Uranium Metal with polyethylene and Ti	9.995	polyethylene	Bottom=9.94 Top=9.94 Side=9.393

5.1.2.6 Tinkertoys [7]

In 1962-1963 a set of detailed criticality experiments utilizing highly enriched uranium metal cylinders was conducted at the Oak Ridge Critical Experimental Facility (CEF). Critical arrays of uranium metal cylinders were constructed on a split table apparatus and surface-to-surface spacings (STS) between the units were measured as a function of the number of units and the thickness of a paraffin reflector. HEU-MET-FAST-023 [7] provides a detailed description of the experimental configuration for 22 evaluated benchmark experiments developed from these experiments. Details on the benchmark specifications used in validation model development are provided in the following paragraphs.

Arrays were built using cylinders of uranium metal with paraffin blocks for reflector walls. Two stainless steel rods passed through each cylinder and through the paraffin to support and space the units in the array.

Dimensions for the benchmark are given in Table 28. Table 29 provides the uranium metal composition.

Table 28, Benchmark Array Dimensions

Case #	Array	Cylinder Diameter, D (cm)	Cylinder Height, H (cm)	Cylinder Spacing, STS (cm)	Reflector Thickness, RTH (cm)
2	2x2x2	11.506	5.382	0.229	1.3
3	2x2x2	11.506	5.382	1.981	3.8
4	2x2x2	11.506	5.382	3.416	7.6
5	2x2x2	11.506	5.382	3.696	15.2
6	3x3x3	11.509	5.382	2.007	0.0
7	3x3x3	11.509	5.382	2.992	1.3
8	3x3x3	11.509	5.382	5.872	3.8
9	3x3x3	11.509	5.382	8.258	7.6
10	3x3x3	11.509	5.382	8.689	15.2
12	2x2x2	9.116	8.641	0.602	1.3
13	2x2x2	9.116	8.641	2.362	3.8
14	2x2x2	9.116	8.641	3.97	7.6
15	2x2x2	9.116	8.641	4.308	15.2
16	3x3x3	9.116	8.641	2.436	0.0
17	3x3x3	9.116	8.641	3.426	1.3
18	3x3x3	9.116	8.641	6.579	3.8
19	3x3x3	9.116	8.641	9.017	7.6
20	3x3x3	9.116	8.641	9.434	15.2
21	4x4x4	11.481	5.382	3.952	0.0
22	4x4x4	11.481	5.382	12.36	15.2
28	3x3x3	11.506	5.382	1.349	0.0
29	3x3x5	11.494	5.382	3.442	0.0

Table 29, Uranium Metal Composition (18.76 g/cm³)

Isotope	Wt %
U-234	1.0
U-235	93.2
U-236	0.2
U-238	5.6

Several arbitrary materials were used in the validation models. Arbitrary materials for the 0.88 g/cm and 0.93 g/cm paraffin were modeled as compounds (C₂₅H₅₂) with the appropriate density (0.88 g/cm for 1.3 cm thick paraffin and 0.93 for all other paraffin thicknesses). Standard SCALE 4.4 compositions of SS304 and RFCONCRETE were used for the stainless steel rods and room walls, respectively.

5.1.3 Bias and Uncertainty

All SCALE eigenvalues were found by running 250,000 to 450,000 histories. This provided maximum standard deviations of no more than 0.0017.

Table 30 presents the results of the normalcy tests performed on the results provided in tabular form in the Appendix A, Table A.3. Weighted and unweighted means are also provided in this table. A discussion of trend identification follows this table.

Table 30, Normalcy Results

Cross Sections	Normal (Y/N)	Kmean	Weighted (Y/N)
27-group	N	1.0095	Y
		1.0086	N
238-group	N	0.9939	Y
		0.9961	N

K_{effective} was plotted against energy group for the 27-group and 238-group results to identify trends. Figures 7 and 8 provide the plots used to analyze trends. The data used to construct these plots is provided in Appendix A, Table A.3.

**Figure 7, Average Energy Group vs. Keffective (27-group)
(U Metal Systems)**

**Figure 8, Energy Group vs. Keffective (238-group)
(U Metal Systems)**

A set of benchmark experiments for single units and arrays of HEU metal has been evaluated. These experiments cover bare and reflected HEU metal systems with both 27- and 238-group cross sections in SCALE 4.4 on the DEC Alpha workstation cluster.

The 27-group had non-normal distribution. Because of the poor fit of the trendline to the data series, a non-parametric upper subcritical limit was calculated. With a data sample of 97, there is a 99.3% confidence that 95% of the data lies above the smallest value:

$$\beta = 1 - (0.95)^{97} = 0.993$$

The non-parametric margin for this level of confidence is 0.0. Therefore, the upper subcritical limit is:

$$K_{\text{limit}} = \text{smallest } K_{\text{eff}} \text{ value} - \text{bias uncertainty} - \text{non-parametric margin}$$

27-group:

$$= 0.9967 - \sqrt{(0.0009)^2 + (0.0019)^2} - 0.0 = 0.9946$$

The upper subcritical limit for the 27-group HEU Metals is 0.994.

The 238-group had a non-normal distribution. Because of the poor fit of the trendline to the data series ($R^2 = 0.0725$), a non-parametric upper subcritical limit was calculated. With a data sample of 97, there is a 99.3% confidence that 95% of the data lies above the smallest value:

$$\beta = 1 - (0.95)^{97} = 0.993$$

The non-parametric margin for this level of confidence is 0.0. Therefore, the upper subcritical limit is:

$$K_{\text{limit}} = \text{smallest } K_{\text{eff}} \text{ value} - \text{bias uncertainty} - \text{non-parametric margin}$$

238-group:

$$= 0.9835 - \sqrt{(0.0014)^2 + (0.001)^2} - 0.0 = 0.9818$$

The upper subcritical limit for the 238-group is 0.981.

5.1.4 Limitations

These results are applicable to bare and hydrogenously reflected U-235 metal systems with average neutron fission groups from 4.8 – 24.3 (27gr.) and 24.3 – 215.6 (238 gr.) from SCALE Version 4.4 running on the Digital Equipment Alpha Processors Workstation Cluster. The results are not applicable to systems containing significant interstitial moderation (i.e., H/U-235 ratio $\neq 0$) or systems with non-hydrogenous reflectors.

As can be seen in the tables in this section, the majority of the evaluated experiments have U-238 content near 5%. A subcritical margin as low as 0.02 may be appropriate for those experiments. Use of this bias with cases having U-238 significantly different from 5% requires an increase in the subcritical margin.

5.2 Uranium Solution

5.2.1 Area of Applicability

This section presents the SCALE validation analysis for reflected and unreflected highly enriched uranium solutions. The results of this analysis present weighted (including statistical and experimental uncertainties) single sided lower tolerance limits (based on reflector composition) for the SCALE code system with the 27-group ENDF/B-IV and 238-group ENDF/B-V cross section libraries. Benchmark experiments selected for validation have been previously evaluated and are documented in SRT-EMS-96-0015 [13] and EPD-CTG-950013 [14]. Key areas of applicability for these experiments include:

1. Fuel:	Highly enriched uranium solutions
2. Moderation:	H/U-235 -- 50-1300 ⁹
3. Enrichment:	High (92.3 wt % U-235)
4. Moderating Material:	Water
5. Reflecting Material:	Concrete, Plexiglas, Water, or None
6. Geometry	Single Unit Spheres, Cylinders, and Arrays of
Cylinders $15.3 < 4 V/S < 37.2$
7. Neutron Spectrum	Thermal; $20.7 < AEG (27) < 25$
$186.6 < AEG (238) < 220.6$

5.2.2 System Description

In support of this validation seventy-four critical uranyl nitrate experiments involving bare and concrete or Plexiglas reflected single cylinders or arrays of cylinders were extracted from the International Handbook of Evaluated Criticality Benchmark Experiments [7]. The evaluation of these experiments has been documented in SRT-EMS-96-0015 [13]. In addition, twelve critical uranium oxyfluoride experiments involving single water reflected spheres were extracted from draft reports that will be issued in Reference 7. The evaluation of these experiments has been documented in EPD-CTG-95013 [14].

5.2.2.1 Single Unit Unreflected Cylinders of Uranyl Nitrate

Ten of the experiments utilized single bare cylinders of uranyl nitrate. A summary of the experimental parameters from Reference 7 is provided in Table 31. The isotopic composition of the uranium used in the experiments is provided in Table 32.

⁹ Please note limitations listed in Section 5.2.4 before use.

Table 31, Reported Single Unit Cylinder Parameters

Experiment Descriptor	Tank Composition	Critical Height (cm)	Inner Diameter (cm)	Uranium Concentration (g/l)	Molarity (Excess Nitric Acid – moles/L)	Solution Density (g/cm ³)
HEU-SOL-THERM-001						
1	304 SS	31.20	27.92	145.68	0.294	1.2038
2	304 SS	28.93	27.92	346.73	0.542	1.4800
3	6061 Al	33.55	28.01	142.92	0.283	1.2007
4	6061 Al	30.91	28.01	357.71	0.549	1.4951
5	6061 Al	39.48	33.01	54.89	0.105	1.0758
6	6061 Al	36.67	33.01	59.65	0.114	1.0825
7	6061 Al	23.96	33.01	137.40	0.287	1.1923
8	6061 Al	23.67	33.01	145.68	0.294	1.2038
9	6061 Al	22.53	33.01	357.71	0.549	1.4951
10	6061 Al	20.48	50.69	63.95	0.111	1.0883

Table 32, Uranium Isotopic Composition

Isotope	Weight %
²³⁴ U	1.022
²³⁵ U	93.172
²³⁶ U	0.434
²³⁸ U	5.372

5.2.2.2 Single Unit Concrete-Reflected Cylinders Of Uranyl Nitrate

Fourteen of the experiments utilized single concrete-reflected cylinders of uranyl nitrate. A summary of the experimental parameters from Reference 7 is provided in Table 33. The isotopic composition of the uranium matches that contained in Table 32. The composition of the concrete used in the experimental models is provided in Table 34. Cylinder position was varied within a ~10-inch-thick concrete box. The inside dimensions of this box formed a rough cube (122 cm per side).

Table 33, Reported Single Unit Cylinder Parameters

Experiment Descriptor	Tank Composition	Critical Height (cm)	Inner Diameter (cm)	Uranium Concentration (g/l)	Molarity (Excess Nitric Acid – moles/L)	Solution Density (g/cm ³)
HEU-SOL-THERM-002						
1	304 SS	29.79	27.92	144.38	0.272	1.2023
2	304 SS	24.19	27.92	144.38	0.272	1.2023
3	304 SS	27.23	27.92	334.77	0.521	1.4636
4	304 SS	21.79	27.92	334.77	0.521	1.4636
5	6061 Al	31.37	28.01	144.38	0.272	1.2023
6	6061 Al	24.70	28.01	144.38	0.272	1.2023
7	6061 Al	28.60	28.01	334.77	0.521	1.4636
8	6061 Al	22.33	28.01	334.77	0.521	1.4636
9	6061 Al	34.10	33.01	59.65	0.114	1.0825

**Table 33, Reported Single Unit Cylinder Parameters
(continued)**

Experiment Descriptor	Tank Composition	Critical Height (cm)	Inner Diameter (cm)	Uranium Concentration (g/l)	Molarity (Excess Nitric Acid – moles/L)	Solution Density (g/cm ³)
HEU-SOL-THERM-002						
11	6061 Al	22.85	33.01	144.38	0.272	1.2023
12	6061 Al	18.24	33.01	144.38	0.272	1.2023
13	6061 Al	21.50	33.01	334.77	0.521	1.4636
14	6061 Al	16.78	33.01	334.77	0.521	1.4636

Table 34, Concrete Composition ($\rho = 2.321\text{g/cm}^3$)

Isotope	Wt %
H	0.75
K	1.37
Si	15.50
S	0.19
Na	0.63
Ti	0.1
Ca	23.0
C	5.52
N	0.02
O	48.49
Mg	1.25
Al	2.17
Fe	1.01

5.2.2.3 Single Unit Plexiglas-Reflected Cylinders of Uranyl Nitrate

Nineteen of the experiments utilized single Plexiglas-reflected cylinders of uranyl nitrate. A summary of the experimental parameters from Reference 7 is provided in Table 35. The isotopic composition of the uranium matches that contained in Table 32. The composition of the Plexiglas used in the experimental models is provided in Table 36. Cylinder position was varied within an ~8-inch-thick Plexiglas box. The inside dimensions of this box formed a rough cube (122 cm per side).

Table 35, Reported Single Unit Cylinder Parameters

Experiment Descriptor	Tank Composition	Critical Height (cm)	Inner Diameter (cm)	Uranium Concentration (g/l)	Molarity (Excess Nitric Acid – moles/L)	Solution Density (g/cm ³)
HEU-SOL-THERM-003						
1	304 SS	50.52	27.93	60.32	0.113	1.0837
2	304 SS	67.48	27.93	60.32	0.113	1.0837
3	304 SS	29.71	27.92	147.66	0.271	1.2069
4	304 SS	25.03	27.92	147.66	0.271	1.2069
5	304 SS	27.60	27.92	345.33	0.534	1.4779
6	304 SS	22.75	27.92	345.33	0.534	1.4779
7	6061 Al	51.67	27.88	60.32	0.133	1.0837
8	6061 Al	31.26	28.01	147.66	0.271	1.2069
9	6061 Al	25.26	28.01	147.66	0.271	1.2069
10	6061 Al	28.84	28.01	345.33	0.534	1.4779
11	6061 Al	22.87	28.01	345.33	0.534	1.4779
12	6061 Al	34.33	33.01	60.32	0.113	1.0837
13	6061 Al	27.70	33.01	60.32	0.113	1.0837
14	6061 Al	31.75	33.01	60.32	0.113	1.0837
15	6061 Al	25.10	33.01	66.33	0.120	1.0920
16	6061 Al	22.78	33.01	147.66	0.271	1.2069
17	6061 Al	18.49	33.01	147.66	0.271	1.2069
18	6061 Al	21.67	33.01	345.33	0.534	1.4779
19	6061 Al	17.20	33.01	345.33	0.534	1.4779

Table 36, Plexiglas Composition, wt% (ρ side panels = 1.1863 g/cm³, ρ top and bottom panels = 1.286 g/cm³)

Element	Top and Bottom Panels (Fire Retardant)	Four Side Panels (Non-Fire Retardant)
Hydrogen	7.18	8.03
Carbon	52.68	59.72
Nitrogen	0.10	Not measured
Oxygen	29.4	32.14
Phosphorous	1.54	Not measured
Chlorine	1.63	Not measured
Bromine	6.5	Not measured
Ash	0.71	Not measured

5.2.2.4 Concrete-Reflected Arrays of Uranyl Nitrate Cylinders

Seventeen of the experiments utilized concrete reflected arrays of uranyl nitrate cylinders. A summary of the experimental parameters from Reference 7 is provided in Table 37. Arrays of various sizes were placed with a ~10-inch-thick concrete box that was used for the experiments. The inside dimensions of this box formed a rough cube (122 cm per side). The isotopic composition of the uranium matches that contained in Table 32. The composition of the concrete used in the experimental models is provided above in Table 32.

Table 37, Reported Concrete Reflected Array Parameters

Experiment Descriptor (array size)	Tank Composition	Critical Height (cm)	Inner Diameter (cm)	Uranium Concentration (g/l)	Molarity (Excess Nitric Acid – moles/L)	Solution Density (g/cm ³)
HEU-SOL-THERM-007						
1 (4 x 4 x 1)	6061 Al ¹⁰	28.63	21.12	67.28	0.128	1.0934
2 (4 x 4 x 1)	6061 Al ¹⁰	17.24	21.12	369.96	0.598	1.5120
3 (4 x 4 x 1)	6061 Al	27.15	21.12	67.28	0.128	1.0934
4 (4 x 4 x 1)	6061 Al	17.13	21.12	364.11	0.584	1.5054
5 (2 x 2 x 1)	6061 Al ¹⁰	60.70	21.12	76.09	0.137	1.1057
6 (2 x 2 x 1)	6061 Al ¹⁰	29.49	21.12	360.37	0.585	1.4995
7 (2 x 2 x 1)	6061 Al	62.34	21.12	76.09	0.137	1.1057
8 (2 x 2 x 1)	6061 Al	31.11	21.12	364.11	0.584	1.5054
9 (2 x 2 x 1)	6061 Al	57.88	21.12	80.72	0.143	1.1122
10 (4 x 4 x 1)	6061 Al ¹⁰	57.34	16.12	83.49	0.151	1.1164
11 (4 x 4 x 1)	6061 Al ¹⁰	32.32	16.12	360.37	0.585	1.4995
12 (4 x 4 x 1)	6061 Al	51.21	16.12	83.49	0.151	1.1164
13 (4 x 4 x 1)	6061 Al	31.82	16.12	359.55	0.578	1.4984
14 (2 x 4 x 1)	6061 Al	51.45	16.12	359.55	0.578	1.4984
15 (2 x 3 x 1)	6061 Al	65.49	16.12	359.55	0.578	1.4984
16 (2 x 2 x 1)	6061 Al ¹⁰	101.45	16.12	359.55	0.578	1.4984
17 (2 x 2 x 1)	6061 Al	104.04	16.12	359.55	0.578	1.4984

5.2.2.5 Plexiglas-Reflected Arrays of Uranyl Nitrate Cylinders

Fourteen of the experiments utilized single Plexiglas-reflected cylinders of uranyl nitrate. A summary of the experimental parameters from Reference 7 is provided in Table 38. The isotopic composition of the uranium matches that contained in Table 32. The composition of the Plexiglas used in the experimental models is provided in Table 36. Arrays of various sizes were placed with a ~8-inch-thick Plexiglas box that was used for the experiments. The inside dimensions of this box formed a rough cube (122 cm per side).

Table 38, Reported Plexiglas-Reflected Array Parameters

Experiment Descriptor (array size)	Tank Composition	Critical Height (cm)	Inner Diameter (cm)	Uranium Concentration (g/l)	Molarity (Excess Nitric Acid – moles/L)	Solution Density (g/cm ³)
HEU-SOL-THERM-008						
1 (4 x 4 x 1)	6061 Al ¹⁰	34.82	21.12	60.32	0.113	1.0837
2 (4 x 4 x 1)	6061 Al ¹⁰	19.27	21.12	355.94	0.494	1.4925
3 (4 x 4 x 1)	6061 Al	31.76	21.12	60.32	0.113	1.0837
4 (4 x 4 x 1)	6061 Al	18.82	21.12	355.94	0.494	1.4925
5 (2 x 2 x 1)	6061 Al ¹⁰	110.20	21.12	60.32	0.113	1.0837
6 (2 x 2 x 1)	6061 Al ¹⁰	31.93	21.12	355.94	0.494	1.4925
7 (2 x 2 x 1)	6061 Al	102.29	21.12	60.32	0.113	1.0837
8 (2 x 2 x 1)	6061 Al	33.20	21.12	355.94	0.494	1.4925
9 (4 x 4 x 1)	6061 Al ¹⁰	105.85	16.12	60.32	0.113	1.0837

¹⁰ A 0.32 cm thick stainless steel sleeve was inserted into the tank for this experiment.

Table 38, Reported Plexiglas-Reflected Array Parameters¹¹
(continued)

Experiment Descriptor (array size)	Tank Composition	Critical Height (cm)	Inner Diameter (cm)	Uranium Concentration (g/l)	Molarity (Excess Nitric Acid – moles/L)	Solution Density (g/cm ³)
HEU-SOL-THERM-008						
10 (4 x 4 x 1)	6061 Al ¹⁰	38.10	16.12	355.94	0.494	1.4925
11 (4 x 4 x 1)	6061 Al	78.40	16.12	60.32	0.113	1.0837
12 (4 x 4 x 1)	6061 Al	35.56	16.12	355.94	0.494	1.4925
13 (2 x 3 x 1)	6061 Al ¹⁰	95.20	16.12	355.94	0.494	1.4925
14 (2 x 3 x 1)	6061 Al	89.78	16.12	355.94	0.494	1.4925

5.2.2.6 Uranium Oxyfluoride (UO₂F₂) Solution Experiments

These experiments utilized single water-reflected spheres of uranium oxyfluoride. A summary of the experimental parameters from Reference 13 is provided in Table 39. The isotopic composition of the uranium is provided in Table 40. For all cases the spheres were reflected by at least 15 cm of water.

Table 39, Reported UO₂F₂ Experiment Parameters

Descriptor	Solution Density (g/cc)	Uranium Concentration (g/l)	H/U-235	Radius (cm)	²³⁵ U Mass (Kg)
HEU-SOL-THERM-009					
1	1.79495	696	36	11.5177	4.15
2a	1.62055	543	47	11.4695	3.20
2b	1.59295	518	50	11.5177	3.09
3	1.40045	349	76	11.5177	2.08
4	1.23955	213	126	11.8442	1.37
HEU-SOL-THERM-011					
1	1.0597	53	523	15.9572	0.84
2	1.0596	52	533	15.9569	0.83
HEU-SOL-THERM-012					
1	1.0265	22	1272	27.9244	1.87
HEU-SOL-THERM-010					
1	1.1159	102	270	13.2123	0.92
2	1.1136	104	264	13.2187	0.94
3	1.1015	109	246	13.2359	0.99
4	1.096	112	239	13.2418	1.01

Table 40, Uranium Isotopic Composition

Isotope	Weight %, HEU-SOL-THERM-009, -011, -012	Weight %, HEU-SOL-THERM-010
U-234	0.98	1.1
U-235	93.18	93.13

¹⁰ A 0.32 cm thick stainless steel sleeve was inserted into the tank for this experiment.

U-236	0.50	0.50
U-238	5.34	5.27

5.2.3 Bias and Uncertainty

Statistical analyses of the results of the benchmark calculations were documented in Reference 15.

Validation evaluations were conducted on four groupings of the experiments described in Section 2:

Group 1 was formed from the bare and water-reflected experiments (Sections 5.2.2.1 and 5.2.2.6). Group 2 was formed from the concrete-reflected cases (Sections 5.2.2.2 and 5.2.2.4). Group 3 was formed from the Plexiglas-reflected cases (Sections 5.2.2.3 and 5.2.2.5). The fourth group included all of the experiments.

Table 41 presents the results of the normalcy tests produced from the results provided in tabular form in Appendix A, Table A.4. Additionally, weighted and unweighted means have been provided in this table. A discussion of these results follows this table.

Table 41, Normalcy Test Results

Group	Normal (Y/N)	Kmean	Weighted (Y/N)
27-group			
1 (bare & water)	Y	1.0072	Y
		1.0071	N
2 (concrete)	Y	1.0115	Y
		1.0118	N
3 (Plexiglas)	N	1.0038	Y
		1.0049	N
4 (compilation)	Y	1.0082	Y
		1.0080	N
238-group			
1 (bare & water)	Y	1.0021	Y
		1.0018	N
2 (concrete)	Y	1.0073	Y
		1.0082	N
3 (Plexiglas)	Y	0.9997	Y
		1.0004	N
4 (compilation)	Y	1.0037	Y
		1.0036	N

The concrete reflected experiments (group 2) calculated significantly higher than the other experiments for the 27-group and 238-group libraries. This can be observed by comparing the mean values for each data group. For the weighted 27-group data, the mean value for group 2 calculates 0.0043 and 0.0077 higher than groups 1 & 3, respectively. For the weighted 238-group data, the mean value for group 2 calculates

0.0052 and 0.0076 higher than groups 1 & 3, respectively. The reason for this difference is not known. A discussion of trend identification is provided.

Energy groups and H/U-235 ratios were plotted against $K_{\text{effective}}$ to visually identify trends. Data scatter hampered the identification of trends. Figures 9-12 provide the plots that were used to identify trends. The experimental data used to construct these plots is provided in Appendix A, Table A.4.

Figure 9, H/U-235 Vs. $K_{\text{effective}}$ - 27-group Cross Sections

Figure 10, H/U-235 Vs. $K_{\text{effective}}$ - 238-group Cross Sections

Figure 11, Energy Group Vs. Keffective - 27-group Cross Sections **Figure 12, Energy Group Vs. Keffective - 238-group Cross Sections**

It is possible that the data scatter was caused by the compositions selected for the reflectors. This hypothesis was tested in Reference 21 with the conclusion that concrete composition can have a significant effect (~0.5 %) on $K_{effective}$. Proving that the

positive concrete bias for these experiments is the result of concrete composition would require a more exhaustive evaluation of the benchmark experiments or evaluation of a different set of concrete reflected experiments with similar characteristics.

Weighted single sided lower tolerance limits were calculated for different reflector types to represent $1 + \text{bias} - \text{bias uncertainty}$ for the 27- and 238-group libraries. Conservative lower tolerance limits were selected because of scatter, poor fits and the inability to explain the positive concrete reflector bias. The results of these calculations are provided in Tables 42-45. The limitations and precautions in Section 5.2.4 should be fully understood prior to using these results.

Table 42, Bare and Water Reflected LTL Calculation (27 and 238 group)

Weighted Data	27 group	238 group
One-sided Lower Tolerance Factor (U)	2.371	2.371
Average k_{eff}	1.0072	1.0021
Sqrt. of Pooled Variance (Sp)	4.320E-03	4.192E-03
Variance about the Mean (S^2)	9.113E-06	8.203E-06
Average Uncertainty (σ^2)	9.552E-06	9.368E-06
Lower Tolerance Limit	0.997	0.992

Table 43, Concrete Reflected LTL Calculation (27 and 238 group)

Weighted Data	27 group	238 group
One-sided Lower Tolerance Factor (U)	2.22	2.22
Average k_{eff}	1.0115	1.0073
Sqrt. of Pooled Variance (Sp)	4.352E-03	5.527E-03
Variance about the Mean (S^2)	8.530E-06	2.074E-05
Average Uncertainty (σ^2)	1.018E-05	9.802E-06
Lower Tolerance Limit	1.001	0.995

Table 44, Plexiglas Reflected LTL Calculation (238 group)

Weighted Data	238 group
One-sided Lower Tolerance Factor (U)	2.22
Average k_{eff}	0.9997
Sqrt. of Pooled Variance (Sp)	5.247E-03
Variance about the Mean (S^2)	1.045E-05
Average Uncertainty (σ^2)	1.708E-05
Lower Tolerance Limit	.988

Due to the majority of the reflected systems coming from a single criticality facility, and due to the inability to explain the data scatter within and between reflector systems, a subcritical margin no lower than 0.03 may be appropriate.

Table 45, Lower Tolerance Limit Results

Reflector	27-group Results	238-group Results
Bare & Water	0.9970	0.9921
Concrete	1.0019	0.9951
Plexiglas	N/A	0.9981

The 27-group plexiglas reflected data had a non-normal distribution. Because of the poor fit of the trendline to the data series, a non-parametric upper subcritical limit was calculated. With a data sample of 33, there is a 81.6% confidence that 95% of the data lies above the smallest value:

$$\beta = 1 - (0.95)^{33} = 0.816$$

The non-parametric margin for this level of confidence is 0.01. Therefore, the upper subcritical limit is:

$$K_{\text{limit}} = \text{smallest } K_{\text{eff}} \text{ value} - \text{bias uncertainty} - \text{non-parametric margin}$$

27-group:

$$= 0.9973 - \sqrt{(0.0016)^2 + (0.003)^2} - 0.01 = 0.9839$$

The upper subcritical limit for the 27-group Plexiglass reflected HEU Solutions is 0.983.

5.2.4 Limitations

There are no evaluated experiments presented with an H/U-235 ratio between 530 and 1300. Caution should be taken when using the calculated bias and bias uncertainty within this range. An attempt to expand the data points in this upper range should be undertaken prior to significant use of the developed bias in situations with H/U larger than 650 (20% extrapolation).

The material data of the experiments used in this evaluation is limited in two fashions. The experimental data is limited to a small range of uranium enrichment (~93%). The reflector materials are limited to Plexiglas, water and concrete. Further justification is necessary if other reflectors or uranium enrichments are used with the calculated bias and bias uncertainty.

The evaluated experiments in these reports have concrete and Plexiglas reflectors. Care should be used to determine the importance of concrete or Plexiglas to the system being

* See Section 5.2.4 before using the concrete reflected results

modeled. Concrete and Plexiglas compositions vary. For the concrete, water and iron content can have significant effect on calculated $K_{\text{effective}}$ values (see Reference 16). For Plexiglas, many older chemical analyses did not measure chlorine, which can also have a major effect.

As illustrated in Reference 21, using different SCALE standard concrete compositions can cause variations of up to 0.005 in $K_{\text{effective}}$. It is recommended that the bias and bias uncertainty for bare/water reflected systems be used for analysis using SCALE standard concrete compositions.

5.3 RBOF Fuels

5.3.1 Explicit MTR

This section presents the SCALE validation analysis for MTR type fuel. The results of this analysis present weighted (including statistical and experimental uncertainties) single sided lower tolerance limits (based on reflector composition) for the SCALE code system with the 27-group ENDF/B-IV and 238-group ENDF/B-V cross section libraries.

Benchmark experiments selected for validation have been previously evaluated and are documented in N-CLC-H-00155 [23].

5.3.1.1 Area of Applicability

Key areas of applicability for these experiments include:

1. Fuel:	MTR type fuel (uranium-aluminum alloy)
2. Moderation:	H/U-235 of about 140 (fully flooded fuel assembly)
3. Enrichment:	High (93.3 wt % U-235)
4. Moderating Material:	Water
5. Reflecting Material:	Water
6. Geometry	Fuel plates with interstitial water gaps arranged in lattices
7. Neutron Spectrum	Thermal; $23 < \text{AEG (27)} < 24.5$
$210 < \text{AEG (238)} < 216.5$

5.3.1.2 System Description

Twenty-three critical experiments involving lattices of SPERT-D fuel elements were performed at Oak Ridge National Laboratory (ORNL). The SPERT-D fuel element consists of a 3-inch square aluminum container 0.062 inches thick and 27.625 inches long. The container holds a maximum of 22 fuel plates; each containing an average of 13.93 g U-235. The fuel is a uranium-aluminum alloy with 23.8 wt.% uranium and the isotopic mixture contains 93.17 wt.% of U-235.

Of the twenty-three experiments, sixteen were chosen as acceptable for validation. The remaining experiments were not considered applicable because they involved cadmium sheets or $\text{UO}_2(\text{NO}_3)_2$ as a moderator. The configuration of the applicable experiments included lattice arrangements of elements with surface to surface spacing ranging from 0 to 6.37 inches.

A very detailed area of applicability is presented after the system description of the experiments used in the validation. These experiments are compared individually to the MTR fuel description.

Problems with Data

The following discrepancies are identified:

1. The SCALE 27-group input files of each model published in the report use a unit fuel assembly with a surrounding water boundary equal to half of the surface-to-surface spacing. This gap allows for easy model development of the assembly array. However, Table 4 of the report specifies a reflector thickness (water) above the fuel elements. This thickness is defined as the distance from the top of the fuel plate to the top of the reflector. Examination of the published input files show that this thickness was added to the assembly water gap, thus increasing the reflector thickness by one-half surface-to-surface spacing. The benchmark models use the reported reflector thickness and do not add this additional amount of water. This results in less reflector (although it matches the experiment description) in the benchmark models.
2. The wording of experiment four in Reference 7 is inconsistent. Section 3.2 of the referenced report states that the fuel lattice is placed in a cylinder of water with a diameter of 95.885 cm and 90.4875 cm long. The length of reflector exceeds the thickness of reflector specified in Table 4 of the report. Further interpretation leads to the conclusion that the tank had the above dimensions and the experiment had the water level thickness as specified in Table 4.

Table 46 presents the computer case numbers used for each benchmark calculation.

Table 46, Computer Modeling Case Numbers

HEU-MET-THERM-006 Experiment	27-Group Cross Section Library Case Number	238-Group Cross Section Library Case Number
1	HEUMTS01.27	HEUMTS01.238
2	HEUMTS02.27	HEUMTS02.238
3	HEUMTS03.27	HEUMTS03.238
4	HEUMTS04.27	HEUMTS04.238
5	HEUMTS05.27	HEUMTS05.238
6	HEUMTS06.27	HEUMTS06.238
7	HEUMTS07.27	HEUMTS07.238
8	HEUMTS08.27	HEUMTS08.238
9	HEUMTS09.27	HEUMTS09.238
10	HEUMTS10.27	HEUMTS10.238
11	HEUMTS11.27	HEUMTS11.238
12	HEUMTS12.27	HEUMTS12.238
13	HEUMTS13.27	HEUMTS13.238
14	HEUMTS14.27	HEUMTS14.238
15	HEUMTS15.27	HEUMTS15.238
16	HEUMTS16.27	HEUMTS16.238

Material Selection

The benchmark experiment models were modified from the original models described in Reference 7. The original input files specify material properties by individual element

constituents and atom number densities. For the bias calculations, it is desirable to use standard materials contained within the SCALE library as much as possible. Therefore, the following standard materials were used in place of the individual elements and atom number densities.

Standard Materials Used

27-Group Library

Water
Plexiglas

238-Group Library

Water
Plexiglas

5.3.1.3 Bias and Uncertainty

Statistical analysis of the results of explicitly modeling the benchmark calculations were documented in Reference 18. This section summarizes those analyses.

Independent Variables

The first step in the process is to determine if a fit can be made to an independent variable. A review of potential independent variables is summarized in Reference 18. Those evaluated were the U-235 enrichment, fissile concentration, average energy group, and moderation ratio. However, there were no independent variables that were felt to cover a significant range.

Since a good option for an independent variable was not available, the data was tested for normal distribution. If the data appears normally distributed, the bias can be determined by a single sided lower tolerance limit. Case 13 was left out of both normalcy tests, due to the questionable large value calculated. Results of the normality test showed the data to be normal. Case 13 was left in the calculation of the LTL for conservatism, however.

A lower tolerance limit of 0.978 was determined for the 238-group data.

A lower tolerance limit of 0.977 was calculated for the 27-group data.

A summary of important values used in the LTL calculations is given in Table 47.

Table 47 Explicit MTR LTL Calculation Results (27 and 238 group)

Weighted Data	27 group	238 group
One-sided Lower Tolerance Factor (U)	2.523	2.523
Average K_{eff}	1.001	1.003
Sqrt. of Pooled Variance (S_p)	9.378E-03	9.876E-03
Average Uncertainty (σ^2)	1.773E-05	1.786E-05
Variance about the Mean (S^2)	7.023E-05	7.967E-05
Lower Tolerance Limit	0.977	0.978

Since only a single set of experiments was used in this validation and the material loadings and enrichments were constant, an area of applicability margin of at least 0.03 may be appropriate for fuel types that fall within the area of applicability tables.

5.3.1.4 Limitations

The lower tolerance limits in 5.3.1.3 were developed for explicitly modeled MTR fuel, and only apply to the range of applicability specified in the Table of Applicability. Although the parameters of the benchmark experiments do not completely envelope MTR type fuel, the applicability parameters are considered sufficient for analysis of MTR type fuel in flooded conditions.

5.3.2 Homogenized MTR Type Fuel

This section presents the SCALE 4.4 validation analysis for use with homogeneously modeled MTR type fuel. The results of this analysis present a code bias (including statistical and experimental uncertainties) lower tolerance limit for the 27 group cross-section library and the 238 group cross-section library.

5.3.2.1 Area of Applicability

Key areas of applicability for this validation include:

1. Fuel:	MTR type fuel (uranium-aluminum alloy)
2. Moderation:	H/U-235 of about 140 (fully flooded fuel assembly)
3. Enrichment:	High (93.5 wt% U-235)
4. Geometry:	Fuel plates and interstitial water gaps homogenized and arranged in lattices ($24.6 < V/S < 48.3$)
5. Moderating Material:	Water
6. Neutron Spectrum:	Thermal; $23 < AEG(27) < 24.5$,
$210 < AEG(238) < 216.5$

5.3.2.2 System Descriptions

The same SPERT-D experiments described in 5.3.1.2 were utilized in this aspect of the validation as well. In this case however, they were modeled with the fuel regions homogenized. Previous analysis has shown that a full homogenization of the fuel region will result in a conservative calculation of the k_{eff} (Ref. 14). Reference 14 also demonstrates that the use of this conservative modeling scheme will enable the appropriate and conservative use of the HEU solution bias.

For the full homogenization approach, all of the aluminum structure, including all of the aluminum in each plate, the support plate, and the aluminum box, was included in a cell. This homogenized cell is the length of a fuel plate and includes the aluminum in the fuel plates and the side boxes. The SPERT-D element has an extension of water and aluminum box at the top extending for 6.35 cm. This was modeled as a separate homogenized water-aluminum region and included in the lattice model except for cases 10, 11, and 12 for which the end boxes were removed. Characteristics of the fully homogenized SPERT-D fuel are in Table 48.

Table 48 22-Plate SPERT-D Element, Including all Aluminum Structure

Dimensions	7.6098 x 7.6098 x 63.8175 (22 plates)	cm
Volume	3.696	Liters
Uranium	89	g/L
Aluminum	1454	g/L
Water	451	g/L
Mixture	1.944	g/cc
Enrichment	93.17	wt% U-235
H/F	142	
O/F	71	
(Al + O)/F	224	

5.3.2.3 Bias and Uncertainty

Computed k_{eff} values for fully homogenized SPERT assemblies and explicitly modeled SPERT assemblies are analyzed in Reference 14. The Shapiro-Wilk test was used to evaluate the normalcy of each distribution. In spite of the fact that the distributions in Reference 14 are not normal, a single-sided lower tolerance limit was calculated for each and the results are shown in Table 49. Although the distributions are not normally distributed, the computation was made to compare with the results for the uranium aqueous spheres. These tolerance limits include the bias and bias uncertainty but do not include a minimum subcritical margin (MSM).

Table 49 Reference 14 SPERT Lower Tolerance Limits

	Explicit	Full Hom.	
k_{eff}	1.0009	1.0429	Mean Weighted k_{eff}
U	2.523	2.523	One-Sided Tolerance Factor
s	0.0091	0.0154	Variance about Mean
σ	0.0042	0.0042	Average Statistical Uncertainty
S	0.0100	0.0159	Pooled Variance
LTL	0.976	1.003	Lower Tolerance Limit

The lower tolerance limit for the full homogenization is higher than that for the explicit representation by several percent.

The one-sided lower tolerance limit for the uranium aqueous spheres with the 27-group library is 0.997 and for the full homogenization is 1.003. Implicit in this comparison is the assumption that the distribution of computed k_{eff} values for the full homogenization cases can be treated as a normal distribution. These lower tolerance limits differ by less than 1%, with the uranium aqueous spheres values the lower of the two. Therefore, using the sphere data for fully homogenized SPERT-like fuels is appropriate and conservative.

The final results are lower tolerance limits of 0.997 for 27 group and 0.992 for 238 group for fully homogeneously modeled MTR fuel assemblies. These values correspond with the bare and water reflected uranium solution lower tolerance limits calculated in Section 5.2.3.

Since only a single set of experiments has been used in this validation, and the material loadings and enrichments were constant, a subcritical margin of at least 0.03 may be appropriate for fuel types which fall within the area of applicability tables for MTR fuels.

5.3.2.4 Limitations

The lower tolerance limits in 5.3.2.3 were developed for homogeneously modeled MTR fuel using the full homogenization model, and only apply to the range of applicability specified in the Table of Applicability. Although the parameters of the benchmark experiments do not completely envelope MTR type fuel, the applicability parameters are considered sufficient for analysis of MTR type fuel in flooded conditions.

The conclusion of this study of the homogenized SPERT D critical experiments is that they are bounded by the uranium aqueous spheres and that the lower tolerance limit generated for the uranium aqueous spheres is appropriate for the homogenized SPERT D fuel. It should be noted however, that the full homogenization scheme used in Reference 14 must be followed in order to use the uranium solution bias.

Use of albedos for boundary conditions and neutron weighting in reflectors has not been tested or validated in this validation.

6. Acknowledgments

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R.L. Frost	K. Kimball	S.M. Revolinski	
G.P. Kessler	S.Y. Lee	E. F. Trumble	

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APPENDIX A Validation Results and Parameters

Validation input files reside on WSMS DEC Alphas in the following directory:

/raid1/packages/crit/Validation/Scale4.x

Corresponding output files have been saved to a compact disk.

Table A.1, Parameters Used In Pu Metal Validation Calculations

Experimental Descriptor/Case Number	4V/S (cm)	σ_E	27-group Results			238-group Results		
			Keff	σ_S	Energy Gp	Keff	σ_S	Energy Gp
PU-MET-FAST-001								
1	8.5	0.002	0.9974	0.0017	4.47	0.9940	0.0016	21.44
PU-MET-FAST-002								
2	8.9	0.002	0.9994	0.0016	4.43	0.9978	0.0015	21.25
PU-MET-FAST-011								
6	5.5	0.001	0.9992	0.0010	7.43	0.9964	0.0015	50.64
PU-MET-FAST-003								
101/7	4.4	0.003	0.9920	0.0015	4.47	0.9951	0.0015	21.46
102/8	4.6	0.003	0.9939	0.0016	5.12	0.9913	0.0015	27.78
103/9	5.9	0.003	0.9890	0.0015	4.47	0.9902	0.0014	21.44
104/10	6.3	0.003	0.9936	0.0015	5.22	0.9917	0.0014	28.69
105/11	4.2	0.003	0.9877	0.0017	4.46	0.9883	0.0013	21.4
PU-MET-FAST-004								
207/12	7.0	0.003	0.9902	0.0015	4.51	0.9914	0.0013	21.86
208/13	11.5	0.003	0.9914	0.0015	4.55	0.9900	0.0014	22.27
209/14	10.9	0.003	0.9836	0.0016	4.55	0.9909	0.0015	22.26
210/15	10.6	0.003	0.9865	0.0016	4.56	0.9880	0.0014	22.35
211/16	11.3	0.003	0.9897	0.0016	4.56	0.9899	0.0015	22.27
212/17	11.4	0.003	0.9880	0.0015	4.55	0.9883	0.0015	22.26
213/18	6.9	0.003	0.9896	0.0016	4.49	0.9895	0.0013	21.55
214/19	9.5	0.003	0.9929	0.0015	4.5	0.9894	0.0015	21.7
215/20	6.9	0.003	0.9888	0.0015	4.48	0.9897	0.0014	21.46
PU-MET-FAST-017								
201/21	13.0	0.003	0.9882	0.0015	4.93	0.9905	0.0015	25.53
202/22	15.0	0.003	0.9964	0.0016	5.59	0.9892	0.0015	31.99
203/23	16.6	0.003	0.9976	0.0017	6.19	0.9933	0.0013	38.37
204/24	8.2	0.003	0.9951	0.0015	5.49	0.9902	0.0015	30.74
205/25	9.5	0.003	1.0007	0.0016	7.11	0.9993	0.0014	47.7

Table A.2, Parameters Used In Pu Solution Validation Calculations

Exp. Descriptor/ Case	4V/S (cm)	H/ Pu-239	σ_E	27 Gr. Results		238 Gr. Results	
				Keff.	σ_S	Keff.	σ_S
N-CLC-F-00060							
PU-SOL-THERM-009							
1	81.3	2650	0.0031	1.0266	0.0017	1.0189	0.0010
2	81.3	2781	0.0031	1.0321	0.0016	1.0268	0.0008
3	81.3	2805	0.0031	1.0281	0.0020	1.0219	0.0009
PU-SOL-THERM-011							
18-1/8	30.5	1209	0.0052	1.0043	0.0015	0.9997	0.0013
18-2/9	30.5	1156	0.0052	1.0075	0.0013	1.0074	0.0012
18-3/10	30.5	1101	0.0052	1.0048	0.0015	1.0015	0.0015
18-4/11	30.5	1040	0.0052	1.0143	0.0013	1.0097	0.0013
18-5/12	30.5	909	0.0052	1.0108	0.0016	1.0082	0.0013
18-6/13	30.5	1103	0.0052	1.0096	0.0015	1.0056	0.0014
PU-SOL-THERM-012							
1/14	39.3	1724	0.0043	1.0143	0.0012	1.0081	0.0011
2/15	43.2	1922	0.0043	1.0130	0.0012	1.0129	0.0011
3/16	45.9	2038	0.0058	1.0187	0.0011	1.0134	0.0011
4/17	53.6	2314	0.0058	1.0156	0.0009	1.0146	0.0010
5/18	65.6	2577	0.0058	1.0217	0.0009	1.0162	0.0009
6/19	26.1	311	0.0007	1.0191	0.0015	1.0119	0.0015
7/20	26.1	396	0.0013	1.0162	0.0016	1.0097	0.0014
8/21	27.7	634	0.0013	1.0148	0.0016	1.0111	0.0014
9/22	32.1	1056	0.0043	1.0211	0.0014	1.0183	0.0011
10/23	34.1	1254	0.0043	1.0169	0.0013	1.0105	0.0015
11/24	38.3	1569	0.0043	1.0169	0.0013	1.0137	0.0012
12/25	40.9	1724	0.0043	1.0171	0.0012	1.0139	0.0012
13/26	66.2	2576	0.0058	1.0209	0.0011	1.0150	0.0010
14/27	29.9	634	0.0013	1.0091	0.0014	1.0074	0.0013
15/28	33.9	1056	0.0043	1.0189	0.0016	1.0130	0.0013
16/29	35.8	1254	0.0043	1.0118	0.0016	1.0080	0.0014
17/30	39.9	1569	0.0043	1.0145	0.0013	1.0114	0.0010
18/31	42.4	1724	0.0043	1.0174	0.0012	1.0122	0.0013
19/32	45.9	1922	0.0043	1.0165	0.0013	1.0141	0.0011
20/33	48.4	2038	0.0058	1.0175	0.0013	1.0143	0.0011
21/34	55.9	2314	0.0058	1.0175	0.0011	1.0142	0.0009
22/35	67.2	2576	0.0058	1.0174	0.0013	1.0150	0.0010
23/36	67.4	2576	0.0058	1.0220	0.0011	1.0153	0.0009
PU-SOL-THERM-001							
1/37	19.3	371	0.0050	1.0164	0.0017	1.0132	0.0015
2/38	19.3	272	0.0050	1.0185	0.0016	1.0100	0.0015
3/39	19.3	216	0.0050	1.0196	0.0017	1.0138	0.0014
4/40	19.3	190	0.0050	1.0107	0.0018	1.0047	0.0018
5/41	19.3	180	0.0050	1.0168	0.0018	1.0117	0.0015
6/42	19.3	91.2	0.0050	1.0209	0.0017	1.0095	0.0016

**Table A.2, Parameters Used In Pu Solution Validation Calculations
(continued)**

Exp. Descriptor/ Case	4V/S (cm)	H/ Pu-239	σ_E	27 Gr. Results		238 Gr. Results	
				Keff.	σ_s	Keff.	σ_s
PU-SOL-THERM-002							
1/43	20.4	524	0.0047	1.0155	0.0015	1.0080	0.0014
2/44	20.4	504	0.0047	1.0143	0.0016	1.0094	0.0017
3/45	20.4	451	0.0047	1.0118	0.0016	1.0073	0.0017
4/46	20.4	420	0.0047	1.0151	0.0016	1.0108	0.0015
5/47	20.4	392	0.0047	1.0198	0.0016	1.0122	0.0014
6/48	20.4	344	0.0047	1.0127	0.0015	1.0058	0.0015
7/49	20.4	308	0.0047	1.0200	0.0015	1.0109	0.0015
PU-SOL-THERM-003							
1/50	22.0	788	0.0035	1.0159	0.0015	1.0074	0.0014
2/51	22.0	756	0.0035	1.0132	0.0017	1.0070	0.0014
3/52	22.0	699	0.0035	1.0149	0.0018	1.0092	0.0014
4/53	22.0	681	0.0035	1.0145	0.0015	1.0084	0.0014
5/54	22.0	626	0.0035	1.0175	0.0016	1.0076	0.0014
6/55	22.0	562	0.0035	1.0178	0.0017	1.0111	0.0014
7/81	22.0	987	0.0035	1.0167	0.0015	1.0131	0.0012
8/82	22.0	976	0.0035	1.0149	0.0015	1.0094	0.0014
PU-SOL-THERM-004							
1/56	23.7	934	0.0047	1.0137	0.0015	1.0088	0.0018
2/57	23.7	888	0.0047	1.0094	0.0014	1.0019	0.0015
3/58	23.7	942	0.0047	1.0132	0.0016	1.0058	0.0014
4/59	23.7	927	0.0047	1.0104	0.0016	1.0030	0.0014
5/60	23.7	892	0.0047	1.0101	0.0015	1.0042	0.0014
6/61	23.7	869	0.0047	1.0118	0.0015	1.0056	0.0012
7/62	23.7	804	0.0047	1.0144	0.0015	1.0102	0.0016
8/63	23.7	688	0.0047	1.0136	0.0015	1.0067	0.0012
9/64	23.7	590	0.0047	1.0116	0.0014	1.0001	0.0015
10/65	23.7	892	0.0047	1.0138	0.0016	1.0068	0.0014
11/66	23.7	903	0.0047	1.0103	0.0018	1.0037	0.0014
12/67	23.7	903	0.0047	1.0130	0.0015	1.0080	0.0013
13/68	23.7	868	0.0047	1.0116	0.0015	1.0052	0.0014
PU-SOL-THERM-005							
1/69	23.7	834	0.0047	1.0126	0.0015	1.0069	0.0013
2/70	23.7	764	0.0047	1.0138	0.0016	1.0085	0.0014
3/71	23.7	693	0.0047	1.0116	0.0015	1.0070	0.0015
4/72	23.7	632	0.0047	1.0167	0.0015	1.0105	0.0015
5/73	23.7	600	0.0047	1.0191	0.0015	1.0110	0.0012
6/74	23.7	868	0.0047	1.0187	0.0016	1.0093	0.0014
7/75	23.7	825	0.0047	1.0143	0.0016	1.0072	0.0014
8/76	23.7	1061	0.0047	1.0088	0.0016	1.0022	0.0012
9/77	23.7	1017	0.0047	1.0128	0.0015	1.0085	0.0013
PU-SOL-THERM-006							
1/78	25.4	939	0.0035	1.0101	0.0015	1.0056	0.0014
2/79	25.4	738	0.0035	1.0118	0.0015	1.0072	0.0014
3/80	25.4	714	0.0035	1.0113	0.0014	1.0059	0.0015

Table A.3, Parameters Used In Uranium Metal Validation Calculations

Experimental Descriptor/Case Number	4V/S (cm)	σ_E	27-group Results			238-group Results		
			Keff	σ_S	Energy Gp	Keff	σ_S	Energy Gp
HEU-MET-FAST-001								
1	11.7	0.001	1.0057	0.0012	4.85	0.9975	0.0012	24.39
2		0.001	1.0040	0.0011	4.86	0.9971	0.0014	24.41
HEU-MET-FAST-002								
3	8.1	0.003	1.0036	0.0014	4.88	1.0021	0.0013	25.32
4	7.1	0.003	1.0084	0.0013	4.89	1.0029	0.0012	25.49
5	6.8	0.003	1.0047	0.0014	4.90	1.0026	0.0015	25.56
6	6.4	0.003	1.0034	0.0014	4.91	0.9996	0.0014	25.66
7	6.4	0.003	1.0055	0.0014	4.91	1.0009	0.0013	25.76
8	6.5	0.003	1.0076	0.0014	4.90	1.0016	0.0013	25.67
HEU-MET-FAST-003								
9	9	0.005	0.9997	0.0012	4.87	0.9931	0.0013	24.83
10	8.6	0.005	0.9998	0.0012	4.87	0.9931	0.0012	24.93
11	8.4	0.005	1.0033	0.0012	4.87	0.9978	0.0012	25.01
12	8.2	0.003	1.0026	0.0012	4.86	0.9962	0.0013	25.09
13	8.1	0.003	1.0056	0.0013	4.87	0.9994	0.0013	25.25
14	8.1	0.003	1.0036	0.0014	4.88	1.0021	0.0013	25.32
15	8	0.003	1.0067	0.0014	4.89	1.0037	0.0015	25.51
16	8.8	0.005	1.0037	0.0012	5.20	1.0055	0.0014	27.24
17	8.3	0.005	1.0012	0.0011	5.30	1.0047	0.0011	28.14
18	8.1	0.005	1.0027	0.0011	5.37	1.0096	0.0013	28.89
19	8	0.005	1.0066	0.0011	5.40	1.0121	0.0012	29.13
20		.005	1.0498	0.0011	5.26	1.0200	0.0013	26.82
HEU-MET-FAST-004								
22	8.7	0.002	1.0015	0.0013	8.50	0.9928	0.0013	60.98
HEU-MET-FAST-007								
23	10.3	0.001	1.0014	0.0012	4.84	0.9956	0.0011	24.27
24	10.9	0.001	1.0057	0.0014	5.39	0.9940	0.0015	28.75
25	11	0.001	1.0057	0.0014	5.63	0.9926	0.0013	30.95
26	11.1	0.001	1.0084	0.0014	5.73	0.9906	0.0017	31.78
27	11.3	0.001	1.0059	0.0014	5.96	0.9905	0.0013	33.81
28	11.4	0.001	1.0091	0.0016	6.40	0.9964	0.0013	38.47
29	11.4	0.001	1.0076	0.0013	6.17	0.9930	0.0013	35.93
30	11.4	0.001	1.0068	0.0014	6.14	0.9916	0.0014	35.50
31	11.5	0.001	1.0066	0.0016	6.27	0.9939	0.0014	37.07
32	12.2	0.001	1.0094	0.0014	8.08	0.9902	0.0012	55.92
33	12.8	0.001	1.0173	0.0016	9.66	0.9898	0.0014	72.72
34	12.9	0.001	1.0147	0.0016	9.99	0.9921	0.0014	76.54
35	12.8	0.001	1.0116	0.0013	10.66	0.9919	0.0013	83.58
36	12.9	0.001	1.0138	0.0014	10.06	0.9916	0.0016	77.59
37	12.7	0.001	1.0101	0.0013	10.54	0.9900	0.0016	82.20
38	12.7	0.001	1.0082	0.0017	10.57	0.9885	0.0015	82.45
39	13.4	0.001	1.0181	0.0014	12.84	0.9948	0.0014	106.74
40	13.5	0.001	1.0172	0.0015	12.88	0.9960	0.0014	107.64
41	10	0.001	1.0040	0.0014	4.84	0.9959	0.0013	24.34
42	11	0.001	1.0036	0.0016	6.13	0.9937	0.0013	35.80

**Table A.3, Parameters Used In Uranium Metal Validation Calculations
(continued)**

Experimental Descriptor/Case Number	4V/S (cm)	σ_E	27-group Results			238-group Results		
			Keff	σ_S	Energy Gp	Keff	σ_S	Energy Gp
HEU-MET-FAST-007								
43	11.1	0.001	1.0056	0.0012	6.20	0.9925	0.0013	36.62
44	11.1	0.001	1.0056	0.0013	6.29	0.9911	0.0015	37.34
45	11.5	0.001	1.0051	0.0015	7.37	0.9907	0.0013	48.70
46	11.5	0.001	1.0085	0.0013	7.45	0.9900	0.0013	49.43
47	11.9	0.001	1.0099	0.0013	8.23	0.9899	0.0015	57.44
48	11.9	0.001	1.0069	0.0016	8.31	0.9930	0.0012	58.30
49	11.3	0.001	1.0074	0.0012	5.44	0.9959	0.0012	29.21
50	11.8	0.001	1.0048	0.0015	5.88	0.9902	0.0011	33.26
51	12.3	0.001	1.0098	0.0013	6.36	0.9942	0.0014	37.67
52	13.5	0.001	1.0106	0.0016	8.53	0.9889	0.0015	60.63
53	15	0.001	1.0175	0.0015	11.05	0.9973	0.0015	87.81
54	12.3	0.001	1.0107	0.0014	5.01	1.0012	0.0014	25.44
55	13.6	0.001	1.0139	0.0014	5.12	1.0058	0.0013	26.23
56	14.8	0.001	1.0166	0.0014	5.23	1.0096	0.0014	27.00
57	6.6	0.001	0.9995	0.0013	10.01	0.9835	0.0014	74.36
58	7.2	0.001	1.0140	0.0015	10.62	0.9915	0.0014	80.72
59	7.7	0.001	1.0047	0.0013	11.19	0.9918	0.0014	87.33
60	7.9	0.001	1.0157	0.0013	11.35	0.9909	0.0013	88.28
61	7.9	0.001	1.0150	0.0012	11.37	0.9910	0.0013	88.46
62	7.8	0.001	1.0163	0.0013	11.36	0.9915	0.0014	88.37
63	8.6	0.001	1.0189	0.0012	13.14	0.9917	0.0015	107.87
64	8.6	0.001	1.0191	0.0015	13.20	0.9887	0.0013	108.87
65	9.4	0.001	1.0335	0.0014	15.82	0.9999	0.0014	137.21
HEU-MET-FAST-012								
96		0.002	1.0088	0.0008	4.92	0.9987	0.0009	24.87
HEU-MET-FAST-013								
97		0.002	1.0161	0.0010	4.99	0.9946	0.0008	25.10
HEU-MET-FAST-021								
98		0.002	1.0361	0.0008	5.10	0.9993	0.0008	25.61
HEU-MET-FAST-022								
99		0.002	0.9967	0.0009	4.94	0.9898	0.0009	25.05
HEU-MET-FAST-024								
100		0.002	1.0052	0.0008	7.56	0.9923	0.0008	51.73
HEU-MET-FAST-033								
101		0.001	1.0120	0.0011	8.63	0.9917	0.0009	61.94
102		0.001	1.0102	0.0010	10.93	0.9911	0.0010	86.69
HEU-MET-FAST-034								
103		0.001	1.0043	0.0010	8.64	0.9917	0.0011	63.37
104		0.001	1.0053	0.0009	8.74	0.9900	0.0008	63.34
105		0.001	1.0081	0.0011	8.88	0.9920	0.0010	64.67
HEU-MET-FAST-035								
106		0.001	1.0077	0.0008	10.96	0.9960	0.0009	87.64
HEU-MET-FAST-023								
tn02	11.3	0.0052	1.0034	0.0018	5.43	0.9933	0.0013	29.79
tn03	12.6	0.0052	1.0119	0.0016	8.36	1.0005	0.0013	59.52

tn04	13.7	0.0052	1.0127	0.0018	10.11	1.0050	0.0013	76.8900
tn05	13.9	0.0052	1.0108	0.0014	10.26	1.0002	0.0012	79.1700
tn06	19.7	0.0052	0.9989	0.0016	4.86	0.9938	0.0013	24.6200
tn07	21.2	0.0052	0.9989	0.0014	5.46	0.9891	0.0013	30.1200
tn08	25.3	0.0052	1.0067	0.0015	8.67	1.0005	0.0013	62.8300
tn09	28.7	0.0052	1.0084	0.0015	10.50	0.9987	0.0013	81.1700
tn10	29.3	0.0052	1.0038	0.0018	10.77	0.9980	0.0011	83.5000
tn12	12.3	0.0052	1.0023	0.0016	5.42	0.9933	0.0013	29.6100
tn13	13.5	0.0052	1.0189	0.0016	8.30	1.0072	0.0013	58.9000
tn14	14.6	0.0052	1.0117	0.0018	10.01	1.0034	0.0012	76.2000
tn15	14.8	0.0052	1.0107	0.0016	10.23	1.0049	0.0013	78.5000
tn16	21.2	0.0052	1.0055	0.0017	4.87	1.0000	0.0012	24.6100
tn17	22.5	0.0052	1.0031	0.0015	5.45	0.9954	0.0012	29.9900
tn18	26.7	0.0052	1.0094	0.0017	8.64	0.9988	0.0013	62.0800
tn19	29.9	0.0052	1.0078	0.0018	10.40	1.0002	0.0013	80.0600
tn20	30.5	0.0052	1.0036	0.0016	10.63	0.9987	0.0012	82.4300
tn21	31	0.0057	1.0025	0.0019	4.91	0.9906	0.0013	25.1100
tn22	48.6	0.0052	1.0040	0.0015	10.86	0.9975	0.0014	84.6300
tn28	18.7	0.0052	1.0023	0.0017	4.86	0.9952	0.0013	24.5000
tn29	27.4	0.0052	1.0034	0.0016	4.89	0.9937	0.0012	24.8300

Table A.4, Parameters Used In Uranium Solution Validation Calculations

Exp. Descriptor/ Case	4V/S (cm)	H/ U-235	σ_E	27-group Results			238-group Results		
				Energy	Keff.	σ_S	Energy	Keff.	σ_S
SRT-EMS-96-0015									
HEU-SOL-THERM-001									
1/1	19.3	182	0.0025	23.58	1.0069	0.0018	210.19	1.0013	0.0018
2/2	18.8	71	0.0025	21.69	1.0050	0.0019	195.15	1.0005	0.0017
3/3	19.8	186	0.0025	23.61	1.0106	0.0018	210.4	1.0039	0.0017
4/4	19.2	68	0.0025	21.59	1.0087	0.0018	194.3	1.0009	0.0019
5/5	23.2	499	0.0025	24.57	1.0048	0.0018	217.53	1.0008	0.0014
6/6	22.8	459	0.0025	24.52	1.0113	0.0014	217.14	1.0041	0.0018
7/7	19.6	193	0.0025	23.66	1.0074	0.0018	210.81	1.0013	0.0019
8/8	19.6	182	0.0025	23.57	1.0043	0.0019	210.13	0.9990	0.0020
9/9	18.6	68	0.0025	21.58	1.0043	0.0019	194.25	0.9969	0.0018
10/10	22.6	427	0.0025	24.46	0.9993	0.0017	216.75	0.9946	0.0017
HEU-SOL-THERM-002									
1/11	19	184	0.0020	23.61	1.0102	0.0019	210.47	1.0053	0.0017
2/12	17.8	184	0.0020	23.62	1.0128	0.0016	210.56	1.0075	0.0018
3/13	18.5	74	0.0020	21.85	1.0100	0.0018	196.42	0.9986	0.0019
4/14	17	74	0.0020	21.89	1.0122	0.0019	196.91	1.0070	0.0017
5/15	19.4	184	0.0020	23.62	1.0102	0.0016	210.49	1.0061	0.0017
6/16	17.8	184	0.0020	23.65	1.0086	0.0019	210.71	1.0119	0.0018
7/17	18.8	74	0.0020	21.86	1.0116	0.0020	196.56	1.0045	0.0019
8/18	17.2	74	0.0020	21.94	1.0133	0.0018	197.17	1.0060	0.0016
9/19	22.2	460	0.0020	24.52	1.0063	0.0016	217.2	1.0021	0.0017
10/20	20.6	459	0.0020	24.53	1.0113	0.0016	217.26	1.0104	0.0016
11/21	19.2	184	0.0020	23.62	1.0096	0.0020	210.5	1.0040	0.0018
12/22	17.3	184	0.0020	23.66	1.0154	0.0020	210.78	1.0074	0.0016
13/23	18.6	74	0.0020	21.87	1.0081	0.0018	196.52	0.9981	0.0016
14/24	16.6	74	0.0020	21.96	1.0149	0.0015	197.44	1.0109	0.0016
HEU-SOL-THERM-003									
1/25	21.9	454	0.0050	24.53	1.0075	0.0016	217.25	1.0036	0.0016
2/26	23.2	454	0.0050	24.52	1.0074	0.0019	217.19	1.0060	0.0018
3/27	19	180	0.0050	23.59	1.0085	0.0017	210.26	1.0021	0.0015
4/28	18	180	0.0050	23.63	1.0087	0.0019	210.58	1.0015	0.0016
5/29	18.6	71	0.0050	21.78	1.0074	0.0018	195.81	0.9969	0.0015
6/30	17.4	71	0.0050	21.89	1.0081	0.0017	196.82	0.9966	0.0016
7/31	22	454	0.0050	24.54	1.0067	0.0017	217.36	1.0063	0.0014
8/32	16.9	180	0.0050	23.6	1.0090	0.0018	210.31	1.0024	0.0016
9/33	18	180	0.0050	23.66	1.0078	0.0016	210.88	1.0071	0.0015
10/34	18.8	71	0.0050	21.8	1.0088	0.0020	195.98	1.0000	0.0018
11/35	17.4	71	0.0050	21.96	1.0065	0.0018	197.52	1.0026	0.0017
12/36	22.3	454	0.0050	24.52	1.0061	0.0016	217.19	1.0035	0.0016
13/37	20.6	454	0.0050	24.55	1.0071	0.0013	217.39	1.0036	0.0016
14/38	21.7	454	0.0050	24.53	1.0055	0.0016	217.25	1.0060	0.0014
15/39	19.9	412	0.0050	24.48	1.0012	0.0017	216.92	0.9947	0.0016

**Table A.4, Parameters Used In Uranium Solution Validation Calculations
(continued)**

Exp. Descriptor/ Case	4V/S (cm)	H/ U-235	σ_E	27-group Results			238-group Results		
				Energy	Keff.	σ_S	Energy	Keff.	σ_S
HEU-SOL-THERM-003									
16/40	19.2	180	0.0050	23.6	1.0065	0.0017	210.33	0.9972	0.0016
17/41	17.4	180	0.0050	23.68	1.0065	0.0017	211.04	1.0048	0.0016
18/42	18.8	71	0.0050	21.8	1.0074	0.0020	195.98	0.9970	0.0020
19/43	16.8	71	0.0050	22.02	1.0075	0.0016	197.85	1.0015	0.0016
HEU-SOL-THERM-007									
1/44	19.9	454	0.0035	24.42	1.0129	0.0017	216.49	1.0132	0.0015
2/45	16.2	69	0.0050	21.74	1.0164	0.0016	195.58	1.0151	0.0015
3/46	19.5	454	0.0035	24.46	1.0145	0.0017	216.76	1.0145	0.0014
4/47	16.1	69	0.0035	21.93	1.0159	0.0014	197.03	1.0127	0.0014
5/48	24.4	454	0.0035	24.33	1.0080	0.0015	215.79	1.0078	0.0015
6/49	20.1	69	0.0035	21.7	1.0095	0.0019	195.28	1.0052	0.0016
7/50	24.5	454	0.0035	24.35	1.0105	0.0017	215.92	1.0069	0.0014
8/51	20.4	69	0.0035	21.73	1.0097	0.0020	195.48	1.0023	0.0016
9/52	24.1	454	0.0035	24.3	1.0078	0.0019	215.57	1.0061	0.0014
10/53	24.1	69	0.0035	24.25	1.0147	0.0019	215.23	1.0162	0.0012
11/54	20.7	454	0.0035	21.81	1.0088	0.0015	196.18	1.0096	0.0016
12/55	23.5	69	0.0035	24.3	1.0169	0.0015	215.62	1.0153	0.0014
13/56	20.6	69	0.0035	21.97	1.0161	0.0018	197.37	1.0122	0.0016
14/57	23.5	69	0.0035	21.92	1.0139	0.0017	196.97	1.0080	0.0016
15/58	24.7	406	0.0035	21.9	1.0083	0.0017	196.88	1.0089	0.0016
16/59	26.5	65	0.0035	21.81	1.0116	0.0019	196.21	1.0106	0.0017
17/60	26.6	406	0.0035	21.91	1.0168	0.0017	196.94	1.0104	0.0015
HEU-SOL-THERM-008									
1/61	21.2	67	0.0030	24.51	0.9982	0.0015	217.17	0.9999	0.0018
2/62	17	358	0.0030	21.95	1.0033	0.0021	197.3	0.9995	0.0017
3/63	20.6	67	0.0030	24.56	0.9973	0.0016	217.5	0.9971	0.0012
4/64	16.8	358	0.0030	22.13	1.0016	0.0018	198.7	0.9956	0.0015
5/65	26.8	67	0.0030	24.52	1.0008	0.0015	217.21	1.0009	0.0013
6/66	20.6	337	0.0030	21.81	1.0062	0.0019	196.22	1.0009	0.0016
7/67	26.5	325	0.0030	24.55	1.0002	0.0016	217.4	0.9989	0.0015
8/68	20.9	67	0.0030	21.89	1.0066	0.0021	196.77	0.9998	0.0015
9/69	26.6	325	0.0030	24.53	1.0003	0.0015	217.26	1.0021	0.0012
10/70	21.8	68	0.0030	21.96	1.0036	0.0017	197.39	0.9959	0.0014
11/71	25.5	68	0.0030	24.58	1.0018	0.0015	217.67	1.0000	0.0013
12/72	21.3	68	0.0030	22.17	1.0004	0.0016	199.05	0.9959	0.0015
13/73	26.3	68	0.0030	21.98	1.0041	0.0016	197.45	0.9963	0.0017
14/74	26	68	0.0030	22.13	1.0033	0.0017	198.65	0.9967	0.0018

**Table A.4, Parameters Used In Uranium Solution Validation Calculations
(continued)**

Exp. Descriptor/Case	4V/S (cm)	H/U-235	σ_E	27-group Results			238-group Results		
				Energy	Keff.	σ_S	Energy	Keff.	σ_S
HEU-SOL-THERM-009									
UO₂F₂ Experiments									
1/75	15.3	36	0.0057	20.72	1.0126	0.0015	186.69	1.0028	0.0019
2a/76	15.3	47	0.0057	21.47	1.0091	0.0019	193.23	1.0056	0.0016
3/78	15.3	76	0.0057	22.55	1.0105	0.0015	202.19	1.0035	0.0019
4/79	15.3	126	0.0057	23.42	1.0059	0.0015	209.04	0.9967	0.0016
HEU-SOL-THERM-011									
1/80	21.3	523	0.0019	24.69	1.0104	0.0016	218.43	1.0057	0.0017
2/81	21.3	533	0.0019	24.7	1.0066	0.0015	218.5	1.0043	0.0013
HEU-SOL-THERM-012									
1/82	37.2	1272	0.0058	24.99	0.9992	0.0013	220.6	1.0039	0.0014
HEU-SOL-THERM-010									
1/83	17.6	270	0.0018	24.26	1.0075	0.0018	215.37	1.0047	0.0016
2/84	17.6	264	0.0018	24.25	1.0096	0.0017	215.23	1.0037	0.0015
3/85	17.6	246	0.0018	24.18	1.0064	0.0017	214.79	1.0028	0.0017
4/86	17.6	239	0.0018	24.16	1.0082	0.0015	214.59	1.0017	0.0016

Table A.5, Parameters Used In MTR Type Fuel Validation Calculations

Exp. Descriptor/Case	4V/S (cm)	H/U-235	σ_E	27-group Results			238-group Results		
				Energy	Keff.	σ_S	Energy	Keff.	σ_S
HEU-MET-THERM-006									
1	24.58	140	0.0040	23.53	0.9961	0.0012	210.04	1.0017	0.0015
2	25.80	140	0.0040	23.84	0.9997	0.0014	212.31	1.0014	0.0015
3	27.00	140	0.0040	24.02	1.0041	0.0013	213.67	1.0073	0.0013
4	27.00	140	0.0040	24.05	0.9941	0.0013	213.97	0.9935	0.0014
5	28.17	140	0.0040	24.14	0.9992	0.0014	214.70	1.0023	0.0015
6	29.32	140	0.0040	24.22	1.0008	0.0012	215.29	1.0009	0.0012
7	36.31	140	0.0040	24.27	0.9962	0.0014	215.71	0.9997	0.0014
8	42.94	140	0.0040	24.32	0.9930	0.0012	216.14	0.9964	0.0015
9	48.28	140	0.0040	24.33	0.9982	0.0013	216.21	0.9987	0.0013
10	28.39	140	0.0040	23.59	1.0053	0.0014	210.39	1.0077	0.0014
11	27.26	140	0.0040	24.03	1.0047	0.0016	213.91	1.0068	0.0012
12	36.50	140	0.0040	24.26	1.0059	0.0014	215.67	1.0085	0.0013
13	29.55	140	0.0040	23.58	1.0268	0.0012	210.33	1.0315	0.0015
14	38.30	140	0.0040	24.18	0.9948	0.0013	215.08	0.9969	0.0014
15	46.74	140	0.0040	24.2	0.9927	0.0012	215.13	0.9936	0.0014
16	46.39	140	0.0040	24.01	1.0070	0.0013	213.76	1.0071	0.0013

The 4 V/S parameter for arrays was calculated as though the individual parts of the array composed a rectangular solid. A 3 x 3 x 3 array of cylinders is therefore represented by a cube composed of 27 cylinders, with appropriate spacing taken into consideration to preserve geometry.

For all subcritical experiments, Appendix A presents the normalized values for Keff.

Appendix B Tally Information by Benchmark Experiment (238 group)

Benchmark Experiment	GEN/NPG/NSK
PU-MET-FAST-001	700/700/100
PU-MET-FAST-002	1000/500/100
PU-MET-FAST-011	1200/450/120
PU-MET-FAST-003	1200/450/120
PU-MET-FAST-004	1300/400/130
PU-MET-FAST-017	1100/500/100
PU-SOL-THERM-009	1100/500/100
PU-SOL-THERM-011	1100/500/100
PU-SOL-THERM-012	1100/500/100
PU-SOL-THERM-001	1100/500/100
PU-SOL-THERM-002	1100/500/100
PU-SOL-THERM-003	1100/500/100
PU-SOL-THERM-004	1100/500/100
PU-SOL-THERM-005	1100/500/100
PU-SOL-THERM-006	1100/500/100
HEU-MET-FAST-001	650/800/50
HEU-MET-FAST-002	650/800/50
HEU-MET-FAST-003	650/800/50
HEU-MET-FAST-004	650/800/50
HEU-MET-FAST-007	650/800/50
HEU-MET-FAST-012	1100/1000/100
HEU-MET-FAST-013	1000/1000/100
HEU-MET-FAST-021	1100/1000/100
HEU-MET-FAST-022	1100/1000/100
HEU-MET-FAST-024	1100/1000/100
HEU-MET-FAST-033	1100/1000/100
HEU-MET-FAST-034	1100/1000/100
HEU-MET-FAST-035	1100/1000/100
HEU-MET-FAST-023	650/750/50
HEU-SOL-THERM-001	1000/500/100
HEU-SOL-THERM-002	1100/500/100
HEU-SOL-THERM-003	1100/500/100
HEU-SOL-THERM-007	1100/500/100
HEU-SOL-THERM-008	1100/500/100
HEU-SOL-THERM-009	800/600/100
HEU-SOL-THERM-011	800/600/100
HEU-SOL-THERM-012	800/600/100
HEU-SOL-THERM-010	800/600/100

Appendix C. Sample Input Files

B.1 Plutonium metal input files

Table A.1 Case 1

```
#csas25
pu_m_001
27groupndf4          infhommedium
arbmpu_m_001 15.596 2 1 0 1 94000 99.07 29000 .93 1 1.0 293 94239 95.18
94240 4.52 94241 .3 end
end comp
pu_metal godiva
read parm gen=700 npg=700 nsk=100 run=yes plt=yes nub=yes tme=200 end parm
read geom
unit 1
com=!pu_metal!
sphere 1 1 6.3849
end geom
end data
end
```

Table A.1 Case 2

```
#csas25
pu_m_002
27groupndf4          infhommedium
arbmpu_metal 15.716 2 1 0 1 94000 99.08 29000 .92 1 1.0 293 94239 76.3122
94240 20.1609 94241 3.1223 94242 .4046 end
end comp
pu_metal_002
read parm gen=1000 npg=500 nsk=100 run=yes plt=yes nub=yes end parm
read geom
unit 1
com=!pu_metal!
sphere 1 1 6.6595
end geom
end data
end
```

Table A.1 Case 11

```
#csas25
pu_m_011
27groupndf4          infhommedium
h2o 2 1.0 293 end
arbm_pu 19.74 1 1 0 1 94000 100 1 1.0 293 94239 94.4769
94240 5.2004 94241 0.3024 94242 0.0203 end
end comp
pu_m_011
read parm gen=1100 npg=500 nsk=100 run=yes plt=yes nub=yes tme=200 end parm
read geom
unit 1
com=!pu_m_011!
sphere 1 1 4.1217
sphere 2 1 29.5217
end geom
end data
```

end

Table A.1 Case 7

#csas25

unmoderated pu metal button array/pu-met-fast-003/j. justice/3-96

27groupndf4 latticecell

al 2 den=2.70 .609727145 293 end

al 3 den=2.70 .489740449 293 end

al 4 den=2.70 .500124454 293 end

fe 5 den=7.8012 1.0 293 end

fe 6 den=7.8012 .07 293 end

al 8 den=2.70 .88 293 end

al 9 den=2.70 1.0 293 end

arbmput 19.522 4 0 0 1 94242 .01 94240 5.96973 94239 93.5562 94241 .459975 1
1.0 293 end

arbmhomoshoe 2.03348638 2 0 0 1 26000 35.5312 13027 64.469 7 1.0 293 end

end comp

squarepitch 7.3 6.525 1 0 6.599 2 end

more data res=1 cylinder 3.2625 dan(1)=.57 end

case 101/pu-met-fast-003/j. justice/3-96

read parm tme=120 gen=1 100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm

read geom

unit 1

com=!single plutonium part in can!

zcylinder 1 1 3.2625 4.633 0

zcylinder 9 1 3.2995 4.72 0

zcylinder 5 1 3.2995 4.72 -.021

zcylinder 2 1 3.2995 5.199 -.021

zcylinder 0 1 3.425 5.199 -.021

zcylinder 9 1 3.609 5.199 -.021

cuboid 0 1 3.609 -3.609 3.609 -3.609 5.199 -.021

unit 2

com=!spacer!

zcylinder 0 1 3.104 .18 0

zcylinder 9 1 3.326 .18 0

zcylinder 0 1 3.425 .18 0

zcylinder 9 1 3.609 .18 0

cuboid 0 1 3.609 -3.609 3.609 -3.609 .18 0

unit 3

com=!z stack!

array 1 -3.609 -3.609 0

replicate 0 1 .041 .041 .041 .041 0 0 1

global unit 4

com=!xy planar array!

array 2 -7.3 -7.3 0

cuboid 0 1 23 -23 66 -66 45.734 0

cuboid 8 1 23 -23 66 -66 45.734 -2.54

cuboid 6 1 23 -23 66 -66 45.734 -32.54

unit 5

com=!homogenized shoe!

zcylinder 7 1 3.425 8.3 0

zcylinder 9 1 3.609 8.3 0

cuboid 0 1 3.609 -3.609 3.609 -3.609 8.3 0

unit 6

com=!lower support tube!

zcylinder 0 1 3.104 6.229 0

```

zcylinder 9 1 3.326 6.229 0
zcylinder 0 1 3.425 6.229 0
zcylinder 9 1 3.609 6.229 0
cuboid 0 1 3.609 -3.609 3.609 -3.609 6.229 0
unit 7
com=!upper support tube!
zcylinder 0 1 3.425 19.95 0
zcylinder 9 1 3.609 19.95 0
cuboid 0 1 3.609 -3.609 3.609 -3.609 19.95 0
unit 8
com=!lower heat sink (top of can)!
zcylinder 4 1 3.2995 .635 0
zcylinder 0 1 3.425 .635 0
zcylinder 9 1 3.609 .635 0
cuboid 0 1 3.609 -3.609 3.609 -3.609 .635 0
end geom
read array
ara=1 nux=1 nuy=1 nuz=7
com=!z stack!
fill 5 6 8 1 2 1 7 end fill
ara=2 nux=2 nuy=2 nuz=1
com=!array of units!
fill 3 3 3 3 end fill
end array
read plot
ttl=!plan view of experiment!
plt=yes pic=mixture xul=-10 yul=10 zul=15.2 xlr=10 ylr=-10 zlr=15.2 uax=1
vax=0 wax=0 udn=0 vdn=-1 wdn=0 nax=80
nch=!0123456789 ! end
end plot
end data
end

```

Table A.1 Case 12

#csas25

unmod pu met cyl array-phase ii/pu-met-fast-004/j. justice/3-96

27groupndf4 latticecell

arbmpu 19.53 9 0 0 1 94239 93.5178 94240 5.96728 94241 .4597868 94242 .00999554

6012 .018 20000 .01 26000 .0035 12000 .002 28000 .005 1 1.0 293 end

arbmsupporttube 2.719494 7 0 0 1 24000 .1 29000 4.35 26000

.5 12000 1.5 25055 .6 14000 .5 13027 92.2

2 1.0 293 end

arbmcanlid 7.9 6 0 0 1 6012 .08 25055 .37 15031 .015 16000 .025 14000 .01

26000 99.2 3 1.0 293 end

arbmhomoshoe 5.72772021 8 0 0 1 29000 46.9803 29000 29.8028 26000 17.6578

13027 2.50439 24000 .898374 14000 .176601 6012 .072878 42000

.232064 4 1.0 293 end

arbmboatsprhsink 2.70 8 0 0 1 24000 .2 29000 .25 26000 .7 12000 1 25055 .15

14000 .6 13027 96.7 22000 .15 5 1.0 293 end

arbmtopsink 2.074133315 8 0 0 1 24000 .2 29000 .25 26000 .7 12000 1 25055

.15 14000 .6 22000 .15 13027 96.7 6 1.0 293 end

arbmtabletop 2.84 7 0 0 1 29000 6.3 26000 .3 12000 .02 25055 .3 14000 .2

22000 .06 13027 92.75 7 .881 293 end

arbmalfame 2.7 8 0 0 1 24000 .2 29000 .25 26000 .7 12000 1 25055 .15 14000

.6 22000 .15 13027 96.7 8 .296 293 end

```
arbmibeamupbeam 2.77 7 0 0 1 24000 .1 29000 4.35 26000 .5 12000 1.5 25055 .6
14000 .5 13027 92.2 10 1.0 293 end
arbmpucan 2.72 6 0 0 1 29000 .25 26000 .7 12000 1.05 25055 1.25 14000 .3
13027 96.2 11 1.0 293 end
arbmconcrete 2.343257 9 0 0 1 13027 1.40535 6012 3.24667 20000 32.9114 26000
.778856 1001 1.06195 12000 1.01103 11023 .495269 8016 47.0742 14000 12.0153
9 1.0 293 end
end comp
squarepitch 12.51 6.525 1 0 6.599 11 end
more data res=1 cylinder 3.2625 dan(1)=.66 end
case 207/pu-met-fast-004/jjustice/3-96
read parm tme=120 gen=1100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm
read geom
unit 1
com=!pu in can!
zcylinder 1 1 3.2625 4.633 0
zcylinder 11 1 3.2995 4.72 0
zcylinder 3 1 3.2995 4.72 -.021
zcylinder 0 1 3.429 4.72 -.021
zcylinder 2 1 3.607 4.72 -.021
cuboid 0 1 6.255 -6.255 6.255 -6.255 4.72 -.021
unit 2
com=!bottom heat sink and gap!
zcylinder 5 1 3.2995 0 -.30408
zcylinder 0 1 3.429 0 -.635
zcylinder 2 1 3.607 0 -.635
cuboid 0 1 6.255 -6.255 6.255 -6.255 0 -.635
unit 3
com=!top heat sink!
zcylinder 0 1 1.4986 .479 0
zcylinder 6 1 3.2995 .479 0
zcylinder 0 1 3.429 .479 0
zcylinder 2 1 3.607 .479 0
cuboid 0 1 6.255 -6.255 6.255 -6.255 .479 0
unit 4
com=!lower shoe!
zcylinder 4 1 3.607 4.922 0
cuboid 0 1 6.255 -6.255 6.255 -6.255 4.922 0
unit 5
com=!lower support tube!
zcylinder 0 1 2.8672 20.161 0
zcylinder 2 1 3.607 20.161 0
cuboid 0 1 6.255 -6.255 6.255 -6.255 20.161 0
unit 6
com=!bottom spacer!
zcylinder 0 1 3.123 78.1995 0
zcylinder 5 1 3.3338 78.1995 0
zcylinder 0 1 3.429 78.1995 0
zcylinder 2 1 3.607 78.1995 0
cuboid 0 1 6.255 -6.255 6.255 -6.255 78.1995 0
unit 7
com=!inner spacer!
zcylinder 0 1 3.123 2.005 0
zcylinder 5 1 3.3338 2.005 0
zcylinder 0 1 3.429 2.005 0
zcylinder 2 1 3.607 2.005 0
```

```
cuboid 0 1 6.255 -6.255 6.255 -6.255 2.005 0
unit 8
com=!upper support tube and upper shoe void!
zcylinder 0 1 3.429 75.6965 0
zcylinder 2 1 3.607 75.6965 0
cuboid 0 1 6.255 -6.255 6.255 -6.255 83.6345 0
unit 9
com=!upper support beam - unit cell!
cuboid 0 1 4.3435 -4.3435 6.255 -6.255 1.8035 -1.8035
cuboid 10 1 5.08 -5.08 6.255 -6.255 2.54 -2.54
cuboid 0 1 6.255 -6.255 6.255 -6.255 2.54 -2.54
unit 10
com=!z stack of units!
array 1 0 0 0
unit 11
com=!xy array!
array 2 -25.02 -25.02 0
cuboid 0 1 106.5 -106.5 96.34 -96.34 221.432 0
unit 12
com=!i-beam rail!
cuboid 10 1 106.5 -106.5 3.175 -3.175 4.445 -4.445
cuboid 0 1 106.5 -106.5 5.08 -5.08 4.445 -4.445
cuboid 10 1 106.5 -106.5 5.08 -5.08 5.08 -5.08
cuboid 0 1 106.5 -106.5 5.08 -5.08 10.16 -211.272
global unit 13
com=!room!
array 3 -106.5 -106.5 0
cuboid 7 1 106.5 -106.5 106.5 -106.5 221.432 -2.382
cuboid 8 1 106.5 -106.5 106.5 -106.5 221.432 -12.542
cuboid 0 1 457.2 -457.2 457.2 -457.2 554.058 -360.342
cuboid 9 1 609.6 -609.6 609.6 -609.6 615.018 -451.782
end geom
read array
ara=1 nux=1 nuy=1 nuz=20
com=!z stack of units!
fill 4 5 6 2 1 3 7 2 1 3 7 2 1 3 7 2 1 3 8 9 end fill
ara=2 nux=4 nuy=4 nuz=1
com=!xy array!
fill 16r10 end fill
ara=3 nux=1 nuy=3 nuz=1
com=!room!
fill 12 11 12 end fill
end array
read start
xsm=-22.372
xsp=22.372
ysm=-22.372
yxp=22.372
zsm=103.895
zsp=132.105
nst=1
end start
read plot
ttl=!plan view of experiment!
plt=yes pic=mixture xul=-25.02 yul= 25.02 zul=113.07 xlr=25.02 ylr=-25.02
zlr=113.07 uax=1
```

```
vax=0 wax=0 udn=0 vdn=-1 wdn=0 nax=120
nch=!0123456789 ! end
ttl!=elevation view of experiment!
plt=yes pic=mixture xul=-25.02 yul=6.255 zul=230 xlr=0 ylr=6.255 zlr=-14 uax=1
vax=0 wax=0 udn=0 vdn=0 wdn=-1 nax=120
nch=!0123456789 ! end
end plot
end data
end
```

Table A.1 Case 21

```
#csas25
unmod pu met cyl array-phase ii/pu-met-fast-004/j. justice/3-96
27groupndf4 latticecell
arbmput 19.53 9 0 0 1 94239 93.5178 94240 5.96728 94241 .4597868 94242 .00999554
6012 .018 20000 .01 26000 .0035 12000 .002 28000 .005 1 1.0 293 end
arbmupporttube 2.719494 7 0 0 1 24000 .1 29000 4.35 26000
.5 12000 1.5 25055 .6 14000 .5 13027 92.2
2 1.0 293 end
arbmcanlid 7.9 7 0 0 1 6012 .08 25055 .37 15031 .015 16000 .025 14000 .01
50000 .3 26000 99.2 3 1.0 293 end
arbmhomoshoe 5.72772021 9 0 0 1 29000 46.9803 29000 29.8028 26000 17.6578
13027 2.5044 24000 .898374 14000 .176601 6012 .072878 50000 .587374 42000
.232064 4 1.0 293 end
arbmbspersink 2.70 8 0 0 1 24000 .2 29000 .25 26000 .7 12000 1 25055 .15
14000 .6 13027 96.7 22000 .15 5 1.0 293 end
arbmtopsink 2.074133315 8 0 0 1 24000 .2 29000 .25 26000 .7 12000 1 25055
.15 14000 .6 22000 .15 13027 96.7 6 1.0 293 end
arbmtabletop 2.84 7 0 0 1 29000 6.3 26000 .3 12000 .02 25055 .3 14000 .2
22000 .06 13027 92.72 7 .881 293 end
arbmframe 2.7 8 0 0 1 24000 .2 29000 .25 26000 .7 12000 1 25055 .15 14000
.6 22000 .15 13027 96.7 8 .296 293 end
arbmbeamupbeam 2.77 7 0 0 1 24000 .1 29000 4.35 26000 .5 12000 1.5 25055 .6
14000 .5 13027 92.2 10 1.0 293 end
arbmpucan 2.72 6 0 0 1 29000 .25 26000 .7 12000 1.05 25055 1.25 14000 .3
13027 96.2 11 1.0 293 end
arbmiddlesink 1.667844 8 0 0 1 24000 .2 29000 .25 26000 .7 12000 1 25055
.15 14000 .6 22000 .15 13027 96.7 12 1.0 293 end
arbmconcrete 2.343257 9 0 0 0 13027 1.40535 6012 3.24667 20000 32.9114 26000
.778856 1001 1.06195 12000 1.01103 11023 .495269 8016 47.0742 14000 12.0153
9 1.0 293 end
arbmmoderator 1.559 9 0 0 1 1001 3.140034 6012 30.5595 8016 34.7035 5010
.000018244 5011 .000081774 11023 .002 26000 .0025 19000 .02 7014 31.5702 13
1.0 293 end
end comp
squarepitch 17.5 6.525 1 13 6.599 11 end
more data res=1 cylinder 3.2625 dan(1)=.66 end
case 201\pu-met-fast-017/jjustice/4-96
read parm tme=520 gen=1100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm
read geom
unit 1
com=!pu in can!
zcylinder 1 1 3.2625 4.633 0
zcylinder 11 1 3.2995 4.72 0
zcylinder 3 1 3.2995 4.72 -.021
```

zcylinder 0 1 3.429 4.72 -.021
zcylinder 2 1 3.607 4.72 -.021
zcylinder 0 2 3.8141 4.72 -.021
zcylinder 13 1 5.0848 4.72 -.021
cuboid 0 1 8.75 -8.75 8.75 -8.75 4.72 -.021
unit 2
com=!bottom heat sink and gap!
zcylinder 5 1 3.2995 0 -.30408
zcylinder 0 1 3.429 0 -.635
zcylinder 2 1 3.607 0 -.635
zcylinder 0 1 3.8141 0 -.635
zcylinder 13 1 5.0848 0 -.635
cuboid 0 1 8.75 -8.75 8.75 -8.75 0 -.635
unit 3
com=!top heat sink!
zcylinder 0 1 1.4986 .479 0
zcylinder 6 1 3.2995 .479 0
zcylinder 0 1 3.429 .479 0
zcylinder 2 1 3.607 .479 0
zcylinder 0 1 3.8141 .479 0
zcylinder 13 1 5.0848 .479 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 .479 0
unit 4
com=!lower shoe!
zcylinder 4 1 3.607 4.922 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 4.922 0
unit 5
com=!lower support tube!
zcylinder 0 1 2.8672 20.161 0
zcylinder 2 1 3.607 20.161 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 20.161 0
unit 6
com=!bottom spacer!
zcylinder 0 1 3.123 47.4855 0
zcylinder 5 1 3.3338 47.4855 0
zcylinder 0 1 3.429 47.4855 0
zcylinder 2 1 3.607 47.4855 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 47.4855 0
unit 7
com=!inner spacer!
zcylinder 0 1 3.123 12.297 0
zcylinder 5 1 3.3338 12.297 0
zcylinder 0 1 3.429 12.297 0
zcylinder 2 1 3.607 12.297 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 12.297 0
unit 8
com=!upper support tube and upper shoe void!
zcylinder 0 1 3.429 44.9825 0
zcylinder 2 1 3.607 44.9825 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 52.9205 0
unit 9
com=!upper support beam - unit cell!
cuboid 0 1 4.3435 -4.3435 8.75 -8.75 1.8035 -1.8035
cuboid 10 1 5.08 -5.08 8.75 -8.75 2.54 -2.54
cuboid 0 1 8.75 -8.75 8.75 -8.75 2.54 -2.54
unit 10


```
com=!z stack of units!
array 1 0 0 0
unit 11
com=!xy array!
array 2 -35 -35 0
cuboid 0 1 106.5 -106.5 96.34 -96.34 221.432 0
unit 12
com=!i-beam rail!
cuboid 10 1 106.5 -106.5 .3175 -.3175 4.445 -4.445
cuboid 0 1 106.5 -106.5 5.08 -5.08 4.445 -4.445
cuboid 10 1 106.5 -106.5 5.08 -5.08 5.08 -5.08
cuboid 0 1 106.5 -106.5 5.08 -5.08 10.16 -211.272
global unit 13
com=!room!
array 3 -106.5 -106.5 0
cuboid 7 1 106.5 -106.5 106.5 -106.5 221.432 -2.382
cuboid 8 1 106.5 -106.5 106.5 -106.5 221.432 -12.542
cuboid 0 1 457.2 -457.2 457.2 -457.2 554.058 -360.342
cuboid 9 1 609.6 -609.6 609.6 -609.6 615.018 -451.782
unit 14
com=!middle sink!
zcylinder 0 1 1.4986 .3556 0
zcylinder 12 1 3.2995 .3556 0
zcylinder 0 1 3.429 .3556 0
zcylinder 2 1 3.607 .3556 0
zcylinder 0 1 3.8141 .3556 0
zcylinder 13 1 5.0848 .3556 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 .3556 0
unit 15
com=!moderator disk!
zcylinder 13 1 3.3975 1.2707 0
zcylinder 0 1 3.429 1.2707 0
zcylinder 2 1 3.607 1.2707 0
zcylinder 0 1 3.8141 1.2707 0
zcylinder 13 1 5.0848 1.2707 0
cuboid 0 1 8.75 -8.75 8.75 -8.75 1.2707 0
end geom
read array
ara=1 nux=1 nuy=1 nuz=36
com=!z stack of units!
fill 4 5 6 15 2 1 14 1 3 15 7 15 2 1 14 1 3 15
7 15 2 1 14 1 3 15 7 15 2 1 14 1 3 15 8 9 end fill
ara=2 nux=4 nuy=4 nuz=1
com=!xy array!
fill 16r10 end fill
ara=3 nux=1 nuy=3 nuz=1
com=!room!
fill 12 1 12 end fill
end array
read start
xsm=-31
xsp=31
ysm=-31
yxp=31
zsm=72
zsp=164
```

```

nst=1
end start
read plot
ttl=!plan view of experiment!
plt=yes pic=mixture xul=-35 yul=35 zul=104.105 xlr=35 ylr=-35 zlr=104.105 uax=1
vax=0 wax=0 udn=0 vdn=-1 wdn=0 nax=80
nch=!0123456789 ! end
ttl=!elevation view of experiment!
plt=yes pic=mixture xul=-35 yul=8.75 zul=230 xlr=0 ylr=8.75 zlr=-14 uax=1
vax=0 wax=0 udn=0 vdn=0 wdn=-1 nax=80
nch=!0123456789 ! end
end plot
end data
end

```

C.2 Plutonium Solution Input Files

Table A.2 Case 1

#csas25

pu sol(10.02g/l)/pu-sol-therm-sol/r.rathbun/1995 pu_sls01_27

27groupndf4 infhommedium

```

al      2 1.0 296.5 end
al      1 den=1.002e-4 1.0 296.5 end
b-10    1 den=2.59e-8 1.0 296.5 end
cd      1 den=7.014-8 1.0 296.5 end
ca      1 den=3.006e-6 1.0 296.5 end
cr      1 den=1.503e-5 1.0 296.5 end
gd      1 den=1.002e-7 1.0 296.5 end
fe      1 den=1.148e-4 1.0 296.5 end
mg      1 den=2.003e-6 1.0 296.5 end
mn      1 den=1.503e-6 1.0 296.5 end
ni      1 den=1.002e-5 1.0 296.5 end
p       1 den=1.002e-5 1.0 296.5 end
k       1 den=1.002e-6 1.0 296.5 end
si      1 den=5.011e-6 1.0 296.5 end
na      1 den=3.006e-6 1.0 296.5 end
u-235   1 den=3.006e-6 1.0 296.5 end
cl      1 den=2.004e-6 1.0 296.5 end
f       1 den=1.002e-5 1.0 296.5 end
s       1 den=1.002e-5 1.0 296.5 end
o       1 den=1.107e-5 1.0 296.5 end
solnpu(no3)4 1 10.02 1.119 spg=1.055 1.0 296.5 94238 .004 94239 97.386 94240
2.521 94241 .075 94242 .014 end

```

end comp

pu sol(10.02g/l)/pu-sol-therm-009/r.rathbun/1995 pu_sls01_27

read parm gen=250 npg=450 nsk=25 run=yes plt=yes nub=yes end parm

read geom

global unit 1

com=!sol sphere + void+al shell!

hemisphe-z 1 1 60.964 chord 15.956

sphere 0 1 60.964

sphere 2 1 61.734

end geom

read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum

end bnds

read plot

```

ttl=!y slice!
plt=yes pic=mixture xul=-65 yul=0 zul=65 xlr=65 ylr=0 zlr=-65 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=!.pa                      ! end
end plot

```

```

read mixt eps=1 end mixt

```

```

end data
end

```

Table A.2 Case 8

```

#csas25
18-1 (22.35g/l)/pu-sol-therm-011/r. rathbun/1995 pu_sls08_27
27groupndf4          infhommedium
fe      1 den=0.120e-3 1.0 295 end
cd      3 den=8.65 1.0 295 end
arbm-ss347 8 3 0 0 0 26000 70 24000 18 28000 12 2 1.0 295 end
solnpu(no3)4 1 22.35 0.847 spg=1.0662 1.0 295 94239 95.8 94240 4.2 end
end comp
pu-sol-therm-011...case 18-1...27-group
read parm tme=100 gen=1000 npg=600 nsk=100 run=yes plt=yes nub=yes end parm
read geom
global unit 1
com=!18-inch sph with ss347 & cd shells!
sphere  1 1 22.6974
sphere  2 1 22.8244
sphere  3 1 22.8752
end geom
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
read plot
ttl=!y cut!
plt=yes pic=mixture xul=-23 yul=0 zul=23 xlr=23 ylr=0 zlr=-23 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=130
nch=!.psc                      ! end
end plot

read mixt eps=1 end mixt

end data
end

```

Table A.2 Case 14

```

#csas25
exp 1 (19.7 g/l)/pu-sol-therm-012/r.rathbun/1996/pu_sls14_27
27groupndf4          infhommedium
fe      1 den=0.46e-3 1.0 300 end
cr      1 den=0.14e-3 1.0 300 end
ni      1 den=0.11e-3 1.0 300 end
am-241  1 den=0.12e-3 1.0 300 end
h2o     2 1.0 297 end
arbm-sstank 7.9 3 0 0 1 26000 72 24000 18 28000 10 3 1.0 300 end
arbm-lucoflex 1.420 3 0 1 1 6012 2 1001 3 17000 1 4 1.0 297 end

```

```
arbm-frenconc 2.40133 7 0 0 1 13027 2.91625 5010 .001109 20000 17.8038 26000
2.94315 1001 .72137 8016 48.0943 14000 27.5202 6 1.0 297 end
arbm-air .0012887 2 0 0 1 8016 22.2323 7014 77.7701 7 1.0 297 end
arbm-pool-ss 7.9015 2 0 0 1 26000 99.862 6012 .142 5 1.0 297 end
solnpu(no3)4 1 19.7 2.02 spg=1.100 1.0 300 94239 74.3189 94240 18.9102 94241
5.629 94242 1.1419 end
end comp
pu sol (19.7g/l)/pu-sol-ther-012/r rathbun/1996/pu_sls14_27
read parm tme=60 gen=1100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm
read geom
unit 1
com=!nitrate solution!
cuboid 1 1 130.5 .5 130.5 .5 28.17 0
cuboid 3 1 131 0 131 0 28.17 -0.5
unit 2
com=!floating box!
cuboid 2 1 129.5 1.5 129.5 1.5 19 1
cuboid 4 1 130.5 .5 130.5 .5 20 0
cuboid 3 1 131 0 131 0 20 0
global unit 3
com=!solution+box+water refl!
array 1 0 0 0
replicate 2 1 25 25 25 25 0 25 1
end geom
read array
ara=1 nux=1 nuy=1 nuz=2
com=!solution+floating box!
fill 1 2 end fill
end array
read bnds +xb=vacuum -xb=vacuum +yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum
end bnds
```

read start nst=1 end start

end data
end

Table A.2 Case 37

```
#csas25
pu_sol_001
27groupndf4 infhommedium
h2o 3 den=.9970 1.0 298 end
arbm_ss304l 7.92 4 0 0 1 26000 69.5 24000 19 28000 9.5 25055 2 2 1.0 298
end
solnpu(no3)4 1 73.0 0.2 spg=1.130 1.0 298 94238 .006 94239 95.011 94240 4.669
94241 .305 94242 .009 end
end comp
pu_sol_001
read parm gen=1100 npg=400 nsk=100 run=yes plt=yes nub=yes tme=100 end parm
read geom
unit 1
com=!pu_sol_001!
sphere 1 1 14.5151
sphere 2 1 14.6396
sphere 3 1 14.6396
end geom
```

end data
end

Table A.2 Case 43

```
#csas25
pu_sol_002
27groupndf4          infhommedium
fe      1 den=0.000189 1.0 300 end
h2o     3 den=0.9965 1.0 300 end
arbm_ss_002 8.0 3 0 0 1 26000 70 24000 18 28000 12 2 1.0 300 end
solnpu(no3)4 1 49.84 1.41 spg=1.1312 1.0 300 94239 96.88 94240 3.12 end
end comp
pu_sol_002
read parm gen=1100 npg=400 nsk=100 run=yes plt=yes nub=yes tme=100 end parm
read geom
unit 1
com='!pu_sol_002!
sphere 1 1 15.3399
sphere 2 1 15.4669
sphere 3 1 45.4669
end geom
end data
end
```

Table A.2 Case 50

```
#csas25
pu_sol_003
27groupndf4          infhommedium
fe      1 den=0.000124 1.0 300 end
h2o     3 den=.9965 1.0 300 end
arbm_ss_003 8.0 3 0 0 1 26000 70 24000 18 28000 12 2 1.0 300 end
solnpu(no3)4 1 33.32 0.846 spg=1.0853 1.0 300 94239 98.24 94240 1.76 end
end comp
pu_sol_003
read parm gen=1100 npg=400 nsk=100 run=yes plt=yes nub=yes tme=100 end parm
read geom
unit 1
com='!pu_sol_003!
sphere 1 1 16.5156
sphere 2 1 16.6426
sphere 3 1 46.6426
end geom
end data
end
```

Table A.2 Case 56

```
#csas25
pu_sol_004
27groupndf4          infhommedium
fe      1 den=0.000145 1.0 300 end
h2o     3 den=0.9965 1.0 300 end
arbm_ss_004 8.0 3 0 0 1 26000 70 24000 18 28000 12 2 1.0 300 end
solnpu(no3)4 1 26.27 0.825 spg=1.0694 1.0 300 94239 99.46 94240 0.54 end
```

```
end comp
pu_sol_004
read parm gen=110 npg=400 nsk=100 run=yes plt=yes nub=yes tme=100 end parm
read geom
unit 1
com=!pu_sol_006!
sphere 1 1 17.7865
sphere 2 1 17.9135
sphere 3 1 47.9135
end geom
end data
end
```

Table A.2 Case 69

```
#csas25
pu_sol_005
27groupndf4          inthommedium
fe      1 den=0.000128 1.0 300 end
h2o     3 den=0.9965 1.0 300 end
arbm_ss_005 8.0 3 0 0 1 26000 70 24000 18 28000 12 2 1.0 300 end
solnpu(no3)4 1 29.65 0.922 spg=1.0777 1.0 300 94239 95.95 94240 4.05 end
end comp
pu_sol_005
read parm gen=1100 npg=400 nsk=100 run=yes plt=yes nub=yes tme=100 end parm
read geom
unit 1
com=!pu_sol_005!
sphere 1 1 17.7865
sphere 2 1 17.9135
sphere 3 1 47.9135
end geom
end data
end
```

Table A.2 Case 78

```
#csas25
pu_sol_006
27groupndf4          inthommedium
fe      1 den=0.000088 1.0 300 end
h2o     3 den=0.9965 1.0 300 end
arbm_ss_006 8.0 3 0 0 1 26000 70 24000 18 28000 12 2 1.0 300 end
solnpu(no3)4 1 24.80 1.472 spg=1.0899 1.0 300 94239 96.88 94240 3.12 end
end comp
pu_sol_006
read parm gen=1100 npg=400 nsk=100 run=yes plt=yes nub=yes tme=100 end parm
read geom
unit 1
com=!pu_sol_006!
sphere 1 1 19.0416
sphere 2 1 19.1686
sphere 3 1 49.1686
end geom
end data
end
```

C.3 Highly Enriched Uranium Metal Input Files

Table A.3 Case 1

```
#csas25
heu_m_001
27groupndf4          infhommedium
uranium      1 den=18.74 1.0 300 92234 1.02 92235 93.71 92238 5.27 end
end comp
heu_metal godiva
read parm gen=650 npg=800 nsk=50 run=yes plt=yes nub=yes tme=200 end parm
read geom
unit 1
com=!heu_metal!
sphere 1 1 8.7407
end geom
end data
end
```

Table A.3 Case 3

```
#csas25
heu_mts_fast_002 case1
27groupndf4          infhommedium
uranium      1 den=18.75 1.0 293 92234 1.02 92235 93.50 92238 5.48 end
uranium      2 den=18.90 1.0 293 92234 .0054 92235 .711
92238 99.2836 end
end comp
heu_metal
read parm gen=650 npg=800 nsk=50 run=yes plt=yes nub=yes tme=200 end parm
read geom
unit 1
com=!heu_metal!
sphere 1 1 6.0509
sphere 2 1 26.3709
end geom
end data
end
```

Table A.3 Case 9

```
#csas25
heu_mts_fast_003 case1 2-inch tuballoy-reflected sphere
27groupndf4          infhommedium
uranium      1 den=18.75 1.0 293 92234 1.02 92235 93.50 92238 5.48 end
uranium      2 den=18.90 1.0 293 92234 .0054 92235 .711
92238 99.2836 end
end comp
heu_metal
read parm gen=650 npg=800 nsk=50 run=yes plt=yes nub=yes tme=200 end parm
read geom
unit 1
com=!heu_metal!
sphere 1 1 6.7820
sphere 2 1 11.8620
end geom
end data
end
```

Table A.3 Case 21

#csas25

heu_mts_fast_004 heu sphere with h2o-reflector

27groupndf4 infhommedium

h2o 2 1.0 290 end

uranium 1 den=18.794 1.0 293 92233 .01 92234 1.11

92235 97.675 92236 .2 92238 1.005 end

end comp

heu_metal

read parm gen=650 npg=800 nsk=50 run=yes plt=yes nub=yes tme=200 end parm

read geom

unit 1

com=!heu_metal!

sphere 1 1 6.5537

sphere 2 1 33.4717

end geom

end data

end

Table A.3 Case 23

#csas25

heu_mts_fast_007 case1

27groupndf4 infhommedium

uranium 1 den=18.4816 1.0 293 92234 1.07 92235 93.15

92236 .68 92238 5.10 end

end comp

heu_metal

read parm gen=650 npg=800 nsk=50 run=yes plt=yes nub=yes tme=200 end parm

read geom

unit 1

com=!heu_metal!

cuboid 1 1 12.7 -12.7 12.7 -12.7 8.7220 0.0

end geom

end data

end

Table A.3 Case tn02

#csas25

heu-met-fast-027 case 2

27gr latticecell

arbmumet 18.76 4 0 0 1 92234 1 92235 93.2 92236 .2 92238 5.6 1 1 end

ss304 2 1 end

rfconcrete 3 1 end

ARBMP1 .93 2 0 1 1 1001 52 6012 25 5 1.0 293 END

ARBMP2 .88 2 0 1 1 1001 52 6012 25 4 1.0 293 END

end comp

squarepitch 13.487 11.506 1 0 end

more data

dan(1)=0.71

end more

heu-met-unmod-het-001 case 2

read param

tme=320 fdn=yes run=yes gen=650 npg=750 nsk=50 nub=yes plt=no

end param

read geom

unit 1


```
com='stainless steel support rod in uranium'
zcyl 2 1 0.254 2p2.691
cuboid 1 1 4p0.254 2p2.691
unit 2
com='uranium piece between support rods'
cuboid 1 1 2p4.0195 2p0.254 2p2.691
unit 3
com='uranium cylinder with support rods'
array 1 -4.5275 -0.254 -2.691
zcyl 1 1 5.753 2p2.691
cuboid 0 1 4p5.8675 2p2.691
unit 4
com='inner stainless steel support rod spacer'
zcyl 2 1 0.254 2p0.1145
cuboid 0 1 4p0.254 2p0.1145
unit 5
com='void space between inner support rod spacers'
cuboid 0 1 2p4.0195 2p0.254 2p0.1145
unit 6
com='void space between uranium cylinders'
array 2 -4.5275 -0.254 -0.1145
cuboid 0 1 4p5.8675 2p0.1145
unit 7
com='void space between uranium array and moderator'
cuboid 0 1 4p5.8675 2p0.05725
unit 8
com='moderator with gaps'
cuboid 0 1 2p5.8675 2p0.254 2p0.65
cuboid 4 1 4p5.8675 2p0.65
unit 9
com='uranium column'
array 3 -5.8675 -5.8675 -6.911
unit 10
com='uranium rows'
array 4 -11.735 -5.8675 -6.911
unit 11
com='lower room with uranium array'
array 5 -11.735 -11.735 -6.911
cuboid 4 1 4p13.035 2p6.911
cuboid 0 1 554.99 -344.17 428.96 -502.92 221.1985 -144.5615
cuboid 3 1 600.71 -496.57 581.36 -624.84 221.1985 -236.0015
unit 12
com='upper room'
cuboid 0 1 554.99 -344.17 428.96 -563.88 934.9385 221.1985
cuboid 3 1 600.71 -496.57 581.36 -624.84 965.4185 221.1985
global
unit 13
com='room'
array 6 -496.57 -624.84 -236.0015
end geom
read array
ara=1 nux=3 nuy=1 nuz=1 fill 1 2 1 end fill
ara=2 nux=3 nuy=1 nuz=1 fill 4 5 4 end fill
ara=3 nux=1 nuy=1 nuz=7 fill 8 7 3 6 3 7 8 end fill
ara=4 nux=1 nuy=2 nuz=1 fill 19 end fill
ara=5 nux=2 nuy=1 nuz=1 fill 10 end fill
```

```

ara=6 nux=1 nuy=1 nuz=2 fill 11 12 end fill
end array
read start
nst=1
xsm=-11.6205
xsp=11.6205
ysm=-11.6205
ysp=11.6205
zsm=-5.4965
zsp=5.4965
end start
end plot
end data
end

```

C.4 Highly Enriched Uranium Solution Input Files

Table A.4 Case 1

```

#csas25
heu-sol-001 case1
27groupndf4          infhommedium
arbm_ss_304 7.927 9 0 0 1 6012 .066 14000 .81 15031 .025 16000 .019 24000
18.5 25055 1.29 26000 70.002 28000 9.27 42000 .018 2 1.0 293 end
solnuo2(no3)2 1 145.68 0.294 spg=1.2038 1.0 293 92234 1.022 92235 93.172
92236 .434 92238 5.372 end
end comp
heu_sol_101
read parm tme=100 gen=1000 npg=500 nsk=100 run=yes plt=yes nub=yes end parm
read geom
unit 1
com=!heu_sol_101!
cylinder 1 1 13.96 31.2 0
cylinder 0 1 13.96 41.6 0
cylinder 2 1 14.28 41.6 -.64
end geom
end data
end

```

Table A.4 Case 11

```

#csas25
heu-sol-002 case1
27groupndf4          infhommedium
arbm_ss_304 7.927 9 0 0 1 6012 .066 14000 .81 15031 .025 16000 .019 24000
18.5 25055 1.29 26000 70.002 28000 9.27 42000 .018 2 1.0 293 end
arbm_concre 2.321 13 0 0 1 1001 .75 6012 5.52 7014 .02 8016 48.49 11023
.63 12000 1.25 13027 2.17 14000 15.50 16000 .19 19000 1.37 20000 23.0
22000 .10 26000 1.01 3 1.0 293 end
solnuo2(no3)2 1 144.38 0.272 spg=1.2023 1.0 293 92234 1.022 92235 93.172
92236 .434 92238 5.372 end
end comp
heu_sol_201
read parm tme=100 gen=1100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm
read geom
unit 1
com=!heu_sol_201!
cylinder 1 1 13.96 29.79 0

```

```

cylinder 0 1 13.96 41.6 0
cylinder 2 1 14.28 41.6 -.64
cuboid 0 1 14.28 -14.28 14.28 -14.28 41.6 -0.64
reflector 0 1 50.32 42.92 43.12 50.52 39.125 41.065 1.0
reflector 3 1 25.7 25.7 25.7 25.7 0.0 0.0 1.0
reflector 0 1 4*0.0 0.635 0.635 1.0
reflector 3 1 0.0 0.0 0.0 0.0 25.4 25.4 1.0
end geom
read plot ttl='plot'
pic=mix plt=yes
xul=-80.1 yul=0.0 zul=+110.0
xlr=+91.0 ylr=0.0 zlr=-51.9
uax=+1.0 wdn=-1.0 nax=132 nch='uac' end
end plot
end data
end

```

Table A.4 Case 25

#csas25

heu-sol-003 case1

27groupndf4 infhommedium

arbm_pl_tb 1.286 8 0 0 1 1001 7.25 6012 53.196 7014 .101 8016 29.688

15031 1.555 17000 1.646 35079 3.322 35081 3.242 4 1.0 293 end

arbm_plexi 1.186 3 0 0 1 1001 8.039 6012 59.786 8016 32.175 3 1.0 293 end

arbm_ss_304 7.927 9 0 0 1 6012 .066 14000 .81 15031 .025 16000 .019 24000

18.5 25055 1.29 26000 70.002 28000 9.27 42000 .018 2 1.0 293 end

solnuo2(no3)2 1 60.32 0.113 spg=1.0837 1.0 293 92234 1.022 92235 93.172

92236 .434 92238 5.372 end

end comp

heu_sol_301

read parm tme=100 gen=1100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm

read geom

unit 1

com=!heu_sol_301!

cuboid 0 1 6p10.39999

unit 2

cuboid 0 1 4p10.39999 10.09999 -10.09999

global

unit 3

cylinder 1 1 13.965 50.52 0

cylinder 0 1 13.965 91.5 0

cylinder 2 1 14.285 91.5 -.64

cuboid 0 1 104.64 -18.26 17.71 -105.19 121.625 -0.64

cuboid 3 1 125.44 -39.06 38.51 -125.99 121.625 -0.64

reflector 0 1 0.0 0.0 0.0 0.0 0.635 0.0 1.0

cuboid 4 1 125.44 -39.06 38.51 -125.99 142.46 -21.44

hole 1 -28.66 28.11 -11.04

hole 1 -28.66 -115.59 -11.04

hole 1 +115.04 -115.59 -11.04

hole 1 +115.04 +28.11 -11.04

hole 2 -28.66 28.11 +132.36

hole 2 -28.66 -115.59 +132.36

hole 2 +115.04 -115.59 +132.36

hole 2 +115.04 +28.11 +132.36

end geom

read plot ttl='plot'

```
pic=mix plt=yes
xul=-42.0 yul=0.0 zul=+143.0
xlr=+143.0 ylr=0.0 zlr=-23.0
uax=+1.0 wdn=-1.0 nax=132 nch='*x!=' end
ttl='x-y slice plot'
pic=mix plt=yes
xul=-42.0 yul=+40.0 zul=+47.0
xlr=+128.0 ylr=-128.0 zlr=+47.0
uax=+1.0 vdn=-1.0 nax=130 nch='*x!=' end
end plot
end data
end
```

Table A.4 Case 44

#csas25

heu-sol-007 case1

27groupndf4 infhommedium

al 2 0.0 5.9469e-02 293 end

arbm_concr 2.321 13 0 0 1 1001 .75 6012 5.52 7014 .02 8016 48.49 11023

.63 12000 1.25 13027 2.17 14000 15.50 16000 .19 19000 1.37 20000 23.0

22000 .10 26000 1.01 4 1.0 293 end

arbm_ss_304 7.927 9 0 0 1 6012 .066 14000 .81 15031 .025 16000 .019 24000

18.5 25055 1.29 26000 70.002 28000 9.27 42000 .018 3 1.0 293 end

solnuo2(no3)2 1 67.28 0.128 spg=1.0934 1.0 293 92234 1.022 92235 93.172

92236 .434 92238 5.372 end

end comp

heu_sol_701

read parm tme=100 gen=1 100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm

read geom

unit 1

com=!heu_sol_701!

cylinder 1 1 0.505 0.0 -0.32

cylinder 2 1 10.56 0.0 -0.32

cylinder 1 1 10.56 28.63 -0.32

cylinder 0 1 10.56 119.1 -0.32

cylinder 2 1 10.96 119.1 -0.32

cylinder 0 1 10.96 121.68 -0.32

cylinder 3 1 11.28 121.68 -0.32

cuboid 0 1 15.24 -15.24 15.24 -15.24 123.445 -0.32

unit 2

cylinder 1 1 0.505 25.4 0.0

cylinder 2 1 0.635 25.4 0.0

cuboid 4 1 15.24 -15.24 15.24 -15.24 25.4 0.0

unit 3

cylinder 1 1 0.505 5.0 0.0

cylinder 2 1 0.635 5.0 0.0

cuboid 0 1 15.24 -15.24 15.24 -15.24 5.0 0.0

unit 4

cylinder 1 1 1.14 0.0 -0.32

cylinder 2 1 10.56 0.0 -0.32

cylinder 1 1 10.56 28.63 -0.32

cylinder 0 1 10.56 119.1 -0.32

cylinder 2 1 10.96 119.1 -0.32

cylinder 0 1 10.96 121.68 -0.32

cylinder 3 1 11.28 121.68 -0.32

cuboid 0 1 15.24 -15.24 15.24 -15.24 123.445 -0.32

```
unit 5
cylinder 1 1 1.14 25.4 0.0
cylinder 2 1 1.27 25.4 0.0
cuboid 4 1 15.24 -15.24 15.24 -15.24 25.4 0.0
unit 6
cylinder 1 1 1.14 5.0 0.0
cylinder 2 1 1.27 5.0 0.0
cuboid 0 1 15.24 -15.24 15.24 -15.24 5.0 0.0
unit 7
array=1 3*0.0
unit 8
array=2 3*0.0
unit 9
array=3 3*0.0
unit 10
cuboid 0 1 121.92 0.0 0.14 0.0 5.0 0.0
cuboid 4 1 121.92 0.0 0.14 0.0 30.4 0.0
cuboid 0 1 121.92 0.0 0.14 0.0 154.165 0.0
unit 11
cuboid 0 1 25.7 0.0 122.2 0.0 5.0 0.0
cuboid 4 1 25.7 0.0 122.2 0.0 30.4 0.0
cuboid 0 1 25.7 0.0 122.2 0.0 31.035 0.0
cuboid 4 1 25.7 0.0 122.2 0.0 154.165 0.0
unit 12
cuboid 0 1 173.32 0.0 25.7 0.0 5.0 0.0
cuboid 4 1 173.32 0.0 25.7 0.0 30.4 0.0
cuboid 0 1 173.32 0.0 25.7 0.0 31.035 0.0
cuboid 4 1 173.32 0.0 25.7 0.0 154.165 0.0
unit 13
array=4 3*0.0
unit 14
array=5 3*0.0
global
unit 15
array=6 3*0.0
reflector 0 1 0.0 0.0 0.0 0.0 0.635 0.0 1.0
reflector 4 1 0.0 0.0 0.0 0.0 25.4 0.0 1.0
end geom
read array
ara=1
nux=1 nuy=1 nuz=3
fill 3 2 1 end fill
ara=2
nux=1 nuy=1 nuz=3
fill 6 5 4 end fill
ara=3
nux=4 nuy=4 nuz=1
fill
7 7 7 7
7 8 7 7
7 8 7 7
7 7 7 7 end fill
ara=4
nux=1 nuy=3 nuz=1
fill 10 9 10 end fill
ara=5
```

```
nux=3 nuy=1 nuz=1
fill 11 13 11 end fill
ara=6
nux=1 nuy=3 nuz=1
fill 12 14 12 end fill
end array
read plot ttl=' plot'
pic=mix plt=yes
xul=+25.0 yul=+71.56 zul=+166.0
xlr=+73.0 ylr=+71.56 zlr=-1.0
uax=+1.0 wdn=-1.0 nax=132 nch=' 12345' end
end plot
end data
end
```

Table A.4 Case 61

#csas25

heu-sol-008 case1

27groupndf4 infhommedium

al 2 0.0 5.9469e-02 293 end

arbm_ss_304 7.927 9 0 0 1 6012 .066 14000 .81 15031 .025 16000 .019 24000

18.5 25055 1.29 26000 70.002 28000 9.27 42000 .018 3 1.0 293 end

arbm_pl_tb 1.286 8 0 0 1 1001 7.25 6012 53.196 7014 .101 8016 29.688

15031 1.555 17000 1.646 35079 3.322 35081 3.242 5 1.0 293 end

arbm_pl_sd 1.186 3 0 0 1 1001 8.039 6012 59.786 8016 32.175 4 1.0 293 end

solnuo2(no3)2 1 60.32 0.113 spg=1.0837 1.0 293 92234 1.022 92235 93.172

92236 .434 92238 5.372 end

end comp

heu_sol_801

read parm tme=100 gen=1100 npg=500 nsk=100 run=yes plt=yes nub=yes end parm

read geom

unit 1

com=!heu_sol_801!

cylinder 1 1 0.505 0.0 -0.32

cylinder 2 1 10.56 0.0 -0.32

cylinder 1 1 10.56 34.82 -0.32

cylinder 0 1 10.56 119.1 -0.32

cylinder 2 1 10.96 119.1 -0.32

cylinder 0 1 10.96 121.68 -0.32

cylinder 3 1 11.28 121.68 -0.32

cuboid 0 1 15.24 -15.24 15.24 -15.24 122.945 -0.32

unit 2

cylinder 1 1 0.505 20.8 0.0

cylinder 2 1 0.635 20.8 0.0

cuboid 5 1 15.24 -15.24 15.24 -15.24 20.8 0.0

unit 3

cylinder 1 1 0.505 9.6 0.0

cylinder 2 1 0.635 9.6 0.0

cuboid 0 1 15.24 -15.24 15.24 -15.24 9.6 0.0

unit 4

cylinder 1 1 1.14 0.0 -0.32

cylinder 2 1 10.56 0.0 -0.32

cylinder 1 1 10.56 34.82 -0.32

cylinder 0 1 10.56 119.1 -0.32

cylinder 2 1 10.96 119.1 -0.32

cylinder 0 1 10.96 121.68 -0.32

```
cylinder 3 1 11.28 121.68 -0.32
cuboid 0 1 15.24 -15.24 15.24 -15.24 122.945 -0.32
unit 5
cylinder 1 1 1.14 20.8 0.0
cylinder 2 1 1.27 20.8 0.0
cuboid 5 1 15.24 -15.24 15.24 -15.24 20.8 0.0
unit 6
cylinder 1 1 1.14 9.6 0.0
cylinder 2 1 1.27 9.6 0.0
cuboid 0 1 15.24 -15.24 15.24 -15.24 9.6 0.0
unit 7
array=1 3*0.0
unit 8
array=2 3*0.0
unit 9
array=3 3*0.0
unit 10
cuboid 0 1 0.49 0.0 121.92 0.0 5.0 0.0
cuboid 5 1 0.49 0.0 121.92 0.0 30.4 0.0
cuboid 0 1 0.49 0.0 121.92 0.0 153.665 0.0
unit 11
cuboid 0 1 20.8 0.0 122.9 0.0 5.0 0.0
cuboid 5 1 20.8 0.0 122.9 0.0 30.4 0.0
cuboid 4 1 20.8 0.0 122.9 0.0 153.665 0.0
unit 12
cuboid 0 1 122.9 0.0 0.49 0.0 9.6 0.0
cuboid 5 1 122.9 0.0 0.49 0.0 30.4 0.0
cuboid 0 1 122.9 0.0 0.49 0.0 153.665 0.0
unit 13
cuboid 0 1 10.3998 -10.3998 10.3998 -10.3998 10.3998 -10.3998
unit 14
cuboid 0 1 164.5 0.0 20.8 0.0 9.6 0.0
cuboid 5 1 164.5 0.0 20.8 0.0 30.4 0.0
hole 13 10.4 10.4 20.0
hole 13 154.1 10.4 20.0
cuboid 4 1 164.5 0.0 20.8 0.0 153.665 0.0
unit 15
array=4 3*0.0
unit 16
array=5 3*0.0
unit 17
array=6 3*0.0
unit 18
cuboid 0 1 10.3999 -10.3999 10.3999 -10.3999 10.0999 -10.0999
global
unit 19
array=7 3*0.0
reflector 0 1 0.0 0.0 0.0 0.0 0.635 0.0 1.0
reflector 5 1 0.0 0.0 0.0 0.0 20.2 0.0 1.0
hole 18 10.4 10.4 164.4
hole 18 10.4 154.1 164.4
hole 18 154.1 10.4 164.4
hole 18 154.1 154.1 164.4
end geom
read array
ara=1
```

```

nux=1 nuy=1 nuz=3
fill 3 2 1 end fill
ara=2
nux=1 nuy=1 nuz=3
fill 6 5 4 end fill
ara=3
nux=4 nuy=4 nuz=1
fill
  7 7 7
  7 8 7
  7 8 7
  7 7 7 end fill
ara=4
nux=3 nuy=1 nuz=1
fill 10 9 10 end fill
ara=5
nux=1 nuy=3 nuz=1
fill 12 15 12 end fill
ara=6
nux=3 nuy=1 nuz=1
fill 11 16 11 end fill
ara=7
nux=1 nuy=3 nuz=1
fill 14 17 14 end fill
end array
read plot ttl=' plot'
pic=mix plt=yes
xul=+30.0 yul=+66.52 zul=+166.0
xlr=+70.9 ylr=+66.52 zlr=-1.0
uax=+1.0 wdn=-1.0 nax=132 nch=' 12345' end
ttl='x-y slice at z=50 plot'
pic=mix plt=yes
xul=-21.8 yul=+165.5 zul=+50.0
xlr=+165.5 ylr=-21.8 zul=+50.0
uax=+1.0 vdn=-1.0 nax=130 nch=' 12345' end
end plot
end data
end

```

Table A.4 Case 75

#csas25

HEU-SOL-THERM-009 case1 696 gm/l solution sphere

27groupndf4 multiregion

h2o 3 den=.99702 1.0 293 end

arbm1 2.71 4 0 0 0 13027 98.7 14000 .995 29000 .3 25055 .005 2 1.0 293 end

solnuo2f2 1 696.42 0 spg=1.79495 1.0 293 92234 .98 92235 93.18 92236 .5 92238
5.34 end

end comp

spherical vacuum reflected 0 end

1 11.5177 2 11.6764 3 35 end zone

solution 696 g/l 27 gp xsec

read parm gen=800 npg=600 nsk=100 run=yes plt=yes

tme=600 nub=yes end parm

read geom

unit 1

com=!solution sphere!


```

sphere 1 1 11.5177
sphere 2 1 11.6764
sphere 3 1 35
end geom
read plot
ttl=!solution sphere!
plt=yes pic=mixture xul=-36 yul=0 zul=36 xlr=36 ylr=0 zlr=-36 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=75
nch=!.f*w ! end
end plot
end data
end

```

Table A.4 Case 80

```

#csas25
HEU-SOL-THERM-011 case1 53 gm/l solution sphere
27groupndf4 multiregion
h2o 3 den=.99702 1.0 293 end
arbm1 2.71 4 0 0 0 13027 98.7 14000 .995 29000 .3 25055 .005 2 1.0 293 end
solnuo2f2 1 53.020 0 spg=1.0597 1.0 293 92234 .98 92235 93.18 92236 .5 92238
5.34 end
end comp
spherical vacuum reflected 0 end
1 15.9572 2 16.0842 3 35 end zone
more data end
solution 696 g/l 27 gp xsec
read parm gen=800 npg=600 nsk=100 run=yes plt=no tme=600 nub=yes end parm
read geom
unit 1
com=!solution sphere!
sphere 1 1 15.9572
sphere 2 1 16.0842
sphere 3 1 35
end geom
read plot
ttl=!solution sphere!
plt=yes pic=mixture xul=-36 yul=0 zul=36 xlr=36 ylr=0 zlr=-36 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=75
nch=!.f*w ! end
end plot
end data
end

```

Table A.4 Case 82

```

#csas25
HEU-SOL-THERM-012 case1 22 gm/l solution sphere
27groupndf4 multiregion
h2o 3 den=.99702 1.0 293 end
arbm1 2.71 4 0 0 0 13027 98.7 14000 .995 29000 .3 25055 .005 2 1.0 293 end
solnuo2f2 1 21.970 0 spg=1.0265 1.0 293 92234 .98 92235 93.18 92236 .5 92238
5.34 end
end comp
spherical vacuum reflected 0 end
1 27.9244 2 28.1244 3 43.1244 end zone
more data end
solution 22 g/l 27 gp xsec

```

```
read parm gen=800 npg=600 nsk=100 run=yes plt=no tme=600 nub=yes end parm
read geom
unit 1
com=!solution sphere!
sphere 1 1 27.9244
sphere 2 1 28.1244
sphere 3 1 43.1244
end geom
read plot
ttl=!solution sphere!
plt=yes pic=mixture xul=-36 yul=0 zul=36 xlr=36 ylr=0 zlr=-36 uax=1 vax=0
wax=0 udn=0 vdn=0 wdn=-1 nax=75
nch=!.f*w ! end
end plot
end data
end
```

Table A.4 Case 83

#csas25

HEU-SOL-THERM-010 case1 102 gm/l solution sphere 27.5 o f

27groupndf4 multiregion

h2o 3 den=.99702 1.0 293 end

arbmal 2.71 4 0 0 0 13027 98.7 14000 .995 29000 .3 25055 .005 2 1.0 293 end

solnuo2f2 1 102.06 0 spg=1.1159 1.0 293 92234 1.1 92235 93.13 92236 .5 92238

5.27 end

end comp

spherical vacuum reflected 0 end

1 13.2123 2 13.3393 3 35 end zone

more data end

solution 22 g/l 27 gp xsec

read parm gen=800 npg=600 nsk=100 run=yes plt=no tme=600 nub=yes end parm

read geom

unit 1

com=!solution sphere!

sphere 1 1 13.2123

sphere 2 1 13.3393

sphere 3 1 35

end geom

read plot

ttl=!solution sphere!

plt=yes pic=mixture xul=-36 yul=0 zul=36 xlr=36 ylr=0 zlr=-36 uax=1 vax=0

wax=0 udn=0 vdn=0 wdn=-1 nax=75

nch=!.f*w

! end

end plot

end data

end

APPENDIX D 27 Group Comparison Results

Discussion and analysis of the data contained in Table D-1 follows in Appendix E.

Table D-1. Results From SRS and WSMS SCALE 4.4 (27grp) Comparison.

	file	DFS k_{eff}	DFS σ	WSMS k_{eff}	WSMS σ	Δk
1	HEUMTS01.out	1.0060	0.0012	1.0057	0.0012	0.0003
2	HEUMTS22.out	1.0052	0.0013	1.0035	0.0013	0.0017
3	HEUMTS31.out	1.0090	0.0016	1.0083	0.0016	0.0007
4	HEUMTS61.out	1.0196	0.0012	1.0168	0.0012	0.0028
5	HEUMTS65.out	1.0329	0.0015	1.0333	0.0014	-0.0004
6	HEUMTS09.out	0.9976	0.0012	0.9997	0.0012	-0.0021
7	HEUMTS23.out	1.0016	0.0012	0.9985	0.0012	0.0031
8	HEUMTS67.out	0.9859	0.0013	0.9885	0.0012	-0.0026
9	HEUMTS71.out	0.9796	0.0013	0.9808	0.0016	-0.0012
10	HEUMTS99.out	0.9956	0.0009	0.9967	0.0009	-0.0011
11	tn15.out	1.0101	0.0014	1.0107	0.0016	-0.0005
12	HEUSLS05.out	1.0062	0.0018	1.0048	0.0018	0.0014
13	HEUSLS13.out	1.0106	0.0023	1.0100	0.0018	0.0006
14	HEUSLS27.out	1.0109	0.0017	1.0085	0.0017	0.0024
15	HEUSLS66.out	1.0090	0.0019	1.0062	0.0019	0.0028
16	HEUSLS67.out	1.0021	0.0015	1.0002	0.0016	0.0020
17	HEUSLS10.out	0.9971	0.0018	0.9993	0.0017	-0.0022
18	HEUSLS33.out	1.0102	0.0018	1.0078	0.0016	0.0024
19	HEUSLS43.out	1.0062	0.0015	1.0075	0.0016	-0.0013
20	HEUSLS63.out	0.9973	0.0015	0.9973	0.0016	0.0000
21	HEUSLS72.out	1.0000	0.0015	1.0004	0.0016	-0.0004
22	HEUSLS75.out	1.0123	0.0017	1.0126	0.0015	-0.0003
23	HEUSLS78.out	1.0056	0.0017	1.0105	0.0015	-0.0049
24	HEUSLS79.out	1.0021	0.0019	1.0059	0.0015	-0.0039
25	HEUSLS81.out	1.0074	0.0015	1.0066	0.0015	0.0008
26	HEUSLS82.out	1.0003	0.0012	0.9992	0.0013	0.0012
27	HEUSLS84.out	1.0096	0.0015	1.0096	0.0017	0.0000
28	PU_MTS02.out	0.9997	0.0014	0.9994	0.0016	0.0003
29	PU_MTS06.out	0.9965	0.0010	0.9992	0.0010	-0.0028
30	PU_MTS08.out	0.9922	0.0016	0.9939	0.0016	-0.0017
31	PU_MTS23.out	0.9997	0.0015	0.9976	0.0017	0.0021
32	PU_MTS25.out	1.0005	0.0018	1.0007	0.0016	-0.0002
33	PU_MTS10.out	0.99208	0.00173	0.9936	0.00149	-0.0015
34	PU_MTS07.out	0.9967	0.0015	0.9920	0.0015	0.0047
35	PU_MTS17.out	0.9870	0.0015	0.9880	0.0015	-0.0010
36	PU_MTS20.out	0.9862	0.0016	0.9888	0.0015	-0.0025
37	PU_MTS21.out	0.9915	0.0014	0.9882	0.0015	0.0033
38	PU_SLS03.out	1.0257	0.0017	1.0281	0.0020	-0.0024
39	PU_SLS14.out	1.0145	0.0011	1.0143	0.0012	0.0002
40	PU_SLS33.out	1.0174	0.0011	1.0175	0.0013	-0.0001
41	PU_SLS42.out	1.0202	0.0018	1.0209	0.0017	-0.0008
42	PU_SLS21.out	1.0141	0.0018	1.0148	0.0016	-0.0007
43	PU_SLS08.out	1.0037	0.0015	1.0043	0.0015	-0.0006
44	PU_SLS13.out	1.0103	0.0014	1.0096	0.0015	0.0007

Table D-1. Results From SRS and WSMS SCALE 4.4 (27grp) Comparison (Continued).

	file	DFS	DFS	WSMS	WSMS	
		k_{eff}	σ	k_{eff}	σ	Δk
45	PU_SLS27.out	1.0102	0.0015	1.0091	0.0014	0.0011
46	PU_SLS57.out	1.0088	0.0015	1.0094	0.0014	-0.0006
47	PU_SLS76.out	1.0096	0.0016	1.0088	0.0016	0.0008
48	HEUMTS01.out	0.9975	0.0015	0.9961	0.0012	0.0014
49	HEUMTS04.out	0.9943	0.0014	0.9941	0.0013	0.0002
50	HEUMTS06.out	0.9993	0.0014	1.0008	0.0012	-0.0014
51	HEUMTS10.out	1.0064	0.0013	1.0053	0.0014	0.0011
52	HEUMTS15.out	0.9919	0.0012	0.9927	0.0012	-0.0009
	<i>Mean</i>	1.0038	0.0015	1.0038	0.0015	
	Std. Deviation About Mean	0.0103	0.0003	0.0101	0.0002	

APPENDIX E 238 Group Comparison Results

Table E-1. Results From SRS and WSMS SCALE 4.4 (238grp) Comparison.

	file	DFS	DFS	WSMS	WSMS	
		k_{eff}	σ	k_{eff}	σ	Δk
1	HEUMTS02.out	0.9979	0.0012	0.9971	0.0014	0.0008
2	HEUMTS22.out	0.9979	0.0013	0.9948	0.0013	0.0031
3	HEUMTS31.out	0.9918	0.0015	0.9956	0.0014	-0.0038
4	HEUMTS61.out	0.9945	0.0015	0.9928	0.0013	0.0018
5	HEUMTS65.out	1.0009	0.0015	0.9997	0.0014	0.0011
6	HEUMTS09.out	0.9913	0.0011	0.9931	0.0013	-0.0018
7	HEUMTS23.out	0.9919	0.0014	0.9927	0.0011	-0.0008
8	HEUMTS40.out	0.9949	0.0014	0.9951	0.0014	-0.0002
9	HEUMTS60.out	0.9899	0.0014	0.9909	0.0013	-0.0010
10	HEUMTS99.out	0.9902	0.0008	0.9898	0.0009	0.0004
11	tn15.out	1.00188	0.00123	1.00486	0.00129	-0.0030
12	HEUSLS05.out	1.0031	0.0015	1.0008	0.0014	0.0023
13	HEUSLS13.out	1.0030	0.0016	0.9986	0.0019	0.0044
14	HEUSLS27.out	1.0019	0.0017	1.0021	0.0015	-0.0003
15	HEUSLS66.out	1.0037	0.0015	1.0009	0.0016	0.0029
16	HEUSLS67.out	0.9980	0.0013	0.9989	0.0015	-0.0009
17	HEUSLS10.out	0.9918	0.0018	0.9946	0.0017	-0.0029
18	HEUSLS33.out	1.0024	0.0020	1.0071	0.0015	-0.0047
19	HEUSLS43.out	1.0018	0.0017	1.0015	0.0016	0.0003
20	HEUSLS63.out	0.9984	0.0014	0.9971	0.0012	0.0013
21	HEUSLS72.out	0.9956	0.0016	0.9959	0.0015	-0.0003
22	HEUSLS75.out	1.0060	0.0017	1.0028	0.0019	0.0031
23	HEUSLS78.out	1.0028	0.0018	1.0035	0.0019	-0.0006
24	HEUSLS79.out	0.9988	0.0017	0.9967	0.0016	0.0021
25	HEUSLS81.out	1.0037	0.0015	1.0043	0.0013	-0.0006
26	HEUSLS82.out	1.0014	0.0011	1.0039	0.0014	-0.0025
27	HEUSLS84.out	1.0027	0.0017	1.0037	0.0015	-0.0010
28	PU_SLS03.out	1.0227	0.0010	1.0219	0.0009	0.0008
29	PU_SLS14.out	1.0111	0.0011	1.0081	0.0011	0.0030
30	PU_SLS21.out	1.0124	0.0014	1.0081	0.0011	0.0043
31	PU_SLS27.out	1.0050	0.0015	1.0074	0.0013	-0.0024
32	PU_SLS33.out	1.0128	0.0011	1.0143	0.0011	-0.0015
33	PU_SLS42.out	1.0077	0.0014	1.0095	0.0016	-0.0017
34	PU_SLS08.out	0.9981	0.0014	0.9997	0.0013	-0.0016
35	PU_SLS13.out	1.0041	0.0015	1.0056	0.0014	-0.0016
36	PU_SLS57.out	1.0009	0.0014	1.0019	0.0015	-0.0010
37	PU_SLS76.out	1.0040	0.0015	1.0022	0.0012	0.0019
38	PU_MTS02.out	0.9949	0.0015	0.9978	0.0015	-0.0029
39	PU_MTS07.out	0.9933	0.0015	0.9951	0.0015	-0.0018
40	PU_MTS08.out	0.9912	0.0013	0.9913	0.0015	-0.0001
41	PU_MTS10.out	0.994	0.0015	0.9917	0.0014	0.0023
42	PU_MTS14.out	0.9897	0.0014	0.9909	0.0015	-0.0011
43	PU_MTS17.out	0.9906	0.0013	0.9883	0.0015	0.0022
44	PU_MTS20.out	0.9915	0.0014	0.9897	0.0014	0.0018
45	PU_MTS22.out	0.9921	0.0015	0.9892	0.0015	0.0029

Table E-1. Results From SRS and WSMS SCALE 4.4 (238grp) Comparison (Continued).

	file	DFS	DFS	WSMS	WSMS	
		k_{eff}	σ	k_{eff}	σ	Δk
46	PU_MTS25.out	0.9995	0.0018	0.9993	0.0014	0.0003
47	PU_MTS23.out	0.9962	0.0013	0.9933	0.0013	0.0030
48	SPTD01.238	0.9978	0.0017	1.0017	0.0015	-0.0039
49	SPTD04.238	0.9958	0.0013	0.9935	0.0014	0.0023
50	SPTD06.238	0.9999	0.0013	1.0009	0.0012	-0.0010
51	SPTD10.238	1.0072	0.0013	1.0077	0.0014	-0.0005
52	SPTD15.238	0.9936	0.0013	0.9936	0.0014	0.0000
	<i>Mean</i>	0.9993	0.0014	0.9993	0.0014	
	Std. Deviation About Mean	0.0068	0.0002	0.0069	0.0002	

As seen above in Tables D-1 and E-1, the k_{eff} means and standard deviations are very similar (small differences in the 4th decimal place). Due to the fact that the bias/bias uncertainties determined in the WSMS validation documents are only reported to three decimal places, the WSMS validation results and the WSRC validation results would be the same. This results from the fact that a lower tolerance limit is calculated by the equation:

$$K_L = (\text{Mean } K_{eff}) - U S_P$$

where U is a constant (one-sided lower tolerance factor) and S_P is the square root of the pooled variance. S_P is given by:

$$S_P = \sqrt{(s)^2 + (\sigma)^2}$$

where s^2 is the variance (standard deviation) about the mean squared, and σ^2 is the average uncertainty squared. As seen in Tables D-1 and E-1, all of these values are the same between the WSRC and WSMS data, except for the standard deviation about the mean, which at the worst is within two units of the fourth decimal place. This insignificant difference would vanish due to the truncation of the fourth decimal place when LTL values are reported, yielding the same result.

In conclusion, the above results of the subset comparisons prove that the WSMS SCALE 4.4 validation serves as an effective validation of the WSRC certified SCALE 4.4 code, in addition to providing correct and accurate bias and bias uncertainty.