**Criticality Safety Validation:
Simple Geometry, Single Unit ^{233}U Systems**

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Abstract

Typically used LMITCO criticality safety computational methods are evaluated for suitability when applied to INEEL ^{233}U systems which reasonably can be modelled as simple-geometry, single-unit systems.

Sixty-seven critical experiments of uranium highly enriched in ^{233}U , including 57 aqueous solution, thermal-energy systems and 10 metal, fast-energy systems, were modelled. These experiments include 41 cylindrical and 26 spherical cores, and 41 reflected and 26 unreflected systems. No experiments were found for intermediate-neutron-energy ranges, or with interstitial non-hydrogenous materials typical of waste systems, mixed ^{233}U and plutonium, or reflectors such as steel, lead, or concrete. No simple geometry experiments were found with cubic or annular cores, or approximating *infinite sea* systems.

Calculations were performed with various tools and methodologies. Nine cross-section libraries, based on ENDF/B-IV, -V, or -VI.2, or on *Hansen-Roach* source data, were used with cross-section processing methods of MCNP or SCALE. The k_{eff} calculations were performed with neutral-particle transport and Monte Carlo methods of criticality codes DANT, MCNP 4A, and KENO Va.

Keywords: criticality safety validation, ^{233}U , 233-uranium, U-233, nuclear critical experiment, homogeneous, moderated, unmoderated, sphere, cylinder, metal, solution, reflected, unreflected, bare, uranium, uranyl nitrate, uranyl fluoride, water moderator, water reflector, paraffin reflector, highly enriched ^{235}U reflector, normal uranium reflector, tungsten reflector, beryllium reflector, boron, thermal, fast, ONEDANT, TWODANT, SCALE 4.0, SCALE 4.3, KENO Va., MCNP 4A, *Hansen-Roach*, 27GROUPNDF4, 218GROUPNDF4, 44GROUPNDF5, 238GROUPNDF5, .50c, .55c, .60c, ENDF/B-IV, ENDF/B-V, ENDF/B-VI.2, INEL, INEEL

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Abbreviations, Acronyms, Initialisms, and Symbols

afg	average fission group as calculated by KENO in SCALE 4.0 and 4.3
ale	average lethargy energy causing fission as calculated by KENO in SCALE 4.3
ANS	American Nuclear Society (La Grange Park, Illinois)
ANSI	American National Standards Institute, Inc.
CCC	RSIC Computer Code Collection
CS	criticality safety
DANTSYS	Diffusion-Accelerated Neutral Particle Transport Code System
DOE	U. S. Department of Energy (Government Printing Office: Washington D. C.)
EG&G	EG&G of Idaho, Inc. (Idaho Falls, Idaho), contract assumed by LITCO, currently LMITCO
ENDF	Evaluated Nuclear Data File
ENDF/B-x	ENDF data version B release x, where x is a roman numeral. In the case of ENDF/B-VI.2, the arabic numeral 2 indicates the second edition or revision of release six.
exp.	experiment
<i>fm</i>	fissile material
ID	inner diameter, or Idaho
INEEL	Idaho National Engineering and Environmental Laboratory. Formerly Idaho National Engineering Laboratory (INEL), formerly National Reactor Testing Station (NRTS). Herein limited to INEEL parts currently operated by LMITCO
IR	inner radius
JENDL-3	Japan Evaluated Nuclear Data Library release 3
LANL	Los Alamos National Laboratory (University of California: Los Alamos, New Mexico), formerly LASL
LASL	Los Alamos Scientific Laboratory (University of California: Los Alamos, New Mexico), currently LANL
LITCO	Lockheed Idaho Technologies Company, Inc. (Idaho Falls, Idaho), currently LMITCO
LMITCO	Lockheed Martin Idaho Technologies Company, Inc. (Idaho Falls, Idaho), formerly LITCO

LLNL	Lawrence Livermore National Laboratory (University of California: Livermore, California)
M_c	^{233}U critical mass
m	mass
max	maximum
min	minimum
mtl	material
NA	not applicable
N_A	Avogadro's number, 6.0221×10^{23} particles/g-mole from the <i>GE Handbook</i>
NEA	OECD Nuclear Energy Agency
nEm	numeric value of $n \times 10^m$
N_n	density (particles/b-cm) of nuclide n
nom	nominal
NRC	U. S. Nuclear Regulatory Commission (Government Printing Office: Washington D. C.)
NUREG	NRC report or document
OD	outer diameter
OECD	Organization for Economic Co-Operation and Development (OECD Publications: Paris France)
ONEDANT	One-Dimensional Diffusion-Accelerated Neutral Particle Transport
OR	outer radius
ORNL	Oak Ridge National Laboratory (Lockheed Martin Energy Systems: Oak Ridge, Tennessee). As used here, includes K-25 and Y-12 plants now operated by separate organizations. Formerly operated by Martin Marietta Energy Systems, Inc., formerly operated by Union Carbide Nuclear Company, Union Carbide Corporation
RSIC	Radiation Safety Information Center (ORNL), currently RSICC
RSICC	Radiation Safety Information Computational Center (ORNL), formerly RSIC
SCALE	Standardized Computer Analyses for Licensing Evaluation
sol'n	solution

spg specific gravity

TWODANT Two-Dimensional Diffusion-Accelerated Neutral Particle Transport

VF volume fraction

W atomic mass of an isotope or element, from the *GE Handbook*

w/ with

w/o without

WVF water volume fraction (usually in fissile material)

number or identifier

ρ mass density or concentration, assumed to be theoretical density in g/cm³ (from, in order of preference, *SCALE 4.2*, *GE Handbook*, *CRC Handbook*, and *Lange*) unless otherwise specified

σ standard deviation for values calculated with Monte Carlo methods (KENO, MCNP) or standard deviation of an averaged value (for example, of k_{eff} averaged over a set of calculations)

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1 Introduction

Typically used LMITCO criticality safety computational methods are evaluated for suitability when applied to INEEL ^{233}U systems. Validation work is divided into three separately reported categories: (1) simple-geometry, single-unit systems, (2) simple-geometry arrays, and (3) Shippingport LWBR fuels. This report addresses the first category.

Calculations modelling 67 single-unit critical experiments were performed with various tools and methodologies. Nine cross-section libraries, based on ENDF/B-IV, -V, or -VI.2, or on Hansen-Roach source data, were used with cross-section processing methods of MCNP or SCALE. The k_{eff} calculations were performed with neutral-particle transport and Monte Carlo methods of criticality codes DANT, MCNP 4A, and KENO Va.

The 67 critical experiments include 57 aqueous solution, thermal-energy systems and 10 metal, fast-energy systems. These experiments include 41 cylindrical and 26 spherical cores, and 41 reflected and 26 unreflected systems. No experiments were found for intermediate-energy ranges, or with interstitial non-hydrogenous materials typical of waste systems, mixed ^{233}U and Pu, or reflectors such as steel, lead, or concrete. No simple geometry experiments were found with cubic or annular cores, or approximating *infinite sea* systems.^a

The body of this report describes applicable INEEL systems and method validation techniques, and summarizes validation calculations. Experiments and validation calculations are further described in experiment-specific Appendices C through H. Descriptions include more information than typical at request of personnel who supported this study. Appendices A and B respectively list formulas to calculate nuclide densities and evaluate method validity.

2 General Descriptions of INEEL ^{233}U Systems

Typical INEEL ^{233}U systems which reasonably can be enveloped with simple geometry models are categorized as small masses and radioactive waste.^b Each category is briefly described to identify parameters which affect benchmark experiment selection.

2.1 Small Masses

Small masses of fissionable materials, primarily ^{233}U , ^{235}U , ^{239}Pu , and ^{240}Pu , may be present in Mass Limit Criticality Control Areas in accordance with the *LMITCO CS Manual*. Most if not all areas are isolated from each other, areas which may contain large masses of fissionable material, and fissionable material in transfers and shipments.

a An infinite-sea is a homogeneous fissionable-solution system which is infinitely large.

b Nuclear fuel is not addressed. Although nuclear fuel can be modelled in a manner compatible with experiment models here, results are usually too conservative to provide operationally efficient controls.

Fissionable material mass limits range from 175 to 350g, depending on which fissionable nuclides (^{233}U , ^{235}U , ^{239}Pu , and ^{240}Pu) or combinations of nuclides are present. These limits are based on single-parameter subcritical limits of standard ANSI/ANS-8.1 for optimized, water-moderated and -reflected configurations of fissionable material, assuming a double-batch of fissionable material is unlikely but credible.^a

However, these subcritical limits do not necessarily assure safety for all cases because some materials moderate or reflect neutrons better than water. Such materials readily available at INEEL include lead, steels, occasionally beryllium, and others depending on missions. Material-specific nonfissionable mass limits are established for highly efficient neutron moderating and/or reflecting materials in Mass Limit Criticality Control Areas, if it might otherwise be credible to accumulate critically unsafe quantities of such materials.

Benchmarks to validate ^{233}U calculations for isolated Mass Limit Criticality Control Areas should envelope small masses (700g or less) of optimally moderated and reflected ^{233}U , alone and mixed with ^{240}Pu . Benchmarks should envelope all enrichments and, based on Clark's 1982 evaluation, lower epithermal through thermal neutron energy ranges. Benchmarks applied to isolated Mass Limit Criticality Control Areas may be single-unit systems. Benchmarks approximating *infinite-sea* systems and benchmarks of array systems are useful but not essential for these areas.^b

2.2 Typical Radioactive Waste

Most INEEL radioactive waste is packaged in 55-gallon drums or in large, lined wood boxes and stored in the Radioactive Waste Management Complex. Containers received long ago were stored in underground, tarp-covered, three-dimensional arrays. Containers received since 1982, and containers recovered from underground, are stored in weather-protected, above-ground, three-dimensional arrays.

Typical radioactive waste is a variety of radioactively contaminated items for which decontamination is uneconomical or unfeasible.^c Contamination is normally well distributed throughout a waste container but it can be very concentrated in relatively small volumes of a container. In most if not all cases waste contains no more than trace quantities of fissionable material which, because the material cannot concentrate significantly, is not a criticality safety concern. However, it is hypothetically possible to have contamination which includes a quantity or concentration which could be a criticality safety concern. These hypothetical cases could include ^{233}U alone or mixed with other fissionable isotopes.

- a Although there are other fissionable materials at INEEL, mass limits are not specifically established for many actinides because cumulative totals at INEEL are a very small percentage of their respective minimum critical masses predicted in ANSI/ANS-8.15.
- b Applicable benchmarks for Mass Limit Criticality Control Areas which are not completely isolated should include array systems, the subject of a separately reported, in-progress validation study.
- c Typical radioactive waste does not contain nuclear fuel. However, at an INEEL waste facility there are currently a few drums packed with many pieces of a ^{233}U -Th fuel from the Navy's Shippingport Light Water Breeder Reactor program. This fuel is the subject of a separately reported, in-progress validation study.

Validation for ^{233}U in typical INEEL waste systems should address:

- Well-distributed ^{233}U , enveloped by dilute ^{233}U systems in which fissionable material is matrixed with a variety of materials. Validation should address lower epithermal through thermal neutron energy ranges, common interstitial materials, and common reflecting materials. However, with exception of hydrogenous moderators and reflectors, few experiments were found which envelope common interstitial waste materials. In general hydrogenous moderating materials should envelope any significant quantity of nonfissionable waste material at INEEL. For waste material benchmarks which approximate *infinite-sea* systems are also desirable but no applicable critical experiments were found.
- Small pocket(s) of concentrated ^{233}U , enveloped by small mass ^{233}U systems previously described (part 2.1, page 1).

3 Requirements Documentation

Standard, general criticality-safety-validation requirements, specified in ANSI/ANS-8.1 and DOE O 420.1, apply to this report. To satisfy detailed requirements people who use information reported here must indicate applicability to their specific evaluation(s).

Although not required, values are reported in formats consistent with the *Benchmark Handbook*. In some cases these formats are inconsistent with significant figures. For example, calculated k_{eff} s are always reported to four decimal places although such k_{eff} s typically have only two or three significant figures. This format is used for comparison convenience; its use does not imply greater precision than typical for criticality safety calculations.

4 Methodology

4.1 Modeling: Simplifications

Model simplifications are based on descriptions from the *Benchmark Handbook* where available. Otherwise, simplifications are based on experiment descriptions, criticality safety experience, and engineering judgement, and checked or enveloped by sensitivity calculations. Unless otherwise specified, base-case-model simplifications include:

- room temperature (25° C),
- homogenized mixtures for materials with relatively uniform density or concentration,
- naturally-occurring isotopic compositions if specific compositions are not reported,

-
- typical manufactured materials if specific material types are not reported (for example, SS304 is assumed if stainless steel type is not specified),
 - premixed cross-section-library materials if available for materials outside the fissionable core,
 - neglect of small quantities of materials which have relatively insignificant macroscopic neutron-cross-sections,
 - substitute nuclide(s) with similar cross sections if a cross-section-library does not include a significant nuclide,
 - void for air, a reasonable approximation even in humid climates,
 - nominal values for dimensions,
 - typical dimensions from contemporary critical experiments or criticality safety evaluations for vessels and reflectors when specific dimensions are not reported,
 - neglect of minor deviations from intended or idealized geometries,
 - neglect of items which, because of their location, orientation, and/or intervening materials, should have negligible effect on a fissionable system, and
 - elimination of, or filling with void, volumes associated with neglected materials.

4.2 Modeling: Nuclide Density Calculations

Appendix A lists general formulas used in calculating nuclide densities for this validation. Calculation results are listed in experiment-specific appendices.

4.3 Modeling: Parameter Sensitivity and Uncertainty

Affects of environmental variances, manufacturing tolerances, composition uncertainties, measurement uncertainties, and small changes in parameters on which criticality safety controls might be based are either specifically addressed or generally enveloped in sensitivity calculations. Sensitivity calculations performed for the *Benchmark Handbook* are used when available if base-case calculation results compare well. Otherwise, information is obtained by modifying base-case models, primarily addressing cumulative affects. If sufficient information is not identified, sensitivity calculations address typical measurement and manufacturing uncertainties, usually based on experience with ^{235}U critical experiment documents.

4.4 Computations: Platform

All criticality calculations were performed on Hewlett-Packard workstations using HP-UX operating systems (HP-UX 9.05 or 10.01). Available workstations were used interchangeably because they were verified to produce the same results for identical input and start values.^a

4.5 Computations: Codes and Code Options

Most criticality codes include cross-section processing and k_{eff} computation codes. Codes and associated options available for k_{eff} computations include:

- ONEDANT and TWODANT, the one- and two-dimensional options of DANTSYS, a diffusion-accelerated transport code described in LA-12969-M. In all cases here, cross-section libraries described in *SCALE 4.0* and *SCALE 4.3* are used by processing data through a CSASI module for SCALE. Developed at INEEL by Montierth with Petrie's assistance, CSASI processes cross-sections through BONAMI, NITAWL-II, and ICE-S, producing libraries compatible with DANTSYS formats.^a Unless otherwise noted, 1×10^{-6} convergence criteria are used.
- CSAS25 module, described in *SCALE 4.0* and *SCALE 4.3*, which sequentially uses BONAMI and NITAWL-II to process cross-section data for KENO-Va, a three-dimensional Monte Carlo criticality code. KENO-Va programming is the same in these code versions but small differences between cross-section-processing codes are possible.
- The criticality option of MCNP, a three-dimensional Monte Carlo code, as described in *MCNP 4A*.

With exception of cross-section libraries, calculations performed with DANTSYS, SCALE, and MCNP are mostly independent but calculations performed with different versions or options within a code system are not necessarily independent. Independence between systems is due to theories from which codes are developed (transport or Monte Carlo), geometry packages, neutron-tracking methods, methods for treating shielding and self-shielding, and code developers. Strategies for handling specific modelling problems (single units, arrays of identical units, arrays of different units, intersecting units, and more complicated geometric surfaces) can be significantly different but are usually similar between code versions.

4.6 Computations: Cross Section Libraries

Several nuclear cross section libraries and criticality codes are available. When there is a significant difference between k_{eff} s calculated by different library-and-code combinations, the library data or its processing is usually the cause. (For example, one generally expects more consistency between results from ONEDANT and CSAS25 with the *27GROUPNDF4* library than between CSAS25 with *Hansen-Roach* and *27GROUPNDF4* libraries.)

^a Leland M. Montierth, discussions, June 1996 and May 1997.

Libraries and codes are typically used in particular combinations at INEEL. Combinations are limited by compatible data formats, general practice, and validation results.

- *.50c*: an MCNP pointwise (continuous) data library described in *MCNP 4A*, primarily based on ENDF/B-V data. This library is used for most INEEL criticality safety calculations performed with MCNP and is currently incompatible with INEEL processing for DANTSYS and SCALE. This library does not include premixed materials for water, stainless steel, and other compounds.

.50c cross-section data are here supplemented by *MCNP 4A .55c* data, independently developed by the LANL Applied Nuclear Science Group. Data from *.55c* is used if *MCNP 4A* indicates this library is the best available for a specific nuclide.

- *.60c*: an MCNP pointwise (continuous) data library, primarily based on ENDF/B-VI.2 data. Available to INEEL personnel through MCNP code developers, this library is not described in current *MCNP 4A* documentation. As implemented at INEEL *.60c* does not yet include all nuclides listed for *.50c* and it does not include rev. 3 or later corrections.
- *Hansen-Roach*: a SCALE, 16-group, Knight-modified Hansen-Roach library described in *SCALE 4.0* and *SCALE 4.3*. Consisting primarily of data developed for fast-neutron systems and unchanged since the 1970s, *Hansen-Roach* was used for most INEEL criticality safety calculations performed before 1990.^a Although *Hansen-Roach* includes modifications to improve results for thermal neutron systems, this library is expected to perform less well for thermal than for fast systems. *Hansen-Roach* is included here only because we sometimes use it to resolve discrepancies between evaluations performed before and after 1990. *Hansen-Roach* is rarely if ever used now at INEEL for criticality safety evaluations.
- *27Grev*: a 27-group library, mostly collapsed from the *218G(4.0)* library described next. Library data for nuclides used here are described in *SCALE 4.0* and most are tagged with an October 12, 1989 update note. However the INEEL-implemented library is not the *SCALE 4.0* library because it contains a few added or more recently updated data for nuclides not applicable to this study. *27Grev* is used for most INEEL criticality safety calculations performed with SCALE 4.0 codes and, processed through CSASI, with DANTSYS codes. This library is called *27Grev* here to distinguish it from other libraries with the *27GROUPNDF4* name.
- *218G(4.0)*: a 218-group library described in *SCALE 4.0*, primarily based on ENDF/B-IV data, which also includes premixed data for commonly used compounds such as water and some stainless steels. Petrie indicates ²³³U data in unresolved resonance energy

^a SCALE's *Hansen-Roach* library includes premixed cross-sections for stainless steels and inconel, collapsed from the *218GROUPNDF4* library, which are not part of the original Knight-modified *Hansen-Roach* data.

ranges was generated assuming infinite dilution.^a Hopper and Westfall recommend

218G(4.0) for ^{233}U calculations with SCALE 4.0 codes.^{b,c} This library is called 218G(4.0) here to distinguish it from later releases with the 218GROUPNDF4 name.

- 27GROUPNDF4: a 27-group library collapsed from the 218GROUPNDF4 library described next. This library should be identical to 27Grev previously described for nuclides used here, but there are some differences for a few other nuclides. 27GROUPNDF4 is primarily used with SCALE 4.3 codes but it can be processed through CSASI for use with DANTSYS codes.
- 218GROUPNDF4: a SCALE, 218-group library described in SCALE 4.3, primarily based on ENDF/B-IV data. This library should be identical to 218G(4.0) previously described for nuclides used here. However, data for some other nuclides were updated between SCALE 4.0 and 4.3. 218GROUPNDF4 is rarely used at INEEL but it can be used with SCALE 4.3 codes. Although not recommended because of lengthy run times, 218GROUPNDF4 can also be processed through CSASI for use with DANTSYS codes.
- 44GROUPNDF5: a 44-group library collapsed from the 238GROUPNDF5 library described next. 44GROUPNDF5 can be used with SCALE 4.3 codes or processed through CSASI for use with DANTSYS codes.
- 238GROUPNDF5: a 238-group library described in SCALE 4.3, primarily based on ENDF/B-V data. Petrie indicates ^{233}U library data in unresolved resonance energy ranges was generated using Bonderenko correction factors. He further indicated ^{233}U ENDF/B-IV and -V source data are identical.^a Hopper and Westfall expect 238GROUPNDF5 will be the best current SCALE library for ^{233}U .^{b,c} This library can be used with SCALE 4.3 codes. Although not recommended because of lengthy run times, 238GROUPNDF5 can also be processed through CSASI for use with DANTSYS codes.

These libraries are partially independent. Independence includes data sources (ENDF or Hansen-Roach), nuclide-specific data updates (ENDF/B-IV, -V, or -VI.2), and final-processing-method differences (MCNP or SCALE codes). Non-independence includes using NJOY to process source data initially, similarity in final-processing between successive versions of a code, and source data that is not updated when data for other nuclides are updated. For example, Parks, Petrie, and Westfall state ENDF ^{233}U source data has not been updated since ENDF/B-IV or earlier.^{a,c,d}

a Lester J. Petrie, www internet electronic mail, "Re: U233 Cross-Sections," October 21, 1996

b Calvin M. Hopper, telephone conversations, June and July, 1996.

c Robert Michael Westfall, telephone conversations, June, 1996.

d Cecil V. Parks, www internet electronic mail, "Re: U233 Cross-Sections," October 21, 1996.

Although not yet readily available for INEEL criticality safety calculations, Hopper indicates Japan's JENDL-3 library incorporates additional, measured ^{233}U data in thermal and lower epithermal energy ranges.^a ORNL/TM-13313 indicates JENDL ^{233}U data performs better in thermal ranges with SCALE 4.3 than the *238GROUPNDF5* library. JENDL-3 probably also performs better for ^{233}U systems in epithermal ranges, but no applicable benchmark experiments are yet identified to validate this supposition. JENDL-3 is mentioned as a possible means of improving calculations, but is not addressed further in this study.

4.7 Computations: Library-and-Code Combinations

Calculations for each experiment were performed with base-case models and most typically used or recommended library-and-code combinations. Where practical, calculations were also performed for each experiment with atypical combinations to identify best readily available combination(s). However, few calculations were performed with *44GROUPNDF5* cross-sections and ONEDANT or TWODANT due to lengthy run times (more than one week each in some TWODANT cases). No calculations were performed with larger cross-section libraries and either ONEDANT or TWODANT for similar reasons.

4.8 Computations: Code Verification

Code verification confirms proper installation of cross-section libraries and criticality codes on a specific computation platform. As defined here code verification addresses result reproducibility within an environment and between user and developer environments. Verification usually does not address result accuracy and precision, the subject of method validation, although critical experiments may be modelled for both purposes.

Montierth indicates code verification is complete for DANTSYS, CSAS25 modules of SCALE 4.0 and 4.3, and the criticality option of MCNP on platforms used here.^b No platform-specific bias need be applied to criticality calculations using standard library-and-code combinations for this criticality-safety software. If the same verification method produces similar results on another platform, validation results reported here are generally applicable to calculations performed on the other platform with the same library-and-code combinations.

4.9 Interpreting Results

Deviations of $k_{\text{eff,calculated}}$ values from $k_{\text{eff,measured}}$ or $k_{\text{eff,benchmark}}$ values are analyzed to identify potential deviation sources, describe trends, and quantify biases where applicable. In all cases a standard deviation (1σ) reported with an averaged k_{eff} is the standard deviation of calculated k_{eff} s from the averaged k_{eff} . Appendix B describes methods for calculating averages, cumulative uncertainties, biases, and bias contributors.

^a Calvin M. Hopper, telephone conversations, June and July, 1996.

^b Montierth, Leland M. Montierth, discussions, June 1996 and May 1997. Also see Montierth's Code Verification File (reference 20).

5 U233-SOLN-THERM-001 Experiments

Identified as U233-SOLN-THERM-001, the *Benchmark Handbook* includes five benchmark critical experiments involving unreflected, thermalized ^{233}U solution systems. Appendix C lists detailed information about experiments, calculations, and analysis summarized here. The *Benchmark Handbook* provides further experiment information.

Each experiment involved a uranyl-nitrate solution, highly enriched in ^{233}U , in an unreflected thin-walled aluminum sphere. Solutions, comprised of uranyl nitrate, thorium acid, and nitric acid, were basically the same throughout this experiment series except for successive boron additions. One spherical aluminum solution vessel was used in all experiments.

Benchmark experiment descriptions, developed by Sapir for the *Benchmark Handbook*, are used in this study. As shown in Figure 1, benchmarks represent idealized systems of unreflected spherical aluminum shells completely filled with homogenized fissionable solution. Sapir expresses cumulative uncertainty for each benchmark experiment as a Δk (± 0.0031 for the first experiment and ± 0.0033 for the other four experiments).

Affects of benchmark uncertainties are generally more significant than statistical uncertainties inherent in calculation methods. With one exception, average, calculated k_{eff} values are within the Δk uncertainty of the benchmarks' critical k . With a few notable exceptions, individually calculated k_{eff} values are likewise within their respective benchmark's critical k uncertainty.

Table 1 lists averaged calculation results with various library-and-code combination(s). Most individually calculated k_{eff} values, listed in Appendix C, are within $\pm 2\sigma$ of critical ($k = 1.0000$) where σ is the statistical uncertainty of the selected Monte-Carlo method, and all calculated k_{eff} values are within 0.5% of critical ($\Delta k = \pm 0.005$).

Tables 2 and 3 respectively list recommended calculated biases and cumulative experiment uncertainty effects. Biases do not incorporate calculation-method statistical-variation and do not address experiment uncertainty effects.

Figure 1 U233-SOLN-THERM-001 Idealized Experiments and Models

Table 1 Methodology Comparison for U233-SOLN-THERM-001 Experiments			
Library-and-Code Combination	Internal Reference	Averaged k_{eff}	Benchmark Handbook k_{eff} ^a
27GROUPNDF4/CSASI/SCALE4.3/ONEDANT	Table C-11, page C-8	1.0020 ± 0.0005	1.0017 ± 0.0007
27Grev/CSAS25/SCALE4.0	Table C-10, page C-8	1.0021 ± 0.0013	1.0019 ± 0.0004
27GROUPNDF4/CSAS25/SCALE4.3	Table C-8, page C-7	1.0027 ± 0.0012	1.0019 ± 0.0004
218GROUPNDF4/CSAS25/SCALE4.3	Table C-8, page C-7	0.9996 ± 0.0021	calculation not performed
44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	Table C-11, page C-8	0.9991 ± 0.0006	
44GROUPNDF5/CSAS25/SCALE4.3	Table C-9, page C-7	0.9992 ± 0.0007	
238GROUPNDF5/CSAS25/SCALE4.3	Table C-9, page C-7	0.9963 ± 0.0015 ^b	
.50c/MCNP4A	Table C-13, page C-9	1.0001 ± 0.0022	1.0007 ± 0.0007
.60c/MCNP4A	Table C-13, page C-9	0.9974 ± 0.0023 ^c	0.9971 ± 0.0005
Hansen-Roach/CSAS25/SCALE4.3	Table C-7, page C-7	1.0007 ± 0.0024	1.0051 ± 0.0005

a Average of most comparable *Benchmark Handbook* sample calculations.

b Average is not within experiment uncertainty Δk .

c Two of five results included in this average are less than range defined by benchmark $k - \Delta k_{uncertainty}$.

Table 2 Recommended Calculation Biases Based on U233-SOLN-THERM-001 Experiments ^a			
Cross-Section Library	Bias Δk	Cross-Section Library	Bias Δk
27Grev & 27GROUPNDF4	0.000	.50c	0.000
218G(4.0) & 218GROUPNDF4	0.000	.60c	0.003
44GROUPNDF5	0.000	Hansen-Roach	0.000
238GROUPNDF5	0.004		

a Recommended nonconservative biases for DANTSYS, CSAS25 of SCALE 4.0 and 4.3, and MCNP4A, assuming evaluations use $k_{eff} + 2\sigma$ + bias and separately address validation-experiment uncertainty, which could be significant. See Appendix B.

Table 3 U233-SOLN-THERM-001 Cumulative Experiment Uncertainties ^a (internal reference: Table C-4, page C-4)			
Experiment #	Uncertainty Δk	Experiment #	Uncertainty Δk
1	± 0.0031	4	± 0.0033
2	± 0.0033	5	± 0.0033
3	± 0.0033		

a Experiment-uncertainty effects are not necessarily within typical INEEL Monte Carlo calculation uncertainties, which are usually ± 0.0015 or less.

6 Reflected Solution Experiments from ORNL-2143

ORNL-2143 reports a critical experiment series with aqueous ^{233}U solutions in reflected cylinders and spheres, not currently included in the *Benchmark Handbook*. Appendix D lists information about experiments, calculations, and analysis summarized here. Additional information is described in ORNL-2143, ORNL/TM-12374, and by Primm.^a

Performed during the 1950s at the Oak Ridge Critical Experiments Facility, this experiment series included subcritical and critical configurations, and partially- and fully-reflected configurations. Only critical, fully-reflected configurations are addressed because they are expected to involve less uncertainty. These 26 single-unit experiments include paraffin-reflected cylinders and water-reflected spheres of uranyl nitrate and uranyl fluoride. Experiments include a wide range of H: ^{233}U atom ratios and solution vessel diameters.

Calculation models combine idealized and actual configurations but descriptions are incomplete. Each two- and three-dimensional model includes a homogenous fissionable solution in a cylindrical or spherical vessel centered in a tight-fitting cylindrical reflector, as shown in Figures 2 and 3. One-dimensional models with spherical solution vessels model reflectors as spherical shells. Base-case models neglect material impurities, possible non-uniform densities, control blade, control-blade slot, solution feed- and drain-lines, reflector vessel walls and floor, manufacturing tolerances, measurement uncertainties, etc.

Effects of reported cumulative experiment uncertainty are about $\pm 1\%$ but many calculated k_{eff} s are as much as 2% off, which is significantly greater than typical for ^{235}U systems. Apparently the largest contributor is solution-vessel-wall-thickness uncertainty but there is insufficient evidence to model walls thin enough to provide typical calculation accuracies. A 5% cumulative experiment uncertainty is estimated here due to incomplete descriptions and reported uncertainties. Hopper and Primm indicate research is in progress to improve these experiment descriptions but there is no estimate yet of when improved descriptions will be available.^{a,b}

Table 4 summarizes results with various library-and-code combinations. Relatively high statistical σ s indicate experiment-description uncertainties and difficulty in obtaining convergence in a reasonable run time. Results with SCALE and ENDF/B-IV-based cross-section libraries are most consistent and within 2% of critical, but the .50c/MCNP4A combination produces significantly better results for some experiments. Averaged $k_{\text{eff}} + 2\sigma$ is critical for all combinations except 238GROUPNDF5/CSAS25/SCALE4.3 and Hansen-Roach/CSAS25/SCALE4.3, which are both nonconservative. However individual calculated k_{eff} s can be as much as 6% nonconservative.

Tables 5 and 6 respectively list recommended calculation biases and cumulative experiment uncertainties, if it is necessary to use these experiments for validation. However, these experiments should not be used until more complete descriptions are available if at all practical. Biases do not incorporate calculation-method statistical-variation and do not address experiment uncertainty effects. *In these cases experiment uncertainty effects must be considered significant in validating criticality safety calculations.*

a R. Trenton Primm, III, telephone conversations, June, 1996.

b Calvin M. Hopper, telephone conversations, June and July, 1996.

Figure 2 ORNL-2143 Base-Case Models, Radial Cross Section

Cylinder Experiments

Sphere Experiments

Figure 3 ORNL-2143 Base-Case Models, Axial Cross Section

Table 4 Methodology Comparison for ORNL-2143 Experiments

Library-and-Code Combination	Internal Reference	Averaged k_{eff}
27Grev/CSASI/SCALE4.0/...DANT	Table D-19, page D-22	0.9977 ± 0.0117
27Grev/CSAS25/SCALE4.0	Table D-17, page D-20	0.9962 ± 0.0113
27GROUPNDF4/CSASI/SCALE4.3/...DANT	Table D-18, page D-21	0.9959 ± 0.0116
27GROUPNDF4/CSAS25/SCALE4.3	Table D-15, page D-18	0.9952 ± 0.0111
218GROUPNDF4/CSAS25/SCALE4.3	Table D-15, page D-18	0.9957 ± 0.0125
44GROUPNDF5/CSAS25/SCALE4.3	Table D-16, page D-19	0.9856 ± 0.0121
238GROUPNDF5/CSAS25/SCALE4.3	Table D-16, page D-19	0.9801 ± 0.0120
.50c/MCNP4A	Table D-20, page D-23	0.9881 ± 0.0151
.60c/MCNP4A	Table D-20, page D-23	0.9833 ± 0.0148
Hansen-Roach/CSAS25/SCALE4.3	Table D-14, page D-17	0.9695 ± 0.0162

Table 5 Recommended Calculation Biases Based on ORNL-2143 Experiments^a

Cross-Section Library	Bias Δk	Cross-Section Library	Bias Δk
27Grev & 27GROUPNDF4	0.005	.50c	0.012
218G(4.0) & 218GROUPNDF4	0.004	.60c	0.017
44GROUPNDF5	0.014	Hansen-Roach	0.031
238GROUPNDF5	0.020		

- a Recommended as nonconservative biases for DANTSYS, CSAS25 of SCALE 4.0 and 4.3, and MCNP4A, assuming evaluations use $k_{\text{eff}} + 2\sigma + \text{bias}$ and separately address validation experiment uncertainty, which is significant. The formula $\text{bias} = 1.000 - k_{\text{eff,ave}}$ is used here, without setting any bias zero, because calculation statistical variations are less significant than experiment uncertainties but there is no bases to quantify the part of higher-than-normal $\sigma_{k_{\text{eff,ave}}}$ which is attributable to experiment uncertainty

Table 6 ORNL-2143 Estimated Cumulative Experiment Uncertainties^a
(see page 16)

Parameter	Uncertainty Δk	Parameter	Uncertainty Δk
Critical Mass	0.01	H:U, specific gravity, etc.	0.015
Solution Vessel Wall	0.022	Other estimated unknowns	0.03
Reflector Density	0.005	Average	0.05

- a Insufficiently detailed experiment descriptions are largest contributors. If practical, these experiments should not be used until more complete descriptions are available. Experiment-uncertainty effects are not within typical INEEL Monte Carlo calculation uncertainties, which are usually ± 0.0015 or less.

7 Single Unit Solution Experiments from ORNL-4280

ORNL-4280 reports critical experiments with uranyl nitrate, highly enriched in ^{233}U , in unreflected and reflected cylinders and spheres, not currently included in the *Benchmark Handbook*. Appendix E lists information about experiments, calculations, and analysis summarized here. Additional experiment information is described in ORNL-4280.

Calculation models combine idealized and actual experiment configurations. Each two- and three-dimensional model includes a homogenous fissionable solution in a cylindrical or spherical vessel centered in a cylindrical reflector vessel, as shown in Figures 4 and 5. Base-case models neglect material impurities, possible non-uniform densities, solution feed- and drain-lines, reflector vessel walls and floor, manufacturing tolerances, measurement uncertainties, etc.

Sensitivity, trend, and uncertainty analysis indicate data for one of the nine solutions, designated here as Solution B, are suspect and require further evaluation. However, calculations for experiments involving Solution B are included in Appendix E because these experiments are not completely rejected. They simply are not recommended unless it is not practical to validate criticality safety evaluation calculations without these three experiments.

Cumulative experiment uncertainty effects were larger than expected although most individual contributors are within expected ranges. Exceptions are effects of $\text{H}:^{223}\text{U}$ and solution-critical-height uncertainties which might be significantly overestimated. For these two parameters estimated contributing factors are atypically large but reasonably defended. In all cases cumulative effects exceed typical INEEL-Monte-Carlo-calculation uncertainties. Although better experiment descriptions should reduce these uncertainties, their effects are understood. ORNL-4280 experiments without Solution B, are therefore acceptable for validation purposes, although less recommended than U233-THERM-SOLN-001 experiments (part 5 and Appendix C).

Table 7 summarizes results with various library-and-code combinations, neglecting Solution B experiments. Relatively high statistical σ s partially result from difficulty in obtaining calculation convergence in a reasonable run time. Calculations with the .50c/MCNP4A combination converged more rapidly than other combinations. Except for calculations with *Hansen-Roach* cross-sections, subject combinations perform quite well (well within 1% of critical or conservative) otherwise. The exception is dramatic and consistent with differences between these thermal experiments and the fast-system basis for *Hansen-Roach* cross-sections.

Tables 8 and 9 respectively list recommended calculation biases and cumulative experiment uncertainty effects, neglecting experiments with Solution B. Biases do not incorporate calculation-method statistical-variation and do not address experiment uncertainty. *Experiment uncertainty effects in these cases should be considered significant in validating criticality safety calculations.*

Recommended biases envelope this experiment series as a single set, if suspect solution results are not included. However, Appendix E includes sufficient data to support bias estimates for subsets or supersets of the series (for example, an unreflected experiments bias, a radius-dependent bias, or a bias for the suspect solution).

Figure 4 ORNL-4280 Idealized Experiments, Radial Cross Section

Figure 5 ORNL-4280 Idealized Experiments, Axial Cross Section

Table 7 Methodology Comparison for ORNL-4280 Experiments		
Library-and-Code Combination	Internal Reference	Averaged k_{eff} ^a
27GROUPNDF4/CSASI/SCALE4.3/TWODANT	Table E-22, page E-22	1.0185 ± 0.0188
27Grev/CSAS25/SCALE4.0	Table E-21, page E-21	1.0128 ± 0.0202
27GROUPNDF4/CSAS25/SCALE4.3	Table E-19, page E-19	1.0123 ± 0.0209
218GROUPNDF4/CSAS25/SCALE4.3	Table E-19, page E-19	1.0122 ± 0.0211
44GROUPNDF5/CSAS25/SCALE4.3	Table E-20, page E-20	1.0030 ± 0.0205
238GROUPNDF5/CSAS25/SCALE4.3	Table E-20, page E-20	0.9949 ± 0.0211
.50c/MCNP4A	Table E-23, page E-23	1.0031 ± 0.0143
.60c/MCNP4A	Table E-23, page E-23	0.9988 ± 0.0136
Hansen-Roach/CSAS25/SCALE4.3	Table E-18, page E-18	0.9839 ± 0.0208

a Averages do not include experiments involving Solution B.

Table 8 Recommended Calculation Biases Based on ORNL-4280 Experiments ^a			
Cross-Section Library	Bias Δk	Cross-Section Library	Bias Δk
27Grev & 27GROUPNDF4	0.000	.50c	0.004
218G(4.0) & 218GROUPNDF4	0.000	.60c	0.008
44GROUPNDF5	0.007	Hansen-Roach	0.027
238GROUPNDF5	0.016		

a Recommended as nonconservative biases for DANTSYS, CSAS25 of SCALE 4.0 and 4.3, and MCNP4A, assuming evaluations use $k_{\text{eff}} + 2\sigma + \text{bias}$ and separately address validation-experiment uncertainties, which could be significant. An alternate bias formula described in Appendix B is used with $w_{\sigma} = 0.5$

Table 9 ORNL-4280 Estimated Cumulative Experiment Uncertainties ^a (Internal Reference: Table E-8, page E-10)	
Core Shape	Uncertainty Δk
Spherical (7 Experiments)	0.017
Cylindrical (16 experiments without those involving Solution B)	0.020
Average	0.019

a H^{233}U -atom-ratio uncertainties and critical height uncertainties might be overestimated. Calculated k_{eff} s are very sensitive to both parameters. Experiment-uncertainty effects are not within typical INEEL-Monte-Carlo-calculation uncertainties, which are usually ± 0.0015 or less.

8 ^{233}U Jezebel Experiment, U233-MET-FAST-001

Identified as U233-MET-FAST-001, the *Benchmark Handbook* includes a critical experiment of an unreflected, ^{233}U metal sphere. Appendix F lists information about the experiment, calculations, and analysis summarized here. The *Benchmark Handbook* and LA-4208 describe the experiment further.

The ^{233}U Jezebel Assembly at Los Alamos approximated an ideal unreflected, metal-core, spherical system. The *Benchmark Handbook* describes an ideal experiment, developed from the critical assembly. Summarized in Figure 6, this benchmark description is used here. The benchmark is reported to have an experimental $k_{\text{eff}} = 1.000 \pm 0.001$, which incorporates all experiment uncertainty effects.

Table 10 summarizes results with various library-and-code combinations. Although the .60c/MCNP4A combination produced most accurate k_{eff} s and the Hansen-Roach/CSAS25/SCALE4.3 combination produced most conservative results, all combinations using ENDF/B-V- or ENDF/B-VI.2-based cross-section-libraries produce essentially the same results, within -1% of critical. However, ENDF/B-IV-based SCALE libraries perform poorly (as much as 4% non-conservative), consistent with differences between this metal experiment and infinite-dilution assumptions under which these ^{233}U cross-section-library data were developed.

Tables 11 and 12 respectively list recommended calculation biases and cumulative experiment uncertainty effects. Biases do not incorporate calculation-method statistical-variation and do not address experiment uncertainty effect. Averaged experiment-uncertainty effects are not necessarily within typical INEEL-Monte-Carlo-calculation uncertainties.

Figure 6 Idealized ^{233}U Jezebel Experiment and Model

Table 10 Methodology Comparison for ²³³ U Jezebel (Internal Reference: Table F-6, page F-6)		
Library-and-Code Combination	Calculated k_{eff}	Benchmark Handbook k_{eff} ^a
27Grev/CSASI/SCALE4.0/ONEDANT	0.9645	0.9635
27Grev/CSAS25/SCALE4.0	0.9634 ± 0.0014	0.9625 ± 0.0012
27GROUPNDF4/CSASI/SCALE4.3/ONEDANT	0.9645	0.9635
27GROUPNDF4/CSAS25/SCALE4.3	0.9635 ± 0.0015	0.9625 ± 0.0012
218G(4.0)/CSAS25/SCALE4.0	0.9633 ± 0.0014	calculation not performed
218GROUPNDF4/CSAS25/SCALE4.3	0.9613 ± 0.0014	calculation not performed
44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	0.9960	calculation not performed
44GROUPNDF5/CSAS26/SCALE4.3	0.9925 ± 0.0014	calculation not performed
238GROUPNDF5/CSAS25/SCALE4.3	0.9906 ± 0.0014	calculation not performed
.50c/MCNP4A	0.9916 ± 0.0014	0.9970 ± 0.0011
.60c/MCNP4A	0.9940 ± 0.0013	calculation not performed
Hansen-Roach/CSAS25/SCALE4.3	1.0036 ± 0.0016	1.0068 ± 0.0019

^a Most comparable Benchmark Handbook sample calculation.

Table 11 Recommended Biases Based on ²³³ U Jezebel Experiment ^a			
Cross-Section Library	Bias Δk	Cross-Section Library	Bias Δk
27Grev & 27GROUPNDF4	0.035	.50c	0.008
218G(4.0) & 218GROUPNDF4	0.039	.60c	0.006
44GROUPNDF5	0.007	Hansen-Roach	0.000
238GROUPNDF5	0.009		

^a Recommended as nonconservative biases for DANTSYS, CSAS25 of SCALE 4.0 and 4.3, and MCNP4A, assuming evaluations use $k_{eff} + 2\sigma$ + bias and separately address experiment uncertainty, which could be significant.

Appendix B describes methods for determining biases.

Table 12 ²³³ U Jezebel Cumulative Experiment Uncertainties ^a (Internal Reference: Table F-5, page F-4)	
Methodology	Uncertainty Δk
44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	± 0.0011
44GROUPNDF5/CSAS25/SCALE4.3	± 0.0023
Benchmark Handbook	± 0.001

^a Experiment-uncertainty effects are not necessarily within typical INEEL-Monte-Carlo-calculation uncertainties, which are usually ± 0.0015 or less.

9 ^{233}U Flattop Experiment, U233-MET-FAST-006

Identified as U233-MET-FAST-006, the *Benchmark Handbook* includes a benchmark fast-neutron critical experiment with a natural-uranium-reflected ^{233}U metal sphere. Appendix G lists information about experiment, calculations, and analysis summarized here. Barton, et. al., Hansen and Wood, LA-4208, LA-3067-MS, LA-CP-92-235 and the *Benchmark Handbook* describe this experiment or its environment further.

The ^{233}U Flattop configurations approximated an ideal, metal-reflected spherical system of highly enriched ^{233}U metal. Brewer developed a benchmark description from these experiments for the *Benchmark Handbook*. Shown in Figure 7, the benchmark experiment is used here.

The *Benchmark Handbook* incorporates parameter sensitivity analyses for these experiments, expressing cumulative experimental uncertainties as a critical mass uncertainty. Summarized in Table G-3 (page 1-5), benchmark analyses indicate an experimental k_{eff} of 1.0000 ± 0.0014 with which calculations here agree well.

Table 13 summarizes results for various library-and-code combinations. Although the 238GROUPNDF5/CSAS25/SCALE4.3 combination produced most accurate results, all combinations with Hansen-Roach-, ENDF/B-V-, and ENDF/B-VI-based libraries produce essentially the same averaged results, within -1% of critical. However, ENDF/B-IV-based SCALE libraries perform poorly by comparison (as much as 3% non-conservative), consistent with differences between this metal experiment and infinite-dilution assumptions under which these ^{233}U libraries were developed.

Tables 14 and 15 respectively list recommended calculation biases and cumulative experiment uncertainty effects. Biases do not incorporate calculation-method statistical variation and do not address experiment uncertainty effects. Averaged INEEL-calculated experiment-uncertainty effects are not necessarily within typical INEEL-Monte-Carlo-calculation uncertainties.

Figure 7 Idealized ^{233}U Flattop Experiment and Model

Table 13 Methodology Comparison for ²³³ U Flattop (Internal Reference: Table G-4, page G-5)		
Library-and-Code Combination	Calculated k_{eff}	Benchmark Handbook k_{eff} ^a
27Grev/CSASI/SCALE4.0/ONEDANT	0.9764	0.9765
27Grev/CSAS25/SCALE4.0	0.9716 ± 0.0013	0.9757 ± 0.0011
27GROUPNDF4/CSASI/SCALE4.3/ONEDANT	0.9764	0.9765
27GROUPNDF4/CSAS25/SCALE4.3	0.9765 ± 0.0014	0.9757 ± 0.0011
218G(4.0)/CSAS25/SCALE4.0	0.9757 ± 0.0014	calculation not performed
218GROUPNDF4/CSAS25/SCALE4.3	0.9742 ± 0.0013	
44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	0.9946	
44GROUPNDF5/CSAS25/SCALE4.3	0.9916 ± 0.0014	
238GROUPNDF5/CSAS25/SCALE4.3	1.0000 ± 0.0014	
.50c/MCNP4A	1.0098 ± 0.0016	1.0023 ± 0.0011
.60c/MCNP4A	1.0084 ± 0.0016	calculation not performed
Hansen-Roach/CSAS25/SCALE4.3	0.9965 ± 0.0016	0.9931 ± 0.0017

a Most comparable Benchmark Handbook sample calculation.

Table 14 Recommended Calculation Biases Based on ²³³ U Flattop Experiment ^a			
Cross-Section Library	Bias Δk	Cross-Section Library	Bias Δk
27Grev & 27GROUPNDF4	0.025	.50c	0.000
218G(4.0) & 218GROUPNDF4	0.025	.60c	0.000
44GROUPNDF5	0.007	Hansen-Roach	0.003
238GROUPNDF5	0.000		

a Recommended as nonconservative biases for DANTSYS, CSAS25 of SCALE 4.0 and 4.3, and MCNP 4A, assuming evaluations use $k_{eff} + 2\sigma$ + bias and separately address validation experiment uncertainty, which could be significant. Appendix B describes methods for determining biases.

Table 15 ²³³ U Flattop Experiment Cumulative Uncertainty ^a (Internal Reference: Table G-3, page G-5)	
Methodology	Uncertainty Δk
44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	± 0.0014
44GROUPNDF5/CSAS25/SCALE4.3	± 0.0026
Benchmark Handbook	± 0.0014

a Experiment uncertainty effects are not necessarily within typical INEEL-Monte-Carlo-calculation uncertainties, which are usually ± 0.0015 or less.

10 ^{233}U Planet Experiments

Identified as U233-MET-FAST-002, -003, -004, and -005, the *Benchmark Handbook* includes eight benchmark critical experiments with four different metal reflectors and two sizes of ^{233}U metal spheres. Appendix H lists detailed information about experiments, calculations, and analysis summarized here. Additional experiment information is described in LA-3067-MS, LA-4208, and the *Benchmark Handbook*.

The eight experiments, approximating ideal metal-reflected, ^{233}U -metal, spherical systems, were performed in the late 1950s with the Planet Assembly at Los Alamos. Brewer completed the most recent analysis and updated benchmark experiment descriptions for the *Benchmark Handbook*. Shown in Figure 8, Brewer's benchmark descriptions are used here.

The *Benchmark Handbook* incorporates parameter sensitivity analyses for these experiments, expressing the cumulative experimental uncertainties as a reflector thickness uncertainty. Summarized in Table H-4 (page 1-6), analyses indicate an average experimental k_{eff} of 1.0000 ± 0.0010 and a worst case experimental k_{eff} of 1.0000 ± 0.0015 .

Table 16 summarizes results with various library-and-code combinations. Best results, within 0.5% ($\pm 0.005 \Delta k_{\text{eff}}$) of critical ($k_{\text{eff}}=1.0000$) and well within experimental uncertainty, are produced with calculations using ENDF/B-V- and ENDF/B-VI-based cross-section libraries. Results obtained with ENDF/B-IV-based SCALE libraries average about 2.5% low, with the worst individual value ($k_{\text{eff}}-2\sigma$, Table H-12, page H-10) being 3.6% low. These poor results are consistent with differences between these metal experiments and infinite-dilution assumptions under which ENDF/B-IV-based SCALE libraries were developed. Calculations with library-and-code combinations involving the same cross-section source data produce results which are statistically the same regardless of the criticality code used.

Tables 17 and Tables 18 respectively list recommended calculation biases and estimated cumulative experiment uncertainty effects. Biases do not incorporate calculation-method statistical-variation and do not address experiment uncertainty effects. Averaged cumulative experiment uncertainty is within typical INEEL-Monte-Carlo-calculation uncertainties.

Figure 8 Idealized ^{233}U Planet Experiments and Models

Table 16 Methodology Comparison for ²³³ U Planet Experiments			
Library-and-Code Combination	Internal Reference	Averaged k_{eff}	Benchmark Handbook k_{eff} ^a
27Grev/CSASI/SCALE4.0/ONEDANT	Table H-8, page H-8	0.9769 ± 0.0071	0.9771 ± 0.0071
27GROUPNDF4/CSAS25/SCALE4.3	Table H-6, page H-7	0.9762 ± 0.0075	0.9767 ± 0.0072
27Grev/CSAS25/SCALE4.0	Table H-11, page H-10	0.9769 ± 0.0071	0.9767 ± 0.0072
218GROUPNDF4/CSAS25/SCALE4.3	Table H-6, page H-7	0.9747 ± 0.0056	calculation not performed
218G(4.0)/CSAS25/SCALE4.0	Table H-12, page H-10	0.9741 ± 0.0065	
44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	Table H-9, page H-9	1.0004 ± 0.0046	
44GROUPNDF5/CSAS25/SCALE4.3	Table H-7, page H-8	1.0013 ± 0.0051	
238GROUPNDF5/CSAS25/SCALE4.3	Table H-7, page H-8	1.0039 ± 0.0030	
.50c/MCNP4A	Table H-10, page H-9	0.9992 ± 0.0031	0.9997 ± 0.0046
.60c/MCNP4A	Table H-10, page H-9	0.9998 ± 0.0044	not performed
Hansen-Roach/CSAS25/SCALE4.3	Table H-5, page H-7	1.0022 ± 0.0100	1.0066 ± 0.0066

a Average of most comparable Benchmark Handbook sample calculations.

Table 17 Recommended Calculation Biases Based on ²³³ U Planet Experiments ^a			
Cross-Section Library	Bias Δk	Cross-Section Library	Bias Δk
27Grev & 27GROUPNDF4	0.024	.50c	0.000
218G(4.0) & 218GROUPNDF4	0.026	.60c	0.000
44GROUPNDF5	0.000	Hansen-Roach	0.000
238GROUPNDF5	0.000		

a Recommended as nonconservative biases for DANTSYS, CSAS25 of SCALE 4.0 and 4.3, and criticality option of MCNP4A, assuming evaluations use $k_{eff} + 2\sigma + \text{bias}$ and separately address validation-experiment uncertainty. See Appendix B.

Table 18 ²³³ U Planet Experiment Cumulative Uncertainties ^a (Internal Reference: Table H-4, page H-6)			
Experiment #	Uncertainty Δk	Experiment #	Uncertainty Δk
002a	± 0.0011	004a	± 0.0008
002b	± 0.0010	004b	± 0.0007
003a	± 0.0010	005a	± 0.0013
003b	± 0.0009	005b	± 0.0015

a Uncertainties are within typical INEL Monte Carlo calculation uncertainties, which are usually ± 0.0015 or less.

11 Conclusions

Some general conclusions can be drawn, but there are exception(s) to each:

- In many cases a nonconservative calculation bias applies. However, experiment-description uncertainties *might* significantly contribute to biases which exceed 1% (0.01 in Δk_{eff}). Recommended values vary greatly by cross-section library, system neutron energy, and reflection material presence. Consult Tables 2, 5, 8, 11, 14, and 17 for specific recommendations, or develop alternative bias recommendations from results reported in Appendices C through H.
- ^{233}U experiment uncertainty effects are or could be significant in most cases here. Consult Tables 3, 6, 9, 12, 15, and 18 for specific uncertainty values.
- Consistent results are obtained with different codes using the same cross-section library. Result correlation is best when calculation results are closest to $k_{\text{eff}} = 1.000$.
- MCNP4A and its continuous data cross section libraries provide more consistent and usually better results than other readily available library-and-code combinations.

Consistent with assumptions in building specific cross-section libraries:

- ENDF/B-IV-based SCALE libraries (27- and 218-group libraries) are not recommended for fast ^{233}U systems but these libraries perform fairly well for thermal systems.
- ENDF/B-V-based SCALE libraries (44- and 238-group libraries) perform slightly better for fast ^{233}U systems than for thermal systems.
- The 16-group *Hansen-Roach* library is not recommended for thermal ^{233}U systems but it performs fairly well for fast systems.

No specific problems with ^{233}U source data was identified. However, there is a complete lack of measured epithermal data and relevant critical experiments for validation, and a general lack of very well-described thermal critical experiments for validation. Relatively large biases associated with less-well described experiments might significantly and adversely affect selection of and limits on operational control parameters based on criticality safety calculations.

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Appendix A

Nuclide Density Formulas

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Throughout this validation, the following formulas were used in calculating nuclide densities. In order of preference physical-constant values were obtained from *SCALE 4.3*, *GE Handbook*, *CRC Handbook*, *Lange's Chemistry Handbook*, and the *Benchmark Handbook*.

Nuclide densities:

$$N_n = \frac{m_n N_A}{v_{mtl} W_n}$$

Nuclide mass if material composition is reported in nuclide weight percents and material mass:

$$m_n = w_n m_{mtl}$$

Nuclide mass if material composition is reported in nuclide weight percents and one nuclide's mass:

$$m_{n2} = w_{n2} (m_{n1} / w_{n1})$$

Solution mass density if solution specific gravity is reported:

$$\rho = (spg) \rho_{water} = (spg) (0.9982 \text{ g/cm}^3)$$

Atom ratios are frequently used in nuclide density calculations. Here ratios from molecular formulas supplement measured data. Other reported ratios (for example, H:²³³U) are preferentially used to calculate nuclide densities, excess acids in solutions, etc. With exception of molecular formulas, atom ratios are experimenter-calculated values for which uncertainty should be no greater than uncertainty in values from which a ratio was calculated.

$$N_{n1} = R_{N_{n1}/N_{n2}} N_{n2}$$

Solution experiments here used uranyl nitrate (UO₂(NO₃)₂) or uranyl fluoride (UO₂F₂). Nuclide densities incorporate excess acid (HNO₃) or excess fluorine (F) where indicated by reported data. In some cases, a given H:U atom ratio indicates negative excess acid or negative excess fluorine, which is interpreted as a deficiency accompanied by uranium precipitate, unless other information

indicates inconsistent or erroneous data. Uranium precipitate is assumed to be suspended because reports do not indicate presence of uranium deposits, sludges, or slurries, which are significant conditions experimenters would have recognized and reported.

As with H:U atom ratios, water volume fraction is sometimes useful, to identify contributions from water, determine if a particular benchmark applies, or identify comparable experiments:

$$WVF_{fm} = \frac{v_{fm,total} - v_{fm,nonwater}}{v_{fm,total}}$$

In solution cases for which an H:U atom ratio is known or can be determined:

$$WVF_{fm} = \frac{N_{H,WaterInfm}}{N_{H,FullDensityWater}}$$

If these formulas result in atom-density values within 2% of values reported in the *Benchmark Handbook*, *Benchmark Handbook* values are preferentially used to facilitate comparisons with calculations performed elsewhere. Individual and cumulative effects of these atom-density differences should be well within, and masked by, calculational methodology uncertainties.

Appendix B

Average, Bias, and Uncertainty Formulas

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B1 Introduction

Calculation-methodology validation must address methodology bias, methodology uncertainty, and experiment uncertainty effects. A series of experiments, and their averaged values, are preferred for analyzing these effects although in some cases only one experiment is available.

B2 Averages

In most cases values to be averaged are, or are assumed to be, normally distributed. An average value for n values of q , as programmed into most calculators, is:

$$q_{ave} = \frac{\sum_{i=1}^n q_i}{n}$$

Statistical variation in q_i s (specifically, deviation of q_i s from q_{ave}), as programmed into most calculators, is:

$$\sigma_{q_{ave}} = \sqrt{\frac{\sum_{i=1}^n (q_{ave} - q_i)^2}{n}}$$

These averaging formulas do not incorporate statistical variations in q_i values, which if included would be an averaged variation on $\sigma_{q_{ave}}$. Such variations are neglected here because they are typically third-order effects and do not significantly affect averaged k_{eff} s, biases, or uncertainties.

B3 Calculation Bias and Uncertainty

Methodology bias typically incorporates nonconservative deviations of calculated $k_{eff,ave}$ from actual k_{eff} s and any trend in individual deviations. Trends are identified by plotting $k_{eff,i}$ values against parameter(s) which might contribute to the trend. If there is an apparent pattern in $k_{eff,i}$ s relative to $k_{eff,ave}$, attempts are made to curve-fit calculated k_{eff} s, usually with least-squares fit and first- and second-order polynomials. If a resultant curve deviates from $k_{eff,ave}$ by more than effects of subject experiment uncertainties, further analysis is warranted. Otherwise, the apparent trend is not significant. All apparent calculation trends considered in this study were not significant, or were part of a reason for rejecting some experiments of an otherwise accepted experiment series.

Where no trends are evident, bias calculation is fairly straightforward. Conservative biases are set to zero. Nonconservative biases are set to zero if calculated $k_{eff,ave}$ is not less than experiment $k_{eff} - \Delta k_{uncertainty}$ and experiment $\Delta k_{uncertainty}$ is reasonably small. Otherwise bias is usually:

$$bias = 1.000 - k_{eff,ave}$$

These biases do not incorporate $\sigma_{k_{eff,ave}}$ because it should be on the order of $\sigma_{k_{eff}}$, in which case a traditional $k_{eff} + 2\sigma + bias$ formula is valid for most criticality safety evaluation calculations.

However, an alternate bias formula is more appropriate if calculation uncertainty, $\sigma_{k_{eff,ave}}$, is significant. The possibility for such significance is investigated if

- almost half of calculated $k_{eff,i}$ s are less than experimental $k_{eff,i} - \Delta k_{uncertainty,i}$, and calculated $k_{eff,ave}$ is within experimental uncertainty; or
- $\sigma_{k_{eff,ave}}$ significantly exceeds $\sigma_{k_{eff}}$ s, bias determined with the previous formula, or both.

One of three options is implemented based on investigation results:

- previously determined biases are used if $\sigma_{k_{eff,ave}}$ is not significant to calculation methodology (for example, deviations from $k_{eff,ave}$ appear to be primarily due to experiment uncertainty effects),
- the previous bias formula is used, without setting any nonconservative biases to zero, for results which were within experiment uncertainty if $\sigma_{k_{eff,ave}}$ significance appears to be similar to experiment uncertainty significance, or
- a w_σ weighting factor is assigned to count the part of $\sigma_{k_{eff,ave}}$ significant to calculation methodology (specifically, to minimize experimental uncertainty effects which here should be addressed separately). In this case bias is:

$$bias = [(1.000 - k_{eff,ave} + w_\sigma \sigma_{k_{eff,ave}}) \text{ or } (0.000)]_{max}$$

Biases based on individual rather than averaged k_{eff} values were also investigated to determine if bias should be expressed as a percent of calculated k_{eff} rather than as a Δk . However, results were inconclusive. Therefore, bias formulas described above were selected for application simplicity.

B4 Experiment Uncertainty

Experiment uncertainty effects reported in the *Benchmark Handbook* are preferentially used here. Otherwise individual uncertainty effects are estimated by first calculating k_{eff} for an individual contributor q at its maximum, minimum, and nominal values.

If k_{eff} for q_{nom} falls between k_{eff} for q_{max} and q_{min} , the individual contributor effect is:

$$\Delta k_{uncertainty} = \pm \frac{k_{eff,qmax} - k_{eff,qmin}}{2}$$

Otherwise the individual contributor effect is:

$$\Delta k_{uncertainty} = \pm [|k_{eff,qmax} - k_{eff,qnom}| \text{ or } |k_{eff,qnom} - k_{eff,qmin}|]_{max}$$

Individual contributors to a cumulative uncertainty are assumed to be independent. Cumulative uncertainty here is:

$$\Delta k_{cumulative} = \pm \sqrt{\sum_{i=1}^n \Delta k_{uncertainty,i}^2}$$

However, in most cases individual contributors are not completely independent. In these cases non-independent portions are counted more than once. This summation is conservative for most criticality-safety-validation applications.

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Appendix C

U233-THERM-SOLN-001 Experiments and Calculations

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C1 Experiments

U233-THERM-SOLN-001 experiments were a series of five critical experiments with an unreflected, spherical, volume-averaged 27.24-inch-diameter solution vessel of 0.32-cm-thick Type 1101 aluminum. Conducted at ORNL and analyzed several times (ORNL-CF-60-4-12; Gwin and Magnuson; ORNL-2609; Staub, Harris, and Goldsmith; and *Benchmark Handbook*), experiments varied primarily by the quantity of boron in a fissionable solution of uranyl nitrate and thorium and nitric acid. Summarized in Figure 1 (page 9) and Tables C-1 and C-2, Sapir's idealized benchmark descriptions, developed for the *Benchmark Handbook*, are used here. Table C-4 summarizes benchmark uncertainty information, cumulatively expressed as a Δk for the benchmark critical- k_{eff} s listed in Table C-1.

Table C-1 U233-SOLN-THERM-001 Experiment Critical Parameters							
Exp #	Solution Densities					k_{eff}	
	Overall (g/cm ³)	Total U (mg/g)	Total B (mg/g)	Nitrate (mg/g)	Total Th (mg/g)	Measured experiment	Benchmark
1	1.0226	16.76	0.00	11.9	0.074	1.0005	1.0000 $\pm$ 0.0031
2	1.0253	17.42	0.0233	12.3	0.077	1.0010	1.0005 $\pm$ 0.0033
3	1.0274	18.03	0.0453	12.8	0.080	1.0011	1.0006 $\pm$ 0.0033
4	1.0275	18.67	0.0670	13.2	0.083	1.0003	0.9998 $\pm$ 0.0033
5	1.0286	19.27	0.0887	13.6	0.085	1.0004	0.9999 $\pm$ 0.0033

Table C-2 U233-SOLN-THERM-001 Uranium Isotopic Composition	
Isotope	wt%
^{233}U	97.70
^{234}U	1.62
^{235}U	0.04
^{238}U	0.64

Table C-3 U233-THERM-SOLN-001 Vessel CompositionType 1101 Aluminum, density = 2.71 g/cm³ ^a

Nuclide SCALE # [MCNP #]	wt %	N _n (particles/b-cm)
AL [13027]	99.0	5.9881E-02
SI [14000]	0.375	2.1790E-04
FE [26000]	0.375	1.0958E-04
CU [29000] ^b	0.2	5.1364E-05
MN [25055] ^b	0.05	1.4853E-05

a From *Benchmark Handbook*. Source data are from Etherington, which was not readily available. *Benchmark Handbook* wt% values were adjusted slightly to ensure they summed to 100%.

b ENDF/B-V-based libraries were used for this nuclide in all MCNP calculations.

Table C-4 U233-THERM-SOLN-001 Benchmark Experiment Uncertainties

Parameter	Nominal Value	Uncertainty Range (%)	Δk_{eff} by Experiment # ^a		$\Delta k_{\text{eff}}/\Delta p$ ^b
			1	2 through 5	
²³³ U enrichment	97.70 wt%	±0.1	±0.0006		0.60
U concentration	Table C-1, page C-3	±0.5	±0.0025		0.50
Boron concentration	Table C-1, page C-3	±0.5	not applicable	±0.0003	0.06
¹⁰ B isotopic abundance	19.9%	±2.0 (relative)	not applicable	±0.0010	0.0005
Solution density	Table C-1, page C-3	±0.5	±0.0016		0.32
Critical Volume	173.4 liters	±0.5	±0.0006		0.60
Room Return	See <i>Benchmark Handbook</i>		±0.0003		---
Cumulative Uncertainty			±0.0031	±0.0033	

a Sapir indicates these values were determined using an ORNL version of the library-and-code combination identified here as 27GROUPNDF4/CSASI/SCALE4.3/TWODANT. Refer to the *Benchmark Handbook* for further information.

b % change in k_{eff} due to a 1% change in indicated parameter.

C2 Models

Shown in Figure 1 (page 9), calculational models represent ideal descriptions of a homogenized fissionable solution in an unreflected, spherical aluminum vessel. Tables C-3 and C-5 list nuclide densities from the *Benchmark Handbook*. Independently calculated values for two experiments indicate INEEL methods would produce essentially the same models, with less than 1.5% difference in hydrogen atom densities and less than 1% difference in other atom densities. Therefore, *Benchmark Handbook* models were used but its sample input listings were not used.

Table C-5 U233-THERM-SOLN-001 Fissionable Solution Atom Densities

Atom SCALE # [MCNP #]	N_n (particles/b-cm) by Experiment Number ^a				
	1	2	3	4	5
U-233 [92233]	4.3271E-05	4.5093E-05	4.6768E-05	4.8433E-05	5.0043E-05
U-234 [92234]	7.1442E-07	7.4451E-07	7.7216E-07	7.9965E-07	8.2623E-07
U-235 [92235]	1.7565E-08	1.8305E-08	1.8984E-08	1.9660E-08	2.0314E-08
U-238 [92238]	2.7748E-07	2.8917E-07	2.9991E-07	3.1059E-07	3.2091E-07
N [7014]	1.1819E-04	1.2248E-04	1.2772E-04	1.3173E-04	1.3586E-04
H [1001]	6.6271E-02	6.6363E-02	6.6413E-02	6.6337E-02	6.6329E-02
O [8016]	3.3564E-02	3.3628E-02	3.3674E-02	3.3653E-02	3.3666E-02
B-10 [5010]	0.0	2.6481E-07	5.1591E-07	7.6312E-07	1.0114E-06
B-11 [5011]	0.0	1.0659E-06	2.0766E-06	3.0716E-06	4.0708E-06
TH [90232]	1.9639E-07	2.0489E-07	2.1331E-07	2.2133E-07	2.2691E-07

- a Values from *Benchmark Handbook*. Independently calculated values for experiments 2 and 5 were within 1.5% for hydrogen and within 1% for all other nuclides. Therefore, *Benchmark Handbook* values were used in models here.

C3 Sensitivity and Uncertainty Effects

Tables C-4 and C-7 through C-6 include information for analyzing calculation sensitivities to small changes in several experiment parameters and to a relatively large change in solution boron content, and for analyzing experiment and methodology uncertainty effect.

As indicated in Tables C-4 and C-6, a 1.0% change in an individual parameter results in a maximum 0.6% ($\pm 0.006 \Delta k_{\text{eff}}$) change in calculated k_{eff} s. Calculations are most sensitive to small changes which directly affect ^{233}U density and least sensitive to small changes in ^{232}Th , as one should suspect from relative concentrations of ^{233}U , ^{10}B , ^{232}Th , ^{235}U , and ^{238}U .

Table C-6 U233-THERM-SOLN-001 Calculation Sensitivity to ^{232}Th
27GROUPNDF4/CSASI/SCALE4.3/ONEDANT

Experiment #	$k_{\text{eff}} \pm 1\sigma$ as a function of $N_{\text{Th}232}^a$			$\Delta k_{\text{eff}}/\Delta N$
	-0.5%	nominal (Table C-11, page C-8)	+0.5%	
1	1.0024	1.0024	1.0024	± 0.0000
2	1.0024	1.0024	1.0024	± 0.0000
3	1.0019	1.0019	1.0019	± 0.0000
4	1.0019	1.0019	1.0019	± 0.0000
5	1.0012	1.0012	1.0012	± 0.0000
Average	1.0020 $\pm$ 0.0005	1.0020 $\pm$ 0.0005	1.0020 $\pm$ 0.0005	

^a Uncertainties are not specified for ^{232}Th . An uncertainty of $\pm 0.5\%$ is assigned for convenience and consistency with reported uncertainties for similar parameters.

These calculations are relatively insensitive to ^{10}B -concentration changes because there is so little boron in any of the experiments. Thus, boron mostly hardens neutron energy spectrums here. Although there appears to be a trend for less conservative results as the spectrum hardens, this trend is not statistically significant because differences are completely within ^{10}B -concentration-uncertainty effects ($\pm 0.001 \Delta k_{\text{eff}}$, Table C-4, page C-4).

Italic font in Tables C-6 through C-13 indicates values outside benchmark-critical- k_{eff} range as defined by its uncertainty (± 0.003 , Table C-1, page C-3). With exception of calculations with the 238GROUPNDF5 library, all averages and almost all individual k_{eff} values are within this range. In the 238GROUPNDF5 case, deviations exceed the ± 0.003 uncertainty by an average $-0.001 \Delta k_{\text{eff}}$ and, for individual values, a maximum $-0.002 \Delta k_{\text{eff}}$. Two of the five experiment results with the .60c library are also disconcertingly less than the benchmark-critical- k_{eff} range.

C4 Library-and-Code Combination Effects

Summarized in Table 1 (page 10), Tables C-7 through C-13 list results for various library-and-code combinations. Values in italic font are outside cumulative Δk_{eff} uncertainties indicated in Table C-4, page 4. All combinations, including one which uses the primarily fast-energy-based Hansen-Roach cross-sections, generally perform well. For these thermal neutron experiments, there are no evident statistical trends to recommend one combination over another combination. However, ENDF/B-V-based libraries consistently produce lower calculated k_{eff} s than other libraries, and 27-group libraries generally produce higher calculated k_{eff} s than other libraries. All results are within 0.5% of critical but few are sufficiently close that use of $k_{\text{eff}}+2\sigma$ would assure a conservative value (calculated k is not less than 1.0000 for a critical condition).

Table C-7 Calculations with Hansen-Roach/CSAS25/SCALE4.3

Experiment #	$k_{\text{eff}} \pm 1\sigma^a$	ale (ev)
1	<i>1.0032 ± 0.0010</i> **	0.0163 ± 0.0000
2	1.0028 ± 0.0010	0.0166 ± 0.0000
3	0.9998 ± 0.0010	0.0169 ± 0.0000
4	1.0003 ± 0.0010	0.0172 ± 0.0000
5	0.9974 ± 0.0010	0.0176 ± 0.0000
Average	1.0007 ± 0.0024	0.0169 ± 0.0005

Table C-8 27GROUPNDF4 and 218GROUPNDF4 Cross-Section-Library Effects

Exp #	27GROUPNDF4/CSAS25/SCALE4.3		218GROUPNDF4/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma^a$	ale (ev)	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
1	<i>1.0044 ± 0.0011</i> **	0.0269 ± 0.0000	1.0010 ± 0.0011	0.0266 ± 0.0000
2	1.0031 ± 0.0010	0.0274 ± 0.0000	1.0023 ± 0.0011	0.0270 ± 0.0000
3	1.0018 ± 0.0010	0.0279 ± 0.0000	0.9997 ± 0.0011	0.0275 ± 0.0000
4	1.0013 ± 0.0010	0.0283 ± 0.0000	0.9978 ± 0.0010	0.0280 ± 0.0000
5	1.0027 ± 0.0011	0.0288 ± 0.0000	0.9973 ± 0.0011	0.0285 ± 0.0000
Average	1.0027 ± 0.0012	0.0279 ± 0.0007	0.9996 ± 0.0021	0.0275 ± 0.0008

Table C-9 44GROUPNDF5 and 238GROUPNDF5 Cross-Section-Library Effects

Exp #	44GROUPNDF5/CSAS25/SCALE4.3		238GROUPNDF5/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma$	ale (ev)	$k_{\text{eff}} \pm 1\sigma^a$	ale (ev)
1	0.9983 ± 0.0010	0.0367 ± 0.0000	<i>0.9965 ± 0.0011</i>	0.0386 ± 0.0000
2	1.0000 ± 0.0011	0.0372 ± 0.0000	0.9989 ± 0.0010	0.0392 ± 0.0000
3	0.9988 ± 0.0011	0.0378 ± 0.0000	<i>0.9957 ± 0.0011</i>	0.0398 ± 0.0000
4	0.9999 ± 0.0010	0.0384 ± 0.0000	<i>0.9951 ± 0.0011</i> **	0.0404 ± 0.0000
5	0.9990 ± 0.0011	0.0390 ± 0.0000	<i>0.9954 ± 0.0011</i>	0.0410 ± 0.0000
Average	0.9992 ± 0.0007	0.378 ± 0.0009	0.9963 ± 0.0015	0.398 ± 0.0009

- a Italic font indicates individual k_{eff} value is more than 1σ from the benchmark k_{eff} value. Double asterisk (**) indicates case was run 10 times with different starting random numbers each time. First run results listed because multiple runs produced results within 0.4σ of each other.

Table C-10 27-Group Library-Processing Effects

Exp #	27Grev/CSAS25/SCALE4.0		27GROUPNDF4/CSAS25/SCALE4.3 (Table C-8, page C-7)	
	$k_{\text{eff}} \pm 1\sigma^a$	afg	$k_{\text{eff}} \pm 1\sigma^a$	afg
1	<i>1.0036 $\pm$ 0.0010 **</i>	24.6288 $\pm$ 0.0008	<i>1.0044 $\pm$ 0.0011 **</i>	24.6278 $\pm$ 0.0008
2	1.0019 $\pm$ 0.0010	24.5995 $\pm$ 0.0008	1.0031 $\pm$ 0.0010	24.5998 $\pm$ 0.0008
3	1.0031 $\pm$ 0.0011	24.5732 $\pm$ 0.0009	1.0018 $\pm$ 0.0010	24.5723 $\pm$ 0.0009
4	1.0014 $\pm$ 0.0010	24.5463 $\pm$ 0.0009	1.0013 $\pm$ 0.0010	24.5470 $\pm$ 0.0009
5	1.0004 $\pm$ 0.0011	24.5222 $\pm$ 0.0009	1.0027 $\pm$ 0.0011	24.5225 $\pm$ 0.0009
Ave	1.0021 $\pm$ 0.0013	24.5740 $\pm$ 0.0421	1.0027 $\pm$ 0.0012	24.5739 $\pm$ 0.0417

Table C-11 DANT and KENO Va Code Effects with 27GROUPNDF4 Library

Experiment #	27GROUPNDF4/CSASI/ SCALE4.3/ONEDANT k_{eff}	27GROUPNDF4/CSAS25/SCALE4.3 (Table C-8, page C-7) $k_{\text{eff}} \pm 1\sigma^a$
1	1.0024	<i>1.0044 $\pm$ 0.0011 **</i>
2	1.0024	1.0031 $\pm$ 0.0010
3	1.0019	1.0018 $\pm$ 0.0010
4	1.0019	1.0013 $\pm$ 0.0010
5	1.0012	1.0027 $\pm$ 0.0011
Average	1.0020 $\pm$ 0.0005	1.0027 $\pm$ 0.0012

Table C-12 DANT and KENO Va Code Effects with 44GROUPNDF5 Library

Experiment #	44GROUPNDF5/CSASI/ SCALE4.3/ONEDANT k_{eff}	44GROUPNDF5/CSAS25/SCALE4.3 (Table C-9, page C-7) $k_{\text{eff}} \pm 1\sigma$
1	0.9996	0.9983 $\pm$ 0.0010
2	0.9995	1.0000 $\pm$ 0.0011
3	0.9991	0.9988 $\pm$ 0.0011
4	0.9990	0.9999 $\pm$ 0.0010
5	0.9982	0.9990 $\pm$ 0.0011
Average	0.9991 $\pm$ 0.0006	0.9992 $\pm$ 0.0007

- a Italic font indicates individual k_{eff} value is more than 1σ from the benchmark k_{eff} value. Double asterisk (**) indicates case was run 10 times with different starting random numbers each time. First run results listed because multiple runs produced results within 0.4σ of each other.

Table C-13 .50c and .60c Cross-Section-Library Effects		
Experiment #	$k_{\text{eff}} \pm 1\sigma^a$	
	.50c/MCNP4A	.60c/MCNP4A
1	1.0029 ± 0.0012	0.9983 ± 0.0012
2	0.9994 ± 0.0011	1.0004 ± 0.0013
3	1.0002 ± 0.0012	0.9982 ± 0.0012
4	1.0011 ± 0.0013	<i>0.9949 ± 0.0013</i>
5	0.9968 ± 0.0012	<i>0.9953 ± 0.0013</i>
Average	1.0001 ± 0.0022	0.9974 ± 0.0023

a Italic font indicates individual k_{eff} value is more than 1σ from the benchmark k_{eff} value.

C5 Analysis Conclusions

Much of any calculational uncertainty or bias for these experiments is well within experimental uncertainty. In addition, most individual calculated k_{eff} s exceed 1.0000 by more than 1σ . However, deviations from critical are such that $k_{\text{eff}} + 2\sigma$ is not necessarily conservative when using Monte Carlo codes. Table 2 (page 10) lists recommended biases for calculations validated with these experiments. Recommended biases do not incorporate calculation-statistical-uncertainty effects and do not address experiment uncertainty effects. Experiment uncertainty effects (± 0.0031 or ± 0.0033) exceed typical INEEL calculation statistical uncertainties (± 0.0015 or less) and therefore should be considered when validating criticality safety evaluations with these experiments.

C6 Sample Inputs

Some single lines of input are listed here on multiple lines due to report's column width. Use caution in regenerating code inputs from these listings.

C6.1 SCALE Inputs

All SCALE calculations were performed with 405 generations, 800 neutrons per generation, skipping 5 generations before averaging k_{eff} values. Results are therefore based on 320,000 neutron histories.

C6.1.1 Hansen-Roach/CSAS25/SCALE4.3 Experiment # 1

```
=CSAS25
U233-SOL-THERM-001.1
HANSEN-ROACH INFHOMMEDIUM
U-233      1 0      4.3271-05      END
U-234      1 0      7.1442-07      END
U-235      1 0      1.7565-08      END
U-238      1 0      2.7748-07      END
N          1 0      1.1819-04      END
H          1 0      6.6271-02      END
O          1 0      3.3564-02      END
TH-232     1 0      1.9639-07      END
AL          2 0      5.9881-02      END
SI          2 0      2.1790-04      END
FE          2 0      1.0958-04      END
CU          2 0      5.1364-05      END
MN          2 0      1.4853-05      END
END COMP
KENOV.A
READ PARAM
TME=60     GEN=405   NPG=800   FLX=YES   FDN=YES
PKI=YES    FAR=YES   FMP=YES   NUB=YES   NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE     1 1      34.595
SPHERE     2 1      34.915
END GEOMETRY
END DATA
END
```

C6.1.2 27Grev/CSAS25/SCALE4.0 Experiment # 2

```
=CSAS25
U233-SOL-THERM-001.2
27G INF
U-233      1 0      4.5093-05      END
U-234      1 0      7.4451-07      END
U-235      1 0      1.8305-08      END
U-238      1 0      2.8917-07      END
N          1 0      1.2248-04      END
H          1 0      6.6363-02      END
O          1 0      3.3628-02      END
B-10       1 0      2.6481-07      END
B-11       1 0      1.0659-06      END
TH-232     1 0      2.0489-07      END
AL          2 0      5.9881-02      END
SI          2 0      2.1790-04      END
FE          2 0      1.0958-04      END
CU          2 0      5.1364-05      END
MN          2 0      1.4853-05      END
END COMP
KENOV.A
READ PARAM
TME=60     GEN=405   NPG=800   FLX=YES   FDN=YES
PKI=YES    FAR=YES   FMP=YES   NUB=YES   NSK=5
END PARAM
```

```
READ GEOM
BOX TYPE 1
SPHERE     1 1      34.595
SPHERE     2 1      34.915
END GEOMETRY
END DATA
END
```

C6.1.3 44GROUPNDF5/CSAS25/SCALE4.3 Experiment # 3

```
=CSAS25
U233-SOL-THERM-001.3
44GROUPNDF5 INF
U-233      1 0      4.6768-05      END
U-234      1 0      7.7216-07      END
U-235      1 0      1.8984-08      END
U-238      1 0      2.9991-07      END
N          1 0      1.2772-04      END
H          1 0      6.6413-02      END
O          1 0      3.3674-02      END
B-10       1 0      5.1591-07      END
B-11       1 0      2.0766-06      END
TH-232     1 0      2.1331-07      END
AL          2 0      5.9881-02      END
SI          2 0      2.1790-04      END
FE          2 0      1.0958-04      END
CU          2 0      5.1364-05      END
MN          2 0      1.4853-05      END
END COMP
KENOV.A
READ PARAM
TME=60     GEN=405   NPG=800   FLX=YES   FDN=YES
PKI=YES    FAR=YES   FMP=YES   NUB=YES   NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE     1 1      34.595
SPHERE     2 1      34.915
END GEOMETRY
END DATA
END
```

C6.1.4 218GROUPNDF4/CSAS25/SCALE4.3 Experiment # 4

```
=CSAS25      PARM=SIZE=1000000
U233-SOL-THERM-001.4
218GROUPNDF4 INF
U-233      1 0      4.8433-05      END
U-234      1 0      7.9965-07      END
U-235      1 0      1.9660-08      END
U-238      1 0      3.1059-07      END
N          1 0      1.3173-04      END
H          1 0      6.6337-02      END
O          1 0      3.3653-02      END
B-10       1 0      7.6312-07      END
B-11       1 0      3.0716-06      END
TH-232     1 0      2.2133-07      END
AL          2 0      5.9881-02      END
SI          2 0      2.1790-04      END
FE          2 0      1.0958-04      END
CU          2 0      5.1364-05      END
MN          2 0      1.4853-05      END
END COMP
KENOV.A
READ PARAM
TME=60     GEN=405   NPG=800   FLX=YES   FDN=YES
PKI=YES    FAR=YES   FMP=YES   NUB=YES   NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE     1 1      34.595
SPHERE     2 1      34.915
END GEOMETRY
END DATA
END
```

C6.1.5 238GROUPNDF5/CSAS25/SCALE4.3 Experiment # 5

```
=CSAS25      PARM=SIZE=1000000
U233-SOL-THERM-001.5
238GROUPNDF5 INF
U-233      1 0      5.0043-05      END
U-234      1 0      8.2623-07      END
U-235      1 0      2.0314-08      END
U-238      1 0      3.2091-07      END
N          1 0      1.3586-04      END
H          1 0      6.6329-02      END
O          1 0      3.3666-02      END
B-10       1 0      1.0114-06      END
B-11       1 0      4.0708-06      END
TH-232     1 0      2.2691-07      END
AL         2 0      5.9881-02      END
SI         2 0      2.1790-04      END
FE         2 0      1.0958-04      END
CU         2 0      5.1364-05      END
MN         2 0      1.4853-05      END
END COMP
KENOV.A
READ PARAM
TME=60      GEN=405      NPG=800      FLX=YES      PDN=YES
PKI=YES     FAR=YES      FMP=YES      NUB=YES      NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE     1 1      34.595
SPHERE     2 1      34.915
END GEOMETRY
END DATA
END
```

C6.2 DANTSYS Input: 27GROUPNDF4/ CSASI/SCALE4.3/ONEDANT Experiment # 1

All DANT calculations were performed with S_{16} quadrature, P_3 scattering, and a 10^{-6} convergence criteria.

Cross Section Processing Input (CSASI/SCALE4.3) Experiment #1 with 1.005% of ^{232}Th :

```
=CSASI
U233-SOL-THERM-001.1 Th+0.5%
27GROUPNDF4 INF
U-233      1 0      4.3271-05      END
U-234      1 0      7.1442-07      END
U-235      1 0      1.7565-08      END
U-238      1 0      2.7748-07      END
N          1 0      1.1819-04      END
H          1 0      6.6271-02      END
O          1 0      3.3564-02      END
TH-232     1 0      1.9737-07      END
AL         2 0      5.9881-02      END
SI         2 0      2.1790-04      END
FE         2 0      1.0958-04      END
CU         2 0      5.1364-05      END
MN         2 0      1.4853-05      END
END COMP
MORE DATA axs=07 END
END
```

k_{eff} Calculation Input (ONEDANT):

```
1 0 0
U233-SOL-THERM-001 geometry, Experiment 1 Densities
/ Block 1
igeom=sphere ngroup=27 isn=16 niso=2 mt=2 nzone=2
im=17 it=170
```

```
maxscm=280000 maxlcm=2600000
T
/ Block 2 (geometry)
/ 16 course mesh intervals in sphere, 1 in vessel
xmesh= 0.0 0.5 1.5 2.5 5.0 10.0 15.0
20.0 25.0 30.0 32.0 33.0 33.5 34.0
34.25 34.5 34.595
34.915
xints= 17R10
zones= 16R1 2
T
/ Block 3 (cross sections)
lib=f27 writmxs=machcd
chivec= 0.020 0.195 0.219 0.126 0.164 0.172 0.088
0.014 0.001 0.000001 17z
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1
T
/ Block 4 (material mixing and assignments)
matls=isos assign=matls
T
/ Block 5 (solver control)
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
T
/ Block 6
zned= 1
T
```

C6.3 MCNP Inputs

All MCNP calculations were performed with 250 generations, 1000 neutrons per generation, skipping the first 15 generations before averaging k_{eff} values. MCNP results are therefore based on 235,000 neutron histories.

C6.3.1 .50c/MCNP4A Experiment # 2

```
U233-SOL-THERM-001.2
c Cells
1 1 1.00161-01 -1 imp:n=1 $ U233 solution
2 2 6.02747-02 +1 -2 imp:n=1 $ solution vessel
3 0 +2 imp:n=0 $ void outside
system

c Surfaces
1 so 34.595 $ vessel inner radius
2 so 34.915 $ vessel outer radius

c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 8 $ start near
soln center
c Data: materials and nuclide densities
m1 $ U-233 Solution, Experiment 2
1001.50c 6.6363-02 $ H
5010.50c 2.6481-07 $ B-10
5011.50c 1.0659-06 $ B-11
7014.50c 1.2248-04 $ N
8016.50c 3.3628-02 $ O
90232.50c 2.0489-07 $ Th-232
92233.50c 4.5093-05 $ U-233
92234.50c 7.4451-07 $ U-234
92235.50c 1.8305-08 $ U-235
92238.50c 2.8917-07 $ U-238
mt1 lwtr.01t
m2 $ Aluminum solution vessel
13027.50c 5.9881-02 $ Al
14000.50c 2.1790-04 $ Si
25055.50c 1.4853-05 $ Mn
26000.55c 1.0958-04 $ Fe
29000.50c 5.1364-05 $ Cu

print
```

C6.3.2 .60c/MCNP4A, Experiment # 3

U233-SOL-THERM-001.3

```
c      Cells
1      1 1.00260-01 -1      imp:n=1 $ U233 solution
2      2 6.02747-02 +1 -2  imp:n=1 $ solution vessel
3      0              +2      imp:n=0 $ void outside
system
```

```
c      Surfaces
1      so 34.595 $ vessel inner radius
2      so 34.915 $ vessel outer radius
```

```
c      Data: run control
kcode 1000      1.0      15 250 $ k-eff calc
ksrc   0         0         8      $ start near
soln center
```

c Data: materials and nuclide densities

m1 \$ U-233 Solution, Experiment 3

```
1001.60c 6.6413-02 $ H
5010.60c 5.1591-07 $ B-10
5011.60c 2.0766-06 $ B-11
7014.60c 1.2772-04 $ N
8016.60c 3.3674-02 $ O
90232.60c 2.1331-07 $ Th-232
92233.60c 4.6768-05 $ U-233
92234.60c 7.7216-07 $ U-234
92235.60c 1.8984-08 $ U-235
92238.60c 2.9991-07 $ U-238
```

mt1 lwtr.01t

m2 \$ Aluminum solution vessel

```
13027.60c 5.9881-02 $ Al
14000.60c 2.1790-04 $ Si
25055.60c 1.4853-05 $ Mn
26000.55c 1.0958-04 $ Fe
29000.50c 5.1364-05 $ Cu
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Appendix D

ORNL-2143 Experiments and Calculations

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D1 Experiments

During the 1950s a series of critical and subcritical experiments were performed at the Oak Ridge Critical Experiment Facility with aqueous ^{233}U solutions in simple, single-unit geometries to develop idealized benchmarks. Target benchmark experiments were fully-homogenized, near-pure ^{233}U systems with cylindrical and spherical cores, with and without infinite hydrogenous reflection. Ideally non- ^{233}U isotopes, solution impurities, vessel materials, vessel imperfections, control mechanisms, etc. would be negligible. Subject experiments are summarized in ORNL-2143. Twenty-six, reflected critical experiments are selected as possible benchmarks here.

Tables D-1 through D-5 list most experiment description information. In addition, ORNL-2143 indicates the presence of but does not provide thickness data for several items:

- Thin layers of hersite (a phenol-based plastic) were used to protect solution vessel walls,
- Hersite layers and vessel walls provided negligible neutron absorption, and
- Reflector size was essentially infinite.

Details such as ambient conditions, room configuration, direct-measurement uncertainties, material-manufacturing tolerances, wall thicknesses, reflector densities, reflector vessel size, control-blade slot dimensions, and control blade particulars are also not reported.

Additional information was indicated in ORNL/TM-12374, by Primm and, through Hopper, from an in-progress experiment evaluation at Oak Ridge:^{a,b}

- Manufacture methods were most probably identical for all cylindrical solution vessels but different techniques were probably used for spherical solution vessels. Subject cylindrical solution vessels are probably manufactured from the same schedule aluminum pipe or from nearly identical aluminum sheets or plates.
- Each reflected solution vessel is radially centered in a reflector vessel. Solution vessel bottoms were probably eight or more inches above reflector vessel floors because eight inches was a contemporary, rule-of-thumb value for near-infinite-water reflection and for near-complete isolation between submerged units.
- Except for radial location, control-blade(s) and associated structure are identical for all experiments because the blade was most probably one of two blades used for most contemporary ORNL critical experiments. However, the blade was probably flexible which would allow small configuration variations.

a R. Trenton Primm, III, telephone conversations, June, 1996.

b Calvin M. Hopper, telephone conversations with author, June and July, 1996.

Table D-1 ORNL-2143 Uranyl Nitrate Critical Experiment Parameters									
UO ₂ (NO ₃) ₂ , N: ²³³ U = 2.66 (assumed to be atom ratio)									
Solution Vessel: Type 3S Al, wall thickness not specified									
H: ²³³ U atomic ratio	Solution ρ (g/cm ³) ^a	²³³ U Density in Solution		Critical Mass ^{a,b} (kg ²³³ U)			Critical Height (cm)	ID (cm)	Exp. # ^c
		(g/cm ³)	(g/g) ^a	min.	nom	max,			
Paraffin-Reflected Single-Cylinder Experiments, Solution vessel height roughly equal to diameter									
57.5	1.543	0.381	0.247	1.72	1.77	1.82	16.3	19.1	B1-k
				1.76	1.813	1.86	14.4	20.5	B1-o
67.0	1.480	0.336	0.227	1.50	1.55	1.60	16.2	19.1	B1-l
84.4	1.394	0.275	0.197	1.29	1.33	1.37	14.7	20.5	B1-p
120	1.287	0.198	0.154	1.04	1.07	1.10	16.4	20.5	B1-q
145	1.238	0.167	0.135	0.89	0.92	0.95	16.7	20.5	B1-r
				0.86	0.89	0.92	18.6	19.1	B1-m
151	1.232	0.160	0.130	0.85	0.88	0.91	16.7	20.5	B1-s
193	1.185	0.127	0.107	0.77	0.79	0.81	18.8	20.5	B1-t
213	1.165	0.117	0.100	0.73	0.75	0.77	19.3	20.5	B1-u
247	1.145	0.101	0.099	0.68	0.70	0.72	19.4	21.5	B1-w
297	1.121	0.084	0.075	0.63	0.65	0.67	21.5	21.5	B1-x
356	1.101	0.070	0.064	0.60	0.62	0.64	21.3	22.9	B1-y
379	1.093	0.067	0.061	0.60	0.62	0.63	22.9	22.9	B1-z
394	1.090	0.063	0.058	0.61	0.63	0.65	19.3	25.5	B1-aa
461	1.077	0.055	0.051	0.61	0.63	0.65	22.5	25.5	B1-ab
582	1.061	0.044	0.041	0.66	0.68	0.70	21.1	30.5	B1-ae
630	1.056	0.040	0.038	0.68	0.70	0.72	23.8	30.5	B1-af
757	1.046	0.033	0.032	0.73	0.75	0.77	30.4	30.5	B1-ag
Water-Reflected Single-Sphere Experiment									
405	1.087	0.062	0.057	0.58	0.60	0.62	full	26.6	B1-ah

a Not used in developing base-case models.

b Experimenter-calculated value. Cumulative uncertainty estimated to not exceed $\pm 3\%$. Individual contributors were estimated to be $\pm 0.5\%$ with exception of solution critical height. Critical heights were measured indirectly and uncertainty was estimated to be greater, although individual values were not reported for this contributor.

c Experiment identification number assigned for this report using location of information in ORNL-2143 tables.

Table D-2 ORNL-2143 Uranyl Fluoride Critical Experiment Parameters										
Solution: UO ₂ F ₂ ; Solution Vessels: Type 3S Al, wall thickness not specified										
H: ²³³ U atomic ratio	Solution ρ (g/cm ³)	²³³ U Density in Solution		Critical Mass ^a (kg ²³³ U)			Critical Height (cm)	ID (cm)	Vessel Height (cm)	Exp # ^b
		(g/cm ³)	(g/g)	min.	nom	max.				
Paraffin-Reflected Single-Cylinder Experiments										
45.9	1.604	0.519	0.324	1.90	1.91	1.92	16.9	16.7	91.44	B2-o
154	1.198	0.165	0.138	0.86	0.87	0.88	18.4	19.1	19.1	B2-s
775	1.035 ^c	0.033	0.032 ^c	0.73	0.74	0.75	30.5	30.5	30.5	B2-y
Water-Reflected Single-Sphere Experiments										
390	1.076	0.066	0.061	0.60	0.61	0.62	24.47 ^d	26.6	NA	B2-ab
419	1.071	0.061	0.057	0.58	0.59	0.60	26.2 ^e	26.6	NA	B2-aa
663	1.043	0.039	0.037	0.65	0.66	0.67	full	31.9	NA	B2-ac

- a Experimenter-calculated value. Cumulative uncertainty estimated to not exceed $\pm 1\%$. Individual contributors each estimated to be $\pm 0.5\%$.
- b Experiment identification number assigned for this report using location of information in ORNL-2143 tables.
- c Not used in developing base-case models.
- d Calculated from an approximate 380 cm^3 void above critical solution. 24.3587 used in models.
- e Calculated from an approximate 40 cm^3 void above critical solution. 26.872 used in models.

Table D-3 ORNL-2143 Uranium Isotopic Compositions ^a		
Isotope	atomic wt%	
	$\text{UO}_2(\text{NO}_3)_2$	UO_2F_2
^{233}U	98.7	98.7
^{234}U	0.50	0.54
^{235}U	0.01	0.04
^{238}U	0.79	0.72

- a ORNL-2143 indicates the same uranium was first used as uranyl nitrate solution and later used as uranyl fluoride solution. This table's information might be, but is not necessarily, inconsistent with that use description depending on various factors including very slight burnup during experiments, solution makeup methods, solution denitration method, and measurement method(s).

Table D-4 ORNL-2143 Fissionable Solution Impurities ^a				
Metal	UO ₂ (NO ₃) ₂ in ppm		UO ₂ F ₂ in ppm	
	before	after	before	after
Al	15	50	400	8000
Ca	300	1500	--	--
Cr	10	15	8	250
Fe	20	300	40	2500
Mg	10	125	0	55
Mo	--	--	0	200
Na	--	--	650	100
Ni	20	70	0	250
Sn	--	--	0	225
Th	150	--	--	--

a Reported for completeness but not used in experiment models. ORNL-2143 indicates the same uranium was first used as uranyl nitrate solution and later used as uranyl fluoride solution. This table's information might be, but is not necessarily, inconsistent with that use depending on various factors including reaction between acids and vessel walls or wall coatings, solution makeup methods, solution denitration method, and measurement method(s).

Table D-5 ORNL-2143 Nonfissionable Materials						
Material	Application	ρ (g/cm ³)	Composition	SCALE # [MCNP #]	VF	N _n (particles/b-cm)
Type 3S ^a Aluminum	vessel walls, floor, lid	2.735	98.75% aluminum	AL [13027]	NA	6.0081E-02
			1.25% manganese	MN [25055]	NA	3.7351E-04
Paraffin	reflector	0.93	premixed: C ₂₅ H ₅₂	PARA(H ₂ O)	1.00	NA
			C ₂₅ H ₅₂	[6000]	NA	3.9699E-02
				[1001]	NA	8.2575E-02
Water	reflector	0.9982	premixed: H ₂ O	H ₂ O	1.00	NA
			H ₂ O	[1001]	NA	6.6741E-02
				[8016]	NA	3.3337E-02

a Composition as described by Lange. Density calculated from 2.74 specific gravity. Aluminum percentage includes 0.75% for unspecified components. Units assumed to be wt%.

- There was probably one reflector vessel for all reflected experiments. However, photographs indicate this vessel was very small compared to the nine-foot-diameter reflector vessel typically used in many other experiments at the facility.

D2 Models

Base-case models are a combination of idealized and actual experiment configurations, with:

- Solution vessel walls, floor, and lid are assumed to be 0.5 inches (1.27 cm) thick, based on a cylindrical-vessel-experiment photograph included in ORNL-2143.^a
- Reflector vessel is assumed to be 16 inches (40.64 cm) larger in diameter and height than the largest fully-reflected solution vessel, which was a 12.6 inch (32 cm) diameter sphere. This assumption is based on a previously mentioned popular rule-of-thumb.

Because of these assumptions and a decision to neglect the control-blade slot, reflectors were modelled with a fixed 29.1 inch (73.91 cm) outer diameter and a variable height, 16 inches (40.64 cm) longer than the outer height of each centered solution vessel.

With exception of ONEDANT models, each model includes a homogenous fissionable solution in a cylindrical or spherical solution vessel, centered in a tight-fitting homogeneous reflector with a cylindrical outer surface. Each ONEDANT model includes the same spherical cores centered in a tight-fitting, 8-inch-thick, spherical reflector shells. Figures 2 and 3 (page 12) illustrates base-case models, Tables D-6 and D-7 list model dimensions and solution nuclide densities for uranyl-nitrate experiments, Tables D-8 and D-9 list model dimensions and solution nuclide densities for uranyl fluoride experiments, and Table D-5 includes nonfissionable-material nuclide densities. Base-case models neglect material impurities, hersite, control blade and slot, feed- and drain-lines, reflector vessel walls and floor, manufacturing tolerances, measurement uncertainties, etc.

D3 Uncertainty and Sensitivity Effects

ORNL-2143 reports uncertainties only for inter-related critical parameters of mass, height, and volume. Estimated values for cumulative and individual contributor uncertainties are reported but individual contributors are not identified. ORNL-2143 does not include specific information for determining manufacturing tolerances, isotopic uncertainties, etc. which are provided in contemporary reports for ^{235}U experiments from the facility. I therefore infer reported uncertainties express cumulative experiment uncertainty rather than only uncertainties directly associated with these parameters. I focus on critical mass here because it was a primary focus of most early critical experiments, especially when one experiment or experiment series was designed to envelope many unspecified activities with and configurations of fissionable materials.

^a ORNL/TM-12374 files indicate 0.10-cm-thick walls were used but, in a June 1996 telephone conversation, Primm said he intended to use 1.00-cm-thick walls based on photographs and preliminary research. Primm's intention supports this assumption. Subject photograph lacks measurement reference but ORNL-2143 reports neutron interaction with solution vessel walls was usually negligible. No photographs were provided to judge spherical vessel wall thicknesses.

Table D-6 ORNL-2143 Uranyl Nitrate Critical Experiment Model Dimensions
(base-case models unless otherwise specified)

Exp. #	Solution Outer Dimensions and Solution Vessel Inner Dimensions (cm)					Solution Vessel Outer Dimensions (cm)		Reflector Height (cm) ^a
	Radius	Solution Critical Height			Vessel Height	Radius	Height	
		min ^b	nom	max ^b				
B1-k	9.55	15.8	16.3	16.7	19.1	10.82	21.64	40.69
B1-o	10.25	14.0	14.4	14.8	20.5	11.52	23.04	42.09
B1-l	9.55	15.6	16.2	16.6	19.1	10.82	21.64	40.69
B1-p	10.25	14.2	14.7	15.1	20.5	11.52	23.04	42.09
B1-q	10.25	15.9	16.4	16.8	20.5	11.52	23.04	42.09
B1-r	10.25	16.1	16.7	17.2	20.5	11.52	23.04	42.09
B1-m	9.55	18.0	18.6	19.2	19.1	10.82	21.64	40.69
B1-s	10.25	16.1	16.7	17.2	20.5	11.52	23.04	42.09
B1-t	10.25	18.4	18.8	19.3	20.5	11.52	23.04	42.09
B1-u	10.25	18.9	19.3	19.9	20.5	11.52	23.04	42.09
B1-w	10.75	18.5	19.4	19.6	21.5	12.02	24.04	43.09
B1-x	10.75	20.7	21.5	21.9	21.5	12.02	24.04	43.09
B1-y	11.45	20.8	21.3	22.2	22.9	12.72	25.44	44.49
B1-z	11.45	22.5	22.9	23.3	22.9	12.72	25.44	44.49
B1-aa	12.75	19.0	19.3	20.2	25.5	14.02	28.04	47.09
B1-ab	12.75	21.7	22.5	23.1	25.5	14.02	28.04	47.09
B1-ae	15.25	20.5	21.1	21.8	30.5	16.52	33.04	52.09
B1-af	15.25	23.3	23.8	24.6	30.5	16.52	33.04	52.09
B1-ag	15.25	29.6	30.4	31.2	30.5	16.52	33.04	52.09
B1-ah	Concentric spheres centered at 0,0,0: solution outer and vessel nom. IR = 13.3 cm, vessel outer and reflector inner radius of 14.57 cm for the base cases.							34.89

a Base cases reflector OR = 36.96 cm in all except ONEDANT model of case B1-ah, for which reflector is a tight-fitting spherical shell with OR = 34.89 cm. Reflector-vessel material is neglected in all base cases.

b Determined from M_c uncertainty, maintaining solution radius and nuclide densities. Used for sensitivity studies only. Model vessel height increased as needed to accommodate maximum solution critical height.

Table D-7 ORNL-2143 Uranyl Nitrate Solution Atom Densities

Exp #	H: ^{233}U	Nuclide # and $N_n^{a,b}$ (particles/b-cm)							WVF ^c
		U-233 [92233]	U-234 [92234]	U-235 [92235]	U-238 [92238]	N [7014]	H [1001]	O [8016]	
B1-k	57.5	9.8456E-4	4.9663E-6	9.8902E-8	7.7146E-6	2.6189E-3	5.6612E-2	3.8158E-2	0.8482
B1-o									
B1-l	67.0	8.6828E-4	4.3797E-6	8.7221E-8	6.8034E-6	2.3096E-3	5.8174E-2	3.7775E-2	0.8795
B1-p	84.4	7.1064E-4	3.5846E-6	7.1386E-8	5.5683E-6	1.8903E-3	5.9978E-2	3.7100E-2	0.8987
B1-q	120	5.1166E-4	2.5809E-6	5.1398E-8	4.0092E-6	1.3610E-3	6.1399E-2	3.5819E-2	0.9200
B1-r	145	4.3155E-4	2.1768E-6	4.3351E-8	3.3815E-6	1.1479E-3	6.2575E-2	3.5606E-2	0.9376
B1-m									
B1-s	151	4.1346E-2	2.0856E-6	4.1534E-8	3.2397E-6	1.0998E-3	6.2543E-2	3.5354E-2	0.9354
B1-t	193	3.2819E-4	1.6554E-6	3.2967E-8	2.5715E-6	8.7298E-4	6.3340E-2	3.4954E-2	0.9490
B1-u	213	3.0235E-4	1.5251E-6	3.0372E-8	2.3690E-6	8.0424E-4	6.4400E-2	3.5225E-2	0.9649
B1-w	247	2.6100E-4	1.3165E-6	2.6218E-8	2.0451E-6	6.9426E-4	6.4467E-2	3.4845E-2	0.9659
B1-x	297	2.1707E-4	1.0949E-6	2.1805E-8	1.7009E-6	5.7740E-4	6.4469E-2	3.4407E-2	0.9967
B1-y	356	1.8089E-4	9.1245E-7	1.8171E-8	1.4174E-6	4.8117E-4	6.4397E-2	3.4008E-2	0.9649
B1-z	379	1.7314E-4	8.7334E-7	1.7392E-8	1.3566E-6	4.6055E-4	6.5619E-2	3.4542E-2	0.9832
B1-aa	394	1.6280E-4	8.2120E-7	1.6354E-8	1.2756E-6	4.3305E-4	6.4144E-2	3.3701E-2	0.9611
B1-ab	461	1.4213E-4	7.1692E-7	1.4277E-8	1.1137E-6	3.7806E-4	6.5521E-2	3.4183E-2	0.9817
B1-ae	582	1.1370E-4	5.7354E-7	1.1422E-8	8.9092E-7	3.0245E-4	6.6175E-2	3.4225E-2	0.9915
B1-af	630	1.0337E-4	5.2140E-7	1.0383E-8	8.0993E-7	2.7495E-4	6.5121E-2	3.3595E-2	0.9757
B1-ag	757	8.5277E-5	4.3015E-7	8.5664E-9	6.6820E-7	2.2684E-4	6.4555E-2	3.3131E-2	0.9672
B1-ah	405	1.6022E-4	8.0817E-7	1.6094E-8	1.2554E-6	4.2618E-4	6.4888E-2	3.4047E-2	0.9722

a Calculated using $N: ^{233}\text{U}=2.66$ and listed H: ^{233}U values, neglecting solution impurities (Table D-4, page 6).

b SCALE identifiers listed first, MCNP identifiers listed in brackets ([]).

c Provided for comparisons but not used in developing models.

Table D-8 ORNL-2143 Uranyl Fluoride Critical Experiment Model Dimensions
base-case models unless otherwise specified

Exp. #	Solution Outer Dimensions (cm)				Solution Vessel Dimensions (cm)			Reflector Height (cm) ^a
	nom Radius	Cylinder Ht or Sphere OR based on Critical Mass			Vessel Inner Height	nom. Outer Radius	nom. Outer Height	
		min ^b	nom	max ^b				
B2-o	8.38	16.8	16.9	17.0	91.44	9.65	93.98	134.62
B2-s	9.55	18.2	18.4	18.6	19.1	10.82	21.64	62.28
B2-y	15.25	30.1	30.5	30.9	30.5	16.52	33.04	73.68
B2-ab	13.3	-- ^c	13.3	-- ^c	NA	14.57	NA	69.78
B2-aa	13.3	-- ^c	13.3	-- ^c	NA	14.57	NA	69.78
B2-ac	15.95	-- ^c	15.95	-- ^c	NA	17.22	NA	75.08

- a Base cases: Reflector OR= 36.96 cm in all, except ONEDANT model of B2-ac, for which reflector is a tight-fitting spherical shell with OR= 34.89 cm. Reflector-vessel material is neglected in all base cases.
- b Determined from M_c uncertainty, maintaining constant atom densities. Cylinder vessel radius was maintained constant. Solution-vessel height increased as needed to accommodate constant atom densities for maximum critical mass cases. Used for sensitivity studies only.
- c Not determined. Calculation model not developed.

Table D-9 ORNL-2143 Uranyl Fluoride Solution Atom Densities

Exp. #	H: ²³³ U	Nuclide # and N_n (particles/b-cm) ^{a,b}							WVF ^c
		U-233 [92233]	U-234 [92234]	U-235 [92235]	U-238 [92238]	F [9019]	H [1001]	O [8016]	
B2-o	45.9	1.3412E-3	7.3063E-6	5.3890E-7	9.5777E-6	2.7031E-3 ^d	6.1560E-2	3.3497E-2	0.9224
B2-s	154	4.2639E-4	2.3228E-6	1.7133E-7	3.0449E-6	8.1809E-4 ^d	6.5663E-2	3.3696E-2	0.9838
B2-y	775	8.5277E-5	4.6457E-7	3.4265E-8	6.0899E-7	2.7041E-4	6.6089E-2	3.3218E-2	0.9902
B2-ab	390	1.7055E-4	9.2913E-7	6.8531E-8	1.2180E-6	1.6258E-4 ^d	6.6516E-2	3.3603E-2	0.9966
B2-aa	419	1.5763E-4	8.5874E-7	6.3339E-8	1.1257E-6	4.0845E-4 ^d	6.6048E-2	3.3343E-2	0.9896
B2-ac ^e	663	1.0078E-4	5.4903E-7	4.0495E-8	7.1971E-7	2.0418E-4	6.6742E-2	3.3575E-2	1.00

- a Calculated using listed H:²³³U atom ratio, neglecting solution impurities (Table D-4, page D-6), unless otherwise noted.
- b SCALE identifier listed first, MCNP identifier listed in brackets ([]).
- c Provided for comparisons but not used in developing models except for Experiment # B2-ac.
- d Negative excess fluorine (F:U < 2) interpreted as uranium precipitate suspended in solution to form homogeneous material.
- e Mass and concentration data produce an impossible result: negative fluorine atom density. Atom densities are therefore calculated from molecular formula UO_2F_2 , assuming WVF is 1.00 in solution.

ORNL-2143 reports uncertainties in experimenter-calculated critical masses, as cumulative-total and maximum-individual-contributing-factor uncertainties. For uranyl nitrate experiments, cumulative uncertainty was estimated to not exceed $\pm 3\%$ and individual contributors were estimated to be $\pm 0.5\%$, except for critical height. ORNL-2143 indicates critical heights were measured indirectly but does not indicate associated uncertainties. For uranyl fluoride experiments, cumulative uncertainty was estimated to not exceed $\pm 1\%$ and individual contributors were each estimated to be 0.5% . These cumulative uncertainties are here assumed to incorporate or envelope uncertainty effects of uranium isotopic distribution including ^{233}U enrichment; uranium concentration or density; solution molarity, density, impurities, volume, and height; solution vessel diameter, wall thickness, floor thickness, and shape irregularities; and to some extent reflector inhomogeneity. Table D-10 lists critical-mass-uncertainty results for cylindrical core experiments. These results indicate experiment- k_{eff} uncertainty is about $\pm 1\%$.

Table D-10 results also indicate there is up to a 3% nonconservative trend in these calculation results although individual σ s are typically small, indicating models and hence experiment-description assumptions, cross-section-library data, or both are inaccurate. Based on results in other appendices, it is likely that experiment-description assumptions and resultant models are the largest contributors to these low k_{eff} calculations, but contribution magnitude is not fully known. Most readily identifiable inaccuracy sources include solution-vessel-wall thicknesses, paraffin-reflector density and homogeneity, and reflector thicknesses. Less important inaccuracy sources include cadmium-blade-slot walls and water in the cadmium-blade slot. The cadmium-blade itself would have been above and to the side of fissionable solution and should therefore have negligible effect. Effects of reflector-vessel walls and surrounding structure should be likewise negligible because reflectors are described as nearly infinite, assumed to be at least eight inches thick.

Table D-11 lists calculation results to quantify solution-vessel-wall-thickness sensitivities. Calculations include models with no wall (0.0 inches), a too-thick (1.00 inch) wall, and two readily believable wall thicknesses (0.25 and 0.50 inches). The no-wall and 0.25-inch-thick-wall models provide results typical of other contemporary critical experiments. No-wall models would be accurate if critical masses were corrected to incorporate wall effects but ORNL-2143 does not mention such corrections, which is highly unusual if such corrections were made. The 0.25-inch-wall models are believable if the vessel shown in ORNL-2143 is one of the smallest vessels used in this series, the photograph hides some of the vessel length, and more than one reflector vessel was used in this experiment series. However, there is currently insufficient evidence available at INEEL to select a significantly thinner wall thickness than 0.50 inches because of the photograph.

Tables D-12 and D-13 list calculation results to quantify reflector-thickness and -density sensitivities. As expected, results are similar between the two variations and much less significant than calculation sensitivity to solution-vessel-wall thickness. Unless reflectors are less than eight inches thick, or there are large voids or near voids in paraffin reflectors, water- and paraffin-reflector-uncertainty effects should be no more than a few tenths of a percent in k_{eff} . Base models here average from 0.5% to 2.0% low. Therefore, it would be unproductive to investigate sensitivities to items within or beyond the reflector (for example, reflector vessel materials, the cadmium-blade slot, etc.) at this time.

Table D-10 ORNL-2143 Cylinder-Experiment Critical-Mass-Uncertainty Effects					
Exp. #	$\Delta m_{ss}\%$	$k_{eff} \pm 1\sigma$ (44GROUPNDF5/CSAS25/SCALE4.3)			Δk_{eff}^a
		minimum M_c	nominal M_c (Table D-16, page D-19)	maximum M_c	
B1-k	± 3	0.9830 ± 0.0017	0.9964 ± 0.0019	1.0058 ± 0.0019	± 0.0114
B1-o	± 3	0.9657 ± 0.0018	0.9782 ± 0.0018	0.9903 ± 0.0019	± 0.0123
B1-l	± 3	0.9761 ± 0.0019	0.9929 ± 0.0017	1.0010 ± 0.0019	± 0.0125
B1-p	± 3	0.9576 ± 0.0019	0.9775 ± 0.0017	0.9899 ± 0.0019	± 0.0162
B1-q	± 3	0.9738 ± 0.0018	0.9873 ± 0.0017	0.9958 ± 0.0020	± 0.0110
B1-m	± 3	0.9734 ± 0.0018	0.9866 ± 0.0018	1.0001 ± 0.0018	± 0.0134
B1-r	± 3	0.9664 ± 0.0019	0.9820 ± 0.0018	0.9948 ± 0.0018	± 0.0142
B1-s	± 3	0.9615 ± 0.0017	0.9713 ± 0.0019	0.9831 ± 0.0020	± 0.0108
B1-t	± 3	0.9790 ± 0.0018	0.9833 ± 0.0017	0.9922 ± 0.0017	± 0.0066
B1-u	± 3	0.9795 ± 0.0017	0.9878 ± 0.0019	0.9948 ± 0.0019	± 0.0077
B1-w	± 3	0.9683 ± 0.0017	0.9874 ± 0.0017	0.9939 ± 0.0017	± 0.0128
B1-x	± 3	0.9782 ± 0.0016	0.9898 ± 0.0016	0.9960 ± 0.0017	± 0.0089
B1-y	± 3	0.9615 ± 0.0018	0.9692 ± 0.0016	0.9858 ± 0.0017	± 0.0122
B1-z	± 3	0.9990 ± 0.0017	0.9958 ± 0.0016	0.9975 ± 0.0017	± 0.0015
B1-aa	± 3	0.9520 ± 0.0016	0.9570 ± 0.0016	0.9745 ± 0.0017	± 0.0113
B1-ab	± 3	0.9716 ± 0.0016	0.9825 ± 0.0016	0.9922 ± 0.0016	± 0.0103
B1-ac	± 3	0.9651 ± 0.0015	0.9762 ± 0.0015	0.9874 ± 0.0015	± 0.0112
B1-af	± 3	0.9750 ± 0.0015	0.9795 ± 0.0015	0.9920 ± 0.0015	± 0.0085
B1-ag	± 3	0.9792 ± 0.0014	0.9836 ± 0.0014	0.9911 ± 0.0013	± 0.0060
B2-o	± 1	0.9749 ± 0.0019	0.9785 ± 0.0019	0.9794 ± 0.0018	± 0.0023
B2-s	± 1	1.0014 ± 0.0020	1.0118 ± 0.0017	1.0147 ± 0.0019	± 0.0067
B2-y	± 1	0.9922 ± 0.0014	0.9958 ± 0.0015	0.9979 ± 0.0014	± 0.0029
Average		0.9743 ± 0.0123	0.9841 ± 0.0113	0.9932 ± 0.0086	± 0.0095

a Δk_{eff} calculation method described in Appendix B.

Table D-11 ORNL-2143 Solution-Vessel-Wall-Thickness Effects

Exp. #	$k_{\text{eff}} \pm 1\sigma$ as a Function of Wall Thickness (44GROUPNDF5/CSAS25/SCALE4.3)				$\Delta k_{\text{eff}}/\Delta \text{wall}^a$ (cm^{-1})
	0.00 in. (0.00 cm)	0.25 in. (0.635 cm)	nominal 0.50 in. (1.270 cm) (Table D-16, page D-19)	1.00 in. (2.540 cm)	
B1-k	1.0217 $\pm$ 0.0019	1.0066 $\pm$ 0.0018	0.9964 $\pm$ 0.0019	0.9688 $\pm$ 0.0018	$\mp$ 0.021
B1-o	1.0101 $\pm$ 0.0019	0.9944 $\pm$ 0.0018	0.9782 $\pm$ 0.0018	0.9559 $\pm$ 0.0019	$\mp$ 0.021
B1-l	1.0202 $\pm$ 0.0019	1.0032 $\pm$ 0.0019	0.9929 $\pm$ 0.0017	0.9669 $\pm$ 0.0018	$\mp$ 0.021
B1-p	1.0084 $\pm$ 0.0019	0.9909 $\pm$ 0.0018	0.9775 $\pm$ 0.0017	0.9506 $\pm$ 0.0018	$\mp$ 0.023
B1-q	1.0181 $\pm$ 0.0019	1.0025 $\pm$ 0.0019	0.9873 $\pm$ 0.0017	0.9659 $\pm$ 0.0019	$\mp$ 0.021
B1-m	1.0239 $\pm$ 0.0019	1.0049 $\pm$ 0.0019	0.9866 $\pm$ 0.0018	0.9645 $\pm$ 0.0019	$\mp$ 0.023
B1-r	1.0124 $\pm$ 0.0019	0.9940 $\pm$ 0.0018	0.9820 $\pm$ 0.0018	0.9523 $\pm$ 0.0019	$\mp$ 0.024
B1-s	1.0013 $\pm$ 0.0017	0.9884 $\pm$ 0.0019	0.9713 $\pm$ 0.0019	0.9454 $\pm$ 0.0019	$\mp$ 0.022
B1-t	1.0182 $\pm$ 0.0018	1.0020 $\pm$ 0.0018	0.9833 $\pm$ 0.0017	0.9619 $\pm$ 0.0018	$\mp$ 0.022
B1-u	1.0177 $\pm$ 0.0019	0.9976 $\pm$ 0.0018	0.9878 $\pm$ 0.0019	0.9639 $\pm$ 0.0018	$\mp$ 0.021
B1-w	1.0177 $\pm$ 0.0018	1.0011 $\pm$ 0.0018	0.9874 $\pm$ 0.0017	0.9637 $\pm$ 0.0019	$\mp$ 0.021
B1-x	1.0181 $\pm$ 0.0017	1.0070 $\pm$ 0.0017	0.9898 $\pm$ 0.0016	0.9703 $\pm$ 0.0018	$\mp$ 0.019
B1-y	0.9968 $\pm$ 0.0017	0.9828 $\pm$ 0.0017	0.9692 $\pm$ 0.0016	0.9491 $\pm$ 0.0017	$\mp$ 0.019
B1-z	1.0199 $\pm$ 0.0017	1.0055 $\pm$ 0.0016	0.9958 $\pm$ 0.0016	0.9777 $\pm$ 0.0016	$\mp$ 0.017
B1-aa	0.9835 $\pm$ 0.0016	0.9668 $\pm$ 0.0016	0.9570 $\pm$ 0.0016	0.9370 $\pm$ 0.0016	$\mp$ 0.018
B1-ab	1.0071 $\pm$ 0.0017	0.9962 $\pm$ 0.0016	0.9825 $\pm$ 0.0016	0.9705 $\pm$ 0.0016	$\mp$ 0.014
B1-ae	0.9941 $\pm$ 0.0016	0.9840 $\pm$ 0.0015	0.9762 $\pm$ 0.0015	0.9616 $\pm$ 0.0016	$\mp$ 0.013
B1-af	0.9961 $\pm$ 0.0015	0.9898 $\pm$ 0.0015	0.9795 $\pm$ 0.0015	0.9692 $\pm$ 0.0015	$\mp$ 0.011
B1-ag	0.9996 $\pm$ 0.0014	0.9940 $\pm$ 0.0013	0.9836 $\pm$ 0.0014	0.9720 $\pm$ 0.0014	$\mp$ 0.011
B1-ah	1.0099 $\pm$ 0.0017	0.9996 $\pm$ 0.0017	0.9942 $\pm$ 0.0016	0.9771 $\pm$ 0.0017	$\mp$ 0.013
B2-o	1.0145 $\pm$ 0.0020	0.9516 $\pm$ 0.0019	0.9785 $\pm$ 0.0019	0.9785 $\pm$ 0.0019	$\mp$ 0.014
B2-s	1.0421 $\pm$ 0.0019	1.0200 $\pm$ 0.0018	1.0118 $\pm$ 0.0017	0.9822 $\pm$ 0.0019	$\mp$ 0.024
B2-y	0.9958 $\pm$ 0.0015	1.0041 $\pm$ 0.0014	0.9958 $\pm$ 0.0015	0.9856 $\pm$ 0.0014	$\mp$ 0.040
B2-ab	1.0335 $\pm$ 0.0018	1.0249 $\pm$ 0.0016	1.0149 $\pm$ 0.0017	1.0015 $\pm$ 0.0017	$\mp$ 0.013
B2-aa	1.0210 $\pm$ 0.0016	1.0088 $\pm$ 0.0017	0.9984 $\pm$ 0.0016	0.9833 $\pm$ 0.0017	$\mp$ 0.015
B2-ac	1.0218 $\pm$ 0.0015	1.0149 $\pm$ 0.0015	1.0092 $\pm$ 0.0014	0.9985 $\pm$ 0.0016	$\mp$ 0.009
Ave.	1.0124 $\pm$ 0.0131	0.9975 $\pm$ 0.0152	0.9872 $\pm$ 0.0131	0.9682 $\pm$ 0.0152	$\mp$ 0.0221

a Δk_{eff} calculation method described in Appendix B.

Table D-12 ORNL-2143 Reflector-Thickness Effects

Exp. #	Solution Outer Radius (cm)	$k_{\text{eff}} \pm 1\sigma$ as a Function of Reflector Outer Radius (44GROUPNDF5/CSAS25/SCALE4.3)			Δk_{eff}^a
		OR = 36.96 cm (Table D-16, page D-19)	OR = 42.04 cm	OR = 47.12 cm ^b	
B1-k	10.82	0.9964 ± 0.0019	0.9951 ± 0.0018	0.9912 ± 0.0019	- 0.0052
B1-o	11.52	0.9782 ± 0.0018	0.9786 ± 0.0019	0.9764 ± 0.0019	- 0.0018 *
B1-l	10.82	0.9929 ± 0.0017	0.9886 ± 0.0018	0.9899 ± 0.0019	- 0.0030
B1-p	11.52	0.9775 ± 0.0017	0.9773 ± 0.0020	0.9776 ± 0.0017	-0.0026
B1-q	11.52	0.9873 ± 0.0017	0.9845 ± 0.0017	0.9871 ± 0.0019	- 0.0028
B1-m	11.52	0.9866 ± 0.0018	0.9895 ± 0.0018	0.9876 ± 0.0018	+ 0.0029
B1-r	10.82	0.9820 ± 0.0018	0.9794 ± 0.0018	0.9779 ± 0.0018	- 0.0041
B1-s	11.52	0.9713 ± 0.0019	0.9723 ± 0.0018	0.9689 ± 0.0019	- 0.0034
B1-t	11.52	0.9833 ± 0.0017	0.9839 ± 0.0018	0.9831 ± 0.0018	- 0.0008 *
B1-u	11.52	0.9878 ± 0.0019	0.9884 ± 0.0018	0.9861 ± 0.0017	- 0.0023
B1-w	12.02	0.9874 ± 0.0017	0.9918 ± 0.0018	0.9877 ± 0.0018	+ 0.0044
B1-x	12.02	0.9898 ± 0.0016	0.9871 ± 0.0018	0.9887 ± 0.0018	- 0.0027
B1-y	12.72	0.9692 ± 0.0016	0.9700 ± 0.0017	0.9715 ± 0.0016	+ 0.0023
B1-z	12.72	0.9958 ± 0.0016	0.9928 ± 0.0017	0.9977 ± 0.0016	+ 0.0049
B1-aa	14.02	0.9570 ± 0.0016	0.9613 ± 0.0016	0.9596 ± 0.0017	+ 0.0043
B1-ab	14.02	0.9825 ± 0.0016	0.9865 ± 0.0016	0.9873 ± 0.0015	+ 0.0048
B1-ae	16.52	0.9762 ± 0.0015	0.9726 ± 0.0016	0.9764 ± 0.0016	+ 0.0038
B1-af	16.52	0.9795 ± 0.0015	0.9812 ± 0.0014	0.9781 ± 0.0016	- 0.0031
B1-ag	16.52	0.9836 ± 0.0014	0.9851 ± 0.0014	0.9854 ± 0.0014	+ 0.0018
B1-ah	13.3	0.9942 ± 0.0016	0.9922 ± 0.0016	0.9916 ± 0.0014	- 0.0026
B2-o	8.38	0.9785 ± 0.0019	0.9769 ± 0.0019	0.9795 ± 0.0019	+ 0.0026
B2-s	9.55	1.0118 ± 0.0017	1.0067 ± 0.0019	1.0103 ± 0.0019	- 0.0051
B2-y	15.25	0.9958 ± 0.0015	0.9958 ± 0.0015	0.9958 ± 0.0015	0.0000
B2-ab	13.3	1.0149 ± 0.0017	1.0135 ± 0.0017	1.0146 ± 0.0017	- 0.0014 *
B2-aa	13.3	0.9984 ± 0.0016	0.9990 ± 0.0016	0.9953 ± 0.0017	- 0.0031
B2-ac	15.95	1.0092 ± 0.0014	1.0079 ± 0.0016	1.0068 ± 0.0015	- 0.0024
Average		0.9872 ± 0.0131	0.9868 ± 0.0121	0.9866 ± 0.0124	- 0.0006 *

a Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other) regardless of reflector thickness.

b Equivalent to 12-inch-thick reflector around largest solution vessel in this experiment series.

Table D-13 ORNL-2143 Reflector-Density Effects				
Exp. #	$k_{\text{eff}} \pm 1\sigma$ as a Function of Reflector Volume Fraction (44GROUPNDF5/CSAS25/SCALE4.3)			Δk_{eff}^a
	VF = 0.90	VF = 1.00 (Table D-16, page D-19)	VF = 1.10	
B1-k	0.9860 ± 0.0018	0.9964 ± 0.0019	1.0044 ± 0.0019	± 0.0092
B1-o	0.9706 ± 0.0018	0.9782 ± 0.0018	0.9861 ± 0.0018	± 0.0078
B1-l	0.9816 ± 0.0018	0.9929 ± 0.0017	0.9972 ± 0.0019	± 0.0078
B1-p	0.9672 ± 0.0019	0.9775 ± 0.0017	0.9876 ± 0.0018	± 0.0102
B1-q	0.9790 ± 0.0019	0.9873 ± 0.0017	0.9932 ± 0.0019	± 0.0071
B1-m	0.9823 ± 0.0019	0.9866 ± 0.0018	0.9893 ± 0.0018	± 0.0035
B1-r	0.9723 ± 0.0018	0.9820 ± 0.0018	0.9864 ± 0.0017	± 0.0071
B1-s	0.9655 ± 0.0019	0.9713 ± 0.0019	0.9776 ± 0.0018	± 0.0061
B1-t	0.9770 ± 0.0018	0.9833 ± 0.0017	0.9913 ± 0.0019	± 0.0072
B1-u	0.9820 ± 0.0017	0.9878 ± 0.0019	0.9931 ± 0.0019	± 0.0056
B1-w	0.9807 ± 0.0017	0.9874 ± 0.0017	0.9918 ± 0.0018	± 0.0056
B1-x	0.9851 ± 0.0018	0.9898 ± 0.0016	0.9909 ± 0.0017	± 0.0029
B1-y	0.9644 ± 0.0015	0.9692 ± 0.0016	0.9787 ± 0.0016	± 0.0072
B1-z	0.9897 ± 0.0016	0.9958 ± 0.0016	0.9970 ± 0.0016	± 0.0037
B1-aa	0.9523 ± 0.0017	0.9570 ± 0.0016	0.9584 ± 0.0017	± 0.0031
B1-ab	0.9800 ± 0.0017	0.9825 ± 0.0016	0.9858 ± 0.0016	± 0.0029
B1-ae	0.9741 ± 0.0016	0.9762 ± 0.0015	0.9777 ± 0.0016	$\pm 0.0018^*$
B1-af	0.9783 ± 0.0015	0.9795 ± 0.0015	0.9824 ± 0.0016	± 0.0021
B1-ag	0.9789 ± 0.0015	0.9836 ± 0.0014	0.9866 ± 0.0014	± 0.0039
B1-ah	0.9888 ± 0.0016	0.9942 ± 0.0016	0.9967 ± 0.0016	± 0.0040
B2-o	0.9702 ± 0.0019	0.9785 ± 0.0019	0.9883 ± 0.0019	± 0.0091
B2-s	0.9977 ± 0.0017	1.0118 ± 0.0017	1.0125 ± 0.0018	± 0.0074
B2-y	0.9961 ± 0.0014	0.9958 ± 0.0015	0.9964 ± 0.0013	$\pm 0.0006^*$
B2-ab	1.0101 ± 0.0017	1.0149 ± 0.0017	1.0182 ± 0.0018	± 0.0020
B2-aa	0.9942 ± 0.0017	0.9984 ± 0.0016	1.0009 ± 0.0016	± 0.0034
B2-ac	1.0019 ± 0.0016	1.0092 ± 0.0014	1.0087 ± 0.0015	± 0.0034
Average	0.9810 ± 0.0127	0.9872 ± 0.0131	0.9914 ± 0.0122	± 0.0052

a Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other) regardless of reflector density.

A cumulative experiment uncertainty of $0.05 \Delta k_{\text{eff}}$ is assigned to these experiments. Although the exact value assigned is arbitrary, it is based on cumulative effects from Tables D-10 through D-13, effects for other solution parameters estimated from Appendices C and E for similar parameters and experiments, and an additional 3% in case other experiments are not as similar as they seem here, or solution vessels truly are thick-walled, or both.

D4 Library-and-Code Combination Effects

Summarized in Table 4 (page 13), Tables D-14 through D-20 list calculation results for various library-and-code combinations. All results are slightly below critical but ENDF/B-IV-based libraries performed best, averaging about 0.5% nonconservative. ENDF/B-V- and ENDF/B-VI-based libraries appear to perform well, averaging about 1.8% nonconservative. The *Hansen-Roach* library performed least well, averaging about 3.1% nonconservative with a worst case of 4.1% nonconservative, consistent with differences between these thermal experiments and this library's fast-system basis. Relatively high average σ s probably reflect experiment-description uncertainties (for example, same density reflector for all paraffin-reflected cases when paraffin was most likely somewhat inhomogeneous and recarved or reformed for each change in solution vessel diameter) rather than calculation uncertainties a full order of magnitude greater than typical.

D5 Analysis Conclusions

Based on results listed in Tables D-11, D-12, and D-13, solution-vessel-wall uncertainty is considered the most significant experiment-description uncertainty at this time. Depending on actual wall thicknesses, it is quite possible that calculation results are within typical accuracies (1% or less) or that there is a significant nonconservative bias in calculation methodology for these experiments.

If it is practical, calculations for thermal ^{233}U systems should not rely on these experiments for validation at least until models can be based on more complete experiment descriptions. However, if it is necessary to use these experiments for validation, it is important to note that any calculation uncertainties and biases might be completely within and masked by experiment-description uncertainty.

Table 5 (page 13) lists recommended calculation biases if it is necessary to use these experiments. Significance of statistical variations in $k_{\text{eff,ave}}$ values were assessed in recommending biases because $\sigma_{k_{\text{eff,ave}}}$ values significantly exceed both $\sigma_{k_{\text{eff}}}$ and $1.000 - k_{\text{eff,ave}}$ values. In each case most of the $\sigma_{k_{\text{eff,ave}}}$ value appears to be due to experiment descriptions causing a consistently high or low value for a specific vessel, solution, reflector, or overall experiment. However, $\sigma_{k_{\text{eff,ave}}}$ might be almost as significant as experiment uncertainty effects. Therefore, the bias = $1.000 - k_{\text{eff,ave}}$ was used but no bias was set to zero if $k_{\text{eff,ave}}$ was less than 1.0000.

Table D-14 Calculations with *Hansen-Roach/CSAS25/SCALE4.3*

Experiment # ^a	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
B1-k	0.9621 ± 0.0018	0.3130 ± 0.0014
B1-o	0.9460 ± 0.0018	0.3143 ± 0.0016
B1-l	0.9598 ± 0.0018	0.2385 ± 0.0010
B1-p	0.9489 ± 0.0017	0.1642 ± 0.0006
B1-q	0.9623 ± 0.0018	0.0969 ± 0.0003
B1-m	0.9665 ± 0.0018	0.7533 ± 0.0002
B1-r	0.9589 ± 0.0018	0.7574 ± 0.0002
B1-s	0.9545 ± 0.0018	0.7145 ± 0.0002
B1-t	0.9675 ± 0.0018	0.5389 ± 0.0001
B1-u	0.9725 ± 0.0018	0.4865 ± 0.0001
B1-w	0.9728 ± 0.0017	0.4225 ± 0.0001
B1-x	0.9737 ± 0.0017	0.3587 ± 0.0001
B1-y	0.9574 ± 0.0017	0.3124 ± 0.0000
B1-z	0.9832 ± 0.0016	0.2982 ± 0.0000
B1-aa **	0.9453 ± 0.0016	0.2931 ± 0.0000
B1-ab	0.9736 ± 0.0016	0.2638 ± 0.0000
B1-ae	0.9654 ± 0.0015	0.2330 ± 0.0000
B1-af	0.9724 ± 0.0016	0.2229 ± 0.0000
B1-ag	0.9788 ± 0.0014	0.2041 ± 0.0000
B1-ah	0.9802 ± 0.0017	0.2889 ± 0.0000
B2-o	0.9398 ± 0.0018	0.5412 ± 0.0028
B2-s **	0.9877 ± 0.0017	0.0695 ± 0.0001
B2-y	0.9881 ± 0.0015	0.2013 ± 0.0000
B2-ab **	1.0008 ± 0.0017	0.0296 ± 0.0000
B2-aa	0.9865 ± 0.0016	0.0281 ± 0.0000
B2-ac	1.0010 ± 0.0015	0.2167 ± 0.0000
Average^b	0.9695 ± 0.0162	0.3216 ± 0.2044

a A double asterisk indicates the case was run 10 times, each with a different starting random number. Results of the first run are listed because all results were within 0.6σ of each other.

b In all cases average σ is the standard deviation of averaged value.

Table D-15 27GROUPNDF4 and 218GROUPNDF4 Cross-Section-Library Effects				
Experiment # ^a	27GROUPNDF4/CSAS25/SCALE4.3		218GROUPNDF4/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma$	ale (ev)	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
B1-k	1.0054 ± 0.0020	0.4439 ± 0.0019	1.0054 ± 0.0018	0.4420 ± 0.0019
B1-o	0.9940 ± 0.0018	0.4460 ± 0.0020	0.9881 ± 0.0019	0.4469 ± 0.0019
B1-l	1.0008 ± 0.0018	0.3439 ± 0.0013	0.9986 ± 0.0018	0.3442 ± 0.0014
B1-p	0.9899 ± 0.0019	0.2440 ± 0.0009	0.9855 ± 0.0018	0.2399 ± 0.0008
B1-q	1.0022 ± 0.0019	0.1462 ± 0.0005	0.9959 ± 0.0018	0.1456 ± 0.0004
B1-m	0.9957 ± 0.0018	0.1143 ± 0.0003	0.9976 ± 0.0017	0.1134 ± 0.0003
B1-r	0.9962 ± 0.0018	0.1152 ± 0.0003	0.9885 ± 0.0018	0.1150 ± 0.0003
B1-s	0.9835 ± 0.0017	0.1098 ± 0.0003	0.9815 ± 0.0018	1.0884 ± 0.0003
B1-t	0.9953 ± 0.0018	0.0835 ± 0.0002	0.9957 ± 0.0018	0.0833 ± 0.0002
B1-u	0.9968 ± 0.0019	0.0760 ± 0.0002	0.9957 ± 0.0017	0.0757 ± 0.0002
B1-w	0.9986 ± 0.0018	0.0660 ± 0.0001	0.9989 ± 0.0018	0.0659 ± 0.0001
B1-x	1.0008 ± 0.0017	0.0566 ± 0.0001	0.9940 ± 0.0015	0.0564 ± 0.0001
B1-y	0.9810 ± 0.0018	0.0496 ± 0.0001	0.9804 ± 0.0017	0.0493 ± 0.0001
B1-z	1.0053 ± 0.0017	0.0476 ± 0.0001	1.0027 ± 0.0016	0.0473 ± 0.0001
B1-aa **	0.9632 ± 0.0016	0.0467 ± 0.0001	0.9690 ± 0.0017	0.0463 ± 0.0001
B1-ab	0.9934 ± 0.0015	0.0423 ± 0.0001	0.9927 ± 0.0017	0.0421 ± 0.0001
B1-ae	0.9823 ± 0.0015	0.0375 ± 0.0001	0.9821 ± 0.0015	0.0372 ± 0.0001
B1-af	0.9876 ± 0.0015	0.0360 ± 0.0000	0.9877 ± 0.0015	0.0358 ± 0.0000
B1-ag	0.9916 ± 0.0014	0.0332 ± 0.0000	0.9906 ± 0.0014	0.0328 ± 0.0000
B1-ah	0.9979 ± 0.0016	0.0460 ± 0.0001	0.9999 ± 0.0016	0.0458 ± 0.0001
B2-o	0.9916 ± 0.0019	0.0739 ± 0.0034	0.9884 ± 0.0020	0.7340 ± 0.0035
B2-s **	1.0154 ± 0.0018	0.1064 ± 00.0003	1.0173 ± 0.0018	0.1056 ± 0.0003
B2-y	1.0030 ± 0.0014	0.0328 ± 0.0000	1.0008 ± 0.0014	0.0325 ± 0.0000
B2-ab **	1.0120 ± 0.0017	0.0471 ± 0.0001	1.0239 ± 0.0017	0.0466 ± 00.0001
B2-aa	1.0083 ± 0.0017	0.0447 ± 00.0001	1.0092 ± 0.0017	0.0445 ± 00.0001
B2-ac	1.0142 ± 0.0015	0.0352 ± 0.0000	1.0185 ± 0.0016	0.0347 ± 0.0000
Average	0.9952 ± 0.0111	0.1493 ± 0.2221	0.9957 ± 0.0125	0.1750 ± 0.2528

a A double asterisk indicates the case was run 10 times, each with a different starting random number. Results of the first run are listed because all results were within 0.6σ of each other.

Table D-16 44GROUPNDF5 and 238GROUPNDF5 Cross-Section-Library Effects				
Experiment # ^a	44GROUPNDF5/CSAS25/SCALE4.3		238GROUPNDF5/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma$	ale (ev)	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
B1-k	0.9964 ± 0.0019	0.4875 ± 0.0019	0.9838 ± 0.0019	0.4963 ± 0.0020
B1-o	0.9782 ± 0.0018	0.4929 ± 0.0019	0.9707 ± 0.0019	0.5027 ± 0.0020
B1-l	0.9929 ± 0.0017	0.3831 ± 0.0013	0.9814 ± 0.0018	0.3902 ± 0.0014
B1-p	0.9775 ± 0.0017	0.2749 ± 0.0009	0.9706 ± 0.0020	0.2794 ± 0.0009
B1-q	0.9873 ± 0.0017	0.1715 ± 0.0004	0.9779 ± 0.0018	0.1760 ± 0.0005
B1-m	0.9866 ± 0.0018	0.1360 ± 0.0003	0.9801 ± 0.0018	0.1406 ± 0.0003
B1-r	0.9820 ± 0.0018	0.1371 ± 0.0003	0.9731 ± 0.0019	0.1416 ± 0.0004
B1-s	0.9713 ± 0.0019	0.1310 ± 0.0003	0.9643 ± 0.0018	0.1349 ± 0.0003
B1-t	0.9833 ± 0.0017	0.1026 ± 0.0002	0.9779 ± 0.0018	0.1061 ± 0.0002
B1-u	0.9878 ± 0.0019	0.0935 ± 0.0002	0.9812 ± 0.0017	0.0969 ± 0.0002
B1-w	0.9874 ± 0.0017	0.0829 ± 0.0001	0.9812 ± 0.0017	0.8618 ± 0.0001
B1-x	0.9898 ± 0.0016	0.0717 ± 0.0001	0.9829 ± 0.0017	0.0748 ± 0.0001
B1-y	0.9692 ± 0.0016	0.0639 ± 0.0001	0.9653 ± 0.0016	0.0665 ± 0.0001
B1-z	0.9958 ± 0.0016	0.0613 ± 0.0001	0.9881 ± 0.0017	0.0641 ± 0.0001
B1-aa **	0.9570 ± 0.0016	0.0603 ± 0.0001	0.9532 ± 0.0016	0.0629 ± 0.0001
B1-ab	0.9825 ± 0.0016	0.0550 ± 0.0001	0.9774 ± 0.0016	0.0577 ± 0.0001
B1-ae	0.9762 ± 0.0015	0.0495 ± 0.0001	0.9705 ± 0.0015	0.0519 ± 0.0001
B1-af	0.9795 ± 0.0015	0.0478 ± 0.0000	0.9756 ± 0.0015	0.0500 ± 0.0000
B1-ag	0.9836 ± 0.0014	0.0441 ± 0.0000	0.9796 ± 0.0014	0.0464 ± 0.0000
B1-ah	0.9942 ± 0.0016	0.0594 ± 0.0001	0.9850 ± 0.0016	0.0621 ± 0.0001
B2-o	0.9785 ± 0.0019	0.7923 ± 0.0033	0.9735 ± 0.0019	0.8030 ± 0.0037
B2-s **	1.0118 ± 0.0017	0.1278 ± 0.0003	0.9981 ± 0.0018	0.1319 ± 0.0003
B2-y	0.9958 ± 0.0015	0.0437 ± 0.0000	0.9876 ± 0.0014	0.0460 ± 0.0000
B2-ab **	1.0149 ± 0.0017	0.0606 ± 0.0001	1.0101 ± 0.0016	0.0632 ± 0.0001
B2-aa	0.9984 ± 0.0016	0.0581 ± 0.0001	0.9919 ± 0.0017	0.0608 ± 0.0001
B2-ac	1.0092 ± 0.0014	0.0466 ± 0.0000	1.0013 ± 0.0015	0.0488 ± 0.0000
Average	0.9856 ± 0.0121	0.1590 ± 0.1833	0.9801 ± 0.0120	0.1929 ± 0.2298

a A double asterisk indicates the case was run 10 times, each with a different starting random number. Results of the first run are listed because all results were within 0.6σ of each other.

Table D-17 27-Group Library-Processing Effects				
Experiment # ^a	27Grev/CSAS25/SCALE4.0		27GROUPNDF4/CSAS25/SCALE4.3 (Table D-15, page D-18)	
	$k_{\text{eff}} \pm 1\sigma$	afg	$k_{\text{eff}} \pm 1\sigma$	afg
B1-k	1.0104 ± 0.0023	20.3080 ± 0.0083	1.0054 ± 0.0020	20.2937 ± 0.0072
B1-o	0.9937 ± 0.0021	20.3095 ± 0.0082	0.9940 ± 0.0018	20.2885 ± 0.0073
B1-l	1.0060 ± 0.0021	20.6898 ± 0.0079	1.0008 ± 0.0018	20.6848 ± 0.0065
B1-p	0.9903 ± 0.0024	21.2334 ± 0.0070	0.9899 ± 0.0019	21.2118 ± 0.0062
B1-q	1.0002 ± 0.0021	22.0019 ± 0.0057	1.0022 ± 0.0019	22.0068 ± 0.0048
B1-m	0.9988 ± 0.0020	22.4030 ± 0.0049	0.9957 ± 0.0018	22.3854 ± 0.0042
B1-r	0.9911 ± 0.0022	22.3861 ± 0.0055	0.9962 ± 0.0018	22.3762 ± 0.0044
B1-s	0.9858 ± 0.0021	22.4576 ± 0.0047	0.9835 ± 0.0017	22.4512 ± 0.0041
B1-t	0.9936 ± 0.0020	22.8762 ± 0.0004	0.9953 ± 0.0018	22.8730 ± 0.0034
B1-u	1.0002 ± 0.0022	23.0312 ± 0.0041	0.9968 ± 0.0019	23.0226 ± 0.0033
B1-w	0.9997 ± 0.0022	23.2339 ± 0.0034	0.9986 ± 0.0018	23.2384 ± 0.0030
B1-x	0.9979 ± 0.0019	23.4837 ± 0.0032	1.0008 ± 0.0017	23.4763 ± 0.0026
B1-y	0.9826 ± 0.0021	23.6789 ± 0.0027	0.9810 ± 0.0018	23.6834 ± 0.0024
B1-z	1.0058 ± 0.0021	23.7502 ± 0.0025	1.0053 ± 0.0017	23.7464 ± 0.0022
B1-aa **	0.9664 ± 0.0018	23.7762 ± 0.0027	0.9632 ± 0.0016	23.7744 ± 0.0022
B1-ab	0.9873 ± 0.0020	23.9303 ± 0.0024	0.9934 ± 0.0015	23.9275 ± 0.0020
B1-ae	0.9852 ± 0.0019	24.1131 ± 0.0019	0.9823 ± 0.0015	24.1150 ± 0.0017
B1-af	0.9894 ± 0.0019	24.1741 ± 0.0017	0.9876 ± 0.0015	24.1755 ± 0.0015
B1-ag	0.9905 ± 0.0016	24.3052 ± 0.0016	0.9916 ± 0.0014	24.3041 ± 0.0014
B1-ah	0.9996 ± 0.0020	23.7985 ± 0.0025	0.9979 ± 0.0016	23.7968 ± 0.0021
B2-o	0.9974 ± 0.0023	19.5320 ± 0.0089	0.9916 ± 0.0019	19.5164 ± 0.0075
B2-s **	1.0210 ± 0.0021	22.4576 ± 0.0047	1.0154 ± 0.0018	22.4985 ± 0.0041
B2-y	1.0020 ± 0.0016	24.3227 ± 0.0015	1.0030 ± 0.0014	24.3234 ± 0.0012
B2-ab **	1.0256 ± 0.0017	23.7657 ± 0.0022	1.0120 ± 0.0017	23.7614 ± 00.0022
B2-aa	1.0059 ± 0.0017	23.8367 ± 0.0020	1.0083 ± 0.0017	23.8397 ± 0.0020
B2-ac	1.0132 ± 0.0018	24.2162 ± 0.0016	1.0142 ± 0.0015	24.2136 ± 0.0015
Average	0.9962 ± 0.0113	22.8489 ± 1.3995	0.9952 ± 0.0111	22.8456 ± 0.9997

a A double asterisk indicates the case was run 10 times, each with a different starting random number. Results of the first run are listed because all results were within 0.6σ of each other.

Table D-18 DANT and KENO Va Code Effects with 27GROUPNDF4 Library			
Exp #	27GROUPNDF4/CSASI/SCALE4.3/...DANT		27GROUPNDF4/CSAS25/SCALE4.3 (Table D-15, page D-18) $k_{eff} \pm 1\sigma^a$
	DANT Option ^b	k_{eff}	
B1-k	TWODANT	1.0073	1.0054 ± 0.0020
B1-o	TWODANT	0.9925	0.9940 ± 0.0018
B1-l	TWODANT	1.0040	1.0008 ± 0.0018
B1-p	TWODANT	0.9907	0.9899 ± 0.0019
B1-q	TWODANT	1.0007	1.0022 ± 0.0019
B1-m	TWODANT	0.9998	0.9957 ± 0.0018
B1-r	TWODANT	0.9928	0.9962 ± 0.0018
B1-s	TWODANT	0.9847	0.9835 ± 0.0017
B1-t	TWODANT	0.9983	0.9953 ± 0.0018
B1-u	TWODANT	0.9982	0.9968 ± 0.0019
B1-w	TWODANT	1.0035	0.9986 ± 0.0018
B1-x	TWODANT	1.0019	1.0008 ± 0.0017
B1-y	TWODANT	0.9719	0.9810 ± 0.0018
B1-z	TWODANT	0.9947	1.0053 ± 0.0017
B1-aa	TWODANT	0.9669	$0.9632 \pm 0.0016^{**}$
B1-ab	TWODANT	0.9936	0.9934 ± 0.0015
B1-ae	TWODANT	0.9900	0.9823 ± 0.0015
B1-af	TWODANT	0.9891	0.9876 ± 0.0015
B1-ag	TWODANT	0.9919	0.9916 ± 0.0014
B1-ah	ONEDANT	1.0003	0.9979 ± 0.0016
B2-o	TWODANT	0.9919	0.9916 ± 0.0019
B2-s	TWODANT	1.0200	$1.0154 \pm 0.0018^{**}$
B2-y	TWODANT	1.0027	1.0030 ± 0.0014
B2-ac	ONEDANT	1.0153	1.0142 ± 0.0015
Average		0.9959 ± 0.0116	0.9952 ± 0.0111

a A double asterisk indicates the case was run 10 times, each with a different starting random number. Results of the first run are listed because all results were within 0.6σ of each other.

b Convergence criteria of 1×10^{-6} .

Table D-19 DANT and KENO Va Code Effects with 27Grev Library			
Exp. #	27Grev/CSASI/...DANT/ SCALE4.0		27Grev/CSAS25/SCALE4.0 (Table D-17, page D-20) $k_{eff} \pm 1\sigma^a$
	DANT Option ^b	k_{eff}	
B1-k	TWODANT	1.0099	1.0104 ± 0.0023
B1-o	TWODANT	0.9951	0.9937 ± 0.0021
B1-l	TWODANT	1.0067	1.0060 ± 0.0021
B1-p	TWODANT	0.9930	0.9903 ± 0.0024
B1-q	TWODANT	1.0030	1.0002 ± 0.0021
B1-m	TWODANT	1.0021	0.9988 ± 0.0020
B1-r	TWODANT	0.9949	0.9911 ± 0.0022
B1-s	TWODANT	0.9869	0.9858 ± 0.0021
B1-t	TWODANT	1.0004	0.9936 ± 0.0020
B1-u	TWODANT	1.0000	1.0002 ± 0.0022
B1-w	TWODANT	1.0054	0.9997 ± 0.0022
B1-x	TWODANT	1.0040	0.9979 ± 0.0019
B1-y	TWODANT	0.9737	0.9826 ± 0.0021
B1-z	TWODANT	0.9965	1.0058 ± 0.0021
B1-aa	TWODANT	0.9679	$0.9664 \pm 0.0018^{**}$
B1-ab	TWODANT	0.9945	0.9873 ± 0.0020
B1-ae	TWODANT	0.9909	0.9852 ± 0.0019
B1-af	TWODANT	0.9901	0.9894 ± 0.0019
B1-ag	TWODANT	0.9926	0.9905 ± 0.0016
B1-ah	ONEDANT	1.0004	0.9996 ± 0.0020
B2-o	TWODANT	0.9944	$0.9974 \pm 0.0023^{**}$
B2-s	TWODANT	1.0222	1.0210 ± 0.0021
B2-y	TWODANT	1.0034	1.0020 ± 0.0016
B2-ac ^c	ONEDANT	1.0157	1.0132 ± 0.0018
Average		0.9977 ± 0.0117	0.9962 ± 0.0113

a A double asterisk indicates the case was run 10 times, each with a different starting random number. Results of the first run are listed because all results were within 0.6σ of each other.

b Convergence criteria of 1×10^{-6} unless otherwise noted.

c Convergence criteria changed to 1×10^{-4} .

Table D-20 .50c and .60c Cross-Section-Library Effects		
Experiment # ^a	$k_{\text{eff}} \pm 1\sigma$	
	.50c/MCNP4A	.60c/MCNP4A
B1-k	0.9952 ± 0.0021	0.9954 ± 0.0021
B1-o	0.9817 ± 0.0020	0.9750 ± 0.0022
B1-l	0.9905 ± 0.0024	0.9884 ± 0.0021
B1-p	0.9802 ± 0.0021	0.9773 ± 0.0022
B1-q	0.9880 ± 0.0021	0.9866 ± 0.0023
B1-m	0.9900 ± 0.0020	0.9859 ± 0.0020
B1-r	0.9823 ± 0.0022	0.9773 ± 0.0021
B1-s	0.9739 ± 0.0023	0.9702 ± 0.0022
B1-t	1.0007 ± 0.0019	0.9927 ± 0.0021
B1-u	0.9552 ± 0.0020	0.9501 ± 0.0019
B1-w	0.9921 ± 0.0020	0.9828 ± 0.0022
B1-x	0.9930 ± 0.0020	0.9859 ± 0.0021
B1-y	0.9765 ± 0.0020	0.9692 ± 0.0019
B1-z	1.0001 ± 0.0020	0.9921 ± 0.019
B1-aa **	0.9620 ± 0.0019	0.9587 ± 0.0019
B1-ab	0.9869 ± 0.0018	0.9845 ± 0.0019
B1-ac	0.9698 ± 0.0018	0.9632 ± 0.0020
B1-af	0.9830 ± 0.0017	0.9778 ± 0.0018
B1-ag	0.9844 ± 0.0016	0.9802 ± 0.0017
B1-ah	0.9923 ± 0.0020	0.9880 ± 0.0018
B2-o	0.9760 ± 0.0022	0.9739 ± 0.0021
B2-s **	1.0057 ± 0.0022	1.0004 ± 0.0023
B2-y	0.9923 ± 0.0016	0.9878 ± 0.0016
B2-ab **	1.0232 ± 0.0020	1.0195 ± 0.0020
B2-aa	0.9995 ± 0.0019	0.9968 ± 0.0020
B2-ac	1.0166 ± 0.0018	1.0067 ± 0.0017
Average	0.9881 ± 0.0151	0.9833 ± 0.0148

a A double asterisk indicates the case was run 10 times, each with a different starting random number. Results of the first run are listed because all results were within 0.6σ of each other.

D6 Sample Inputs

Some single lines of input are listed here on multiple lines due to report's column width. Use caution in regenerating code inputs from these listings.

D6.1 SCALE Inputs

Most SCALE calculations were performed with 605 generations, 900 neutrons per generation, skipping 20 generations before averaging k_{eff} values. Most results are therefore based on 526,500 neutron histories, which is typically more than sufficient to achieve eigenvalue convergence. Several cases used more neutron histories, none used fewer.

D6.1.1 Base-Case B1-k, Hansen-Roach/CSAS25/SCALE4.3

```
=CSAS25
ORNL-2143 TableB1RowK, cyl, wall=1.27, H:U233=57.5,
paraffin refl
HANSEN-ROACH INFHOMMEDIUM
H      1 0 5.6612E-02 END
O      1 0 3.8158E-02 END
N      1 0 2.6189E-03 END
U-233  1 0 9.8456E-04 END
U-234  1 0 4.9663E-06 END
U-235  1 0 9.8902E-08 END
U-238  1 0 7.7146E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 9.55 16.3 0.
CYLINDER 0 1 9.55 19.1 0.
CYLINDER 2 1 10.82 20.37 -1.27
CYLINDER 3 1 36.96 40.69 -21.59
END GEOMETRY
END DATA
END
```

D6.1.2 Base-Case B1-l, 27Grev/CSAS25/SCALE4.0

```
=CSAS25
ORNL-2143 TableB1RowL, cyl, wall=1.27, H:U233=67,
paraffin refl
27G INF
H      1 0 5.8174E-02 END
O      1 0 3.7775E-02 END
N      1 0 2.3096E-03 END
U-233  1 0 8.6828E-04 END
U-234  1 0 4.3797E-06 END
U-235  1 0 8.7221E-08 END
U-238  1 0 6.8034E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
```

```
BOX TYPE 1
CYLINDER 1 1 9.55 16.2 0.
CYLINDER 0 1 9.55 19.1 0.
CYLINDER 2 1 10.82 20.37 -1.27
CYLINDER 3 1 36.96 40.69 -21.59
END GEOMETRY
END DATA
END
```

D6.1.3 Base-Case B1-m, 27GROUPNDF4/CSAS25/SCALE4.3

```
=CSAS25
ORNL-2143 TableB1RowM, cyl, wall=1.27, H:U233=145,
paraffin refl
27GROUPNDF4 INF
H      1 0 6.2575E-02 END
O      1 0 3.5606E-02 END
N      1 0 1.1479E-03 END
U-233  1 0 4.3155E-04 END
U-234  1 0 2.1768E-06 END
U-235  1 0 4.3351E-08 END
U-238  1 0 3.3815E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 9.55 18.6 0.
CYLINDER 0 1 9.55 19.1 0.
CYLINDER 2 1 10.82 20.37 -1.27
CYLINDER 3 1 36.96 40.69 -21.59
END GEOMETRY
END DATA
END
```

D6.1.4 Base-Case B1-o, 218G(4.0)/CSAS25/SCALE4.0

```
=CSAS25
ORNL-2143 TableB1RowO, cyl, wall=1.27, H:U233=57.5,
paraffin refl
218G INF
H      1 0 5.6612E-02 END
O      1 0 3.8158E-02 END
N      1 0 2.6189E-03 END
U-233  1 0 9.8456E-04 END
U-234  1 0 4.9663E-06 END
U-235  1 0 9.8902E-08 END
U-238  1 0 7.7146E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.25 14.4 0.
CYLINDER 0 1 10.25 20.5 0.
CYLINDER 2 1 11.52 21.77 -1.27
CYLINDER 3 1 36.96 42.09 -21.59
END GEOMETRY
END DATA
END
```

**D6.1.5 Base-Case B1-p, 218GROUPNDF4/CSAS25/
SCALE4.3**

```
=CSAS25      PARM=SIZE=1000000
ORNL-2143 TableB1RowP, cyl, wall=1.27, H:U233=84.4,
paraffin refl
218GROUPNDF4 INF
H      1 0 5.9978E-02 END
O      1 0 3.7100E-02 END
N      1 0 1.8903E-03 END
U-233  1 0 7.1064E-04 END
U-234  1 0 3.5846E-06 END
U-235  1 0 7.1386E-08 END
U-238  1 0 5.5683E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0      END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.25 14.7 0.
CYLINDER 0 1 10.25 20.5 0.
CYLINDER 2 1 11.52 21.77 -1.27
CYLINDER 3 1 36.96 42.09 -21.59
END GEOMETRY
END DATA
END
```

**D6.1.6 Base-Case B1-q, 44GROUPNDF5/CSAS25/
SCALE4.3**

```
=CSAS25
ORNL-2143 TableB1RowQ, cyl, wall=127, H:U233=120,
paraffin refl
44GROUPNDF5 INF
H      1 0 6.1399E-02 END
O      1 0 3.5819E-02 END
N      1 0 1.3610E-03 END
U-233  1 0 5.1166E-04 END
U-234  1 0 2.5809E-06 END
U-235  1 0 5.1398E-08 END
U-238  1 0 4.0091E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0      END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.25 16.4 0.
CYLINDER 0 1 10.25 20.5 0.
CYLINDER 2 1 11.52 21.77 -1.27
CYLINDER 3 1 36.96 42.09 -21.59
END GEOMETRY
END DATA
END
```

**D6.1.7 Base-Case B1-r, 238GROUPNDF5/CSAS25/
SCALE4.3**

```
=CSAS25      PARM=SIZE=1000000
ORNL-2143 TableB1RowR, cyl, wall=127, H:U233=145,
paraffin refl
238GROUPNDF5 INF
H      1 0 6.2575E-02 END
O      1 0 3.5606E-02 END
```

```
N      1 0 1.1479E-03 END
U-233  1 0 4.3155E-04 END
U-234  1 0 2.1768E-06 END
U-235  1 0 4.3351E-08 END
U-238  1 0 3.3815E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0      END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.25 16.7 0.
CYLINDER 0 1 10.25 20.5 0.
CYLINDER 2 1 11.52 21.77 -1.27
CYLINDER 3 1 36.96 42.09 -21.59
END GEOMETRY
END DATA
END
```

**D6.1.8 Minimum Critical Mass B1-s,
44GROUPNDF5/CSAS25/SCALE4.3**

```
=CSAS25
ORNL-2143
TableB1RowS, cyl, wall=127, minHt, H:U233=151, paraffinRef
l
44GROUPNDF5 INF
H      1 0 6.2433E-02 END
O      1 0 3.5354E-02 END
N      1 0 1.0998E-03 END
U-233  1 0 4.1346E-04 END
U-234  1 0 2.0856E-06 END
U-235  1 0 4.1534E-08 END
U-238  1 0 3.2397E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0      END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.25 16.1 0.
CYLINDER 0 1 10.25 20.5 0.
CYLINDER 2 1 11.52 21.77 -1.27
CYLINDER 3 1 36.96 42.09 -21.59
END GEOMETRY
END DATA
END
```

**D6.1.9 Maximum Critical Mass B1-t,
44GROUPNDF5/CSAS25/SCALE4.3**

```
=CSAS25
ORNL-2143
TableB1RowT, cyl, wall=1.27, maxHt, H:U233=193, paraffinRe
fl
44GROUPNDF5 INF
H      1 0 6.3340E-02 END
O      1 0 3.4954E-02 END
N      1 0 8.7298E-04 END
U-233  1 0 3.2819E-04 END
U-234  1 0 1.6554E-06 END
U-235  1 0 3.2967E-08 END
U-238  1 0 2.5715E-06 END
AL      2 0 6.0081E-02 END
MN      2 0 3.7351E-04 END
PARA(H2O) 3 1.0      END
END COMP
KENOV.A
```

```

READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.25 19.3 0.
CYLINDER 0 1 10.25 20.5 0.
CYLINDER 2 1 11.52 21.77 -1.27
CYLINDER 3 1 36.96 42.09 -21.59
END GEOMETRY
END DATA
END

```

D6.1.10 No Vessel Wall B1-u, 44GROUPNDF5/ CSAS25/SCALE4.3

```

=CSAS25
ORNL-2143
TableB1RowU,cyl,wall=0.00,H:U233=213,paraffinRef1
44GROUPNDF5 INF
H 1 0 6.4400E-02 END
O 1 0 3.3523E-02 END
N 1 0 8.0424E-04 END
U-233 1 0 3.0235E-04 END
U-234 1 0 1.5251E-06 END
U-235 1 0 3.0372E-08 END
U-238 1 0 2.3690E-06 END
AL 2 0 6.0081E-02 END
MN 2 0 3.7351E-04 END
PARA(H2O) 3 1.0 END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.25 19.3 0.
CYLINDER 0 1 10.25 20.5 0.
CYLINDER 3 1 36.96 40.82 -20.32
END GEOMETRY
END DATA
END

```

D6.1.11 0.25-Inch Vessel Wall B1-w, 44GROUPNDF5/CSAS25/SCALE4.3

```

=CSAS25
ORNL-2143
TableB1RowW,cyl,wall=0.635,H:U233=247,ParaffinRef1
44GROUPNDF5 INF
H 1 0 6.4467E-02 END
O 1 0 3.4845E-02 END
N 1 0 6.9426E-04 END
U-233 1 0 2.6100E-04 END
U-234 1 0 1.3165E-06 END
U-235 1 0 2.6218E-08 END
U-238 1 0 2.0451E-06 END
AL 2 0 6.0081E-02 END
MN 2 0 3.7351E-04 END
PARA(H2O) 3 1.0 END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.75 19.4 0.
CYLINDER 0 1 10.75 21.5 0.
CYLINDER 2 1 11.285 22.135 -0.635
CYLINDER 3 1 36.96 42.455 -20.955
END GEOMETRY
END DATA
END

```

D6.1.12 1.00-Inch Vessel Wall B1-x, 44GROUPNDF5/CSAS25/SCALE4.3

```

=CSAS25
ORNL-2143
TableB1RowX,cyl,wall=2.54,H:U233=297,paraffinRef1
44GROUPNDF5 INF
H 1 0 6.4469E-02 END
O 1 0 3.4407E-02 END
N 1 0 5.7740E-04 END
U-233 1 0 2.1707E-04 END
U-234 1 0 1.0949E-06 END
U-235 1 0 2.1805E-08 END
U-238 1 0 1.7009E-06 END
AL 2 0 6.0081E-02 END
MN 2 0 3.7351E-04 END
PARA(H2O) 3 1.0 END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 10.75 21.5 0.
CYLINDER 2 1 13.29 24.04 -2.54
CYLINDER 3 1 36.96 44.36 -22.86
END GEOMETRY
END DATA
END

```

D6.1.13 90% Dense Paraffin B1-y, 44GROUPNDF5/ CSAS25/SCALE4.3

```

=CSAS25
ORNL-2143
TableB1RowY,cyl,wall=1.27,H:U233=356,90%denseParaffin
Ref1
44GROUPNDF5 INF
H 1 0 6.4397E-02 END
O 1 0 3.4009E-02 END
N 1 0 4.8117E-04 END
U-233 1 0 1.8089E-04 END
U-234 1 0 9.1245E-07 END
U-235 1 0 1.8171E-08 END
U-238 1 0 1.4174E-06 END
AL 2 0 6.0081E-02 END
MN 2 0 3.7351E-04 END
PARA(H2O) 3 0.90 END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 11.45 21.3 0.
CYLINDER 0 1 11.45 22.9 0.
CYLINDER 2 1 12.72 24.17 -1.27
CYLINDER 3 1 36.96 44.49 -21.59
END GEOMETRY
END DATA
END

```

D6.1.14 110% Dense Paraffin B1-z, 44GROUPNDF5/ CSAS25/SCALE4.3

```

=CSAS25
ORNL-2143
TableB1RowZ,cyl,wall=1.27,H:U233=379,110%denseParaffi
nRef1
44GROUPNDF5 INF
H 1 0 6.5619E-02 END
O 1 0 3.4542E-02 END

```

```

END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 12.75 22.5 0.
CYLINDER 0 1 12.75 25.5 0.
CYLINDER 2 1 14.02 26.77 -1.27
CYLINDER 3 1 47.12 57.25 -31.75
END GEOMETRY
END DATA
END

```

All DANT calculations were performed with S_{16} quadrature and P_3 scattering. Most calculations were also performed with a 10^{-6} convergence criteria.

Cross Section Processing Input:

```
=CSASI
ORNL-2143      TableB2rowY, cyl, wall=1.27, H:U233=775,
paraffin refl
27G INF
H              1 0    6.6090E-02  END
O              1 0    3.3218E-02  END
F              1 0    2.7041E-04  END
U-233          1 0    8.5277E-05  END
U-234          1 0    4.6457E-07  END
U-235          1 0    3.4265E-08  END
U-238          1 0    6.0899E-07  END
AL             2 0    6.0081E-02  END
MN             2 0    3.7351E-04  END
PARA (H2O)     3 1.0              END
END COMP
END
```

```

1      0      0
ORNL-2143
TableB2rowY,cyl,wall=1.27,H:U233=775,ParaffinRef1
/ Block 1
igeom=r-z ngroup=27 isn=16 niso=3 mt=3 nzone=3
im=16 it=80 jm=33 jt=165
maxscm=280000 maxicm=2600000
T
/ Block 2 (geometry)
xmesh= 0.0 2.5 5 8.75 10 12 14 15 15.25
      16.52
      17 18 22 28 35 36 36.96
ymesh= -21.59 -21 -20 -15 -10 -5.5 -3 -2 -1.5 -1.27
      0.0
      0.5 1 2 5 10 15 20 25 28 30 30.5
      31.135 31.77
      32 33 34 37 39 43 47 50 51.5 52.09
xints= 16R5
yints= 33R5
zones=
      16R3;
      16R3;
      16R3;
      16R3;
      16R3;
      16R3;
      16R3;
      16R3;
      16R3;
      16R3;
      9R2  7R3;
      8R1  2  7R3;
      8R1  2  7R3;
      8R1  2  7R3;

```

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D6.2.2 Base-Case B2-ac, 27GROUPNDF4/CSASI/SCALE4.3/ONEDANT

Cross Section Processing Input:

```
=CSASI
ORNL-2143 TableB2rowAC WVF=1, sph, wall=1.27,
H:U233=663, water refl
27GROUPNDF4 INF
H      1 0      6.6742E-02 END
O      1 0      3.3575E-02 END
F      1 0      2.0418E-04 END
U-233  1 0      1.0078E-04 END
U-234  1 0      5.4903E-07 END
U-235  1 0      4.0495E-08 END
U-238  1 0      7.1971E-07 END
AL      2 0      6.0081E-02 END
MN      2 0      3.7351E-04 END
H2O     3 1.0      END
END COMP
MORE DATA axs=07 END
END
```

***k_{eff}* Calculation Input:**

```

1      0      0
ORNL-2143
TableB2rowAC,sph,wall=1.27,H:U233=663,H2Orefl
/   Block 1
igeom=sphere ngroup=27 isn=16 niso=3 mt=3 nzone=3
im=16 it=160
maxscm=280000 maxlcm=2600000
T
/   Block 2 (geometry)
/   set up 8 course mesh intervals in sphere, 7 in
refl
xmesh= 0.0 2.5 5 8.75 10 12 12.5 13 15.95
      17.22
      17.5 18 23 29 35.5 36.5 37.54
xints= 16R10

```

```
zones= 8R1      2  7R3
T
/ Block 3 {cross sections}
lib=f27 writmxs=macbcd
chivec= 0.020 0.195 0.219 0.126 0.164 0.172 0.088
        0.014 0.001 0.000001 17z
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1
T
/ Block 4 {material mixing and assignments}
matls=isos assign=matls
-
/ Block 5 {solver control}
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
T
/ Block 6
zned= 1
T
```

D6.3 MCNP Inputs

Most MCNP calculations were performed with 250 generations, 1000 neutrons per generation, skipping the first 15 generations before averaging k_{eff} values. Most MCNP results are therefore based on 235,000 neutron histories. Some cases used more neutron histories, none used fewer.

D6.3.1 Base Case B1-ae, .50c/MCNP4A

```

ORNL-2143 TableB1RowAE, cyl, wall=1.27, H:U233=582,
paraffin refl
C      Cells
1      1  9.998722989E-02      -1 2 -3      imp:n=1
$ U233 solution
2      0      -1 3 -4      imp:n=1
$ void above solution in vessel
3      2  6.0454713E-02      -5 6 -7 (1:-2:4) imp:n=1
$ Al vessel wall
4      3  1.222739E-01      -8 9 -10 (5:-6:7) imp:n=1
$ paraffin reflector
5      0      8:-9:10      imp:n=0
$ void outside system

```

C	Surfaces		
1	cz	15.25	\$ vessel inner radius
2	pz	0.0	\$ vessel inner bottom
3	pz	21.1	\$ U233 solution level
4	pz	30.5	\$ vessel inner top
5	cz	16.52	\$ vessel outer radius
6	pz	1.27	\$ vessel outer bottom
7	pz	31.77	\$ vessel outer top
8	cz	36.96	\$ reflector outer radius
9	pz	-21.59	\$ reflector outer bottom
10	pz	52.09	\$ reflector outer top

```

C      Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc   0 0 10.55 $ start near soln center
C      Data: materials and nuclide densities
m1 92233.50c 1.1370E-04 92234.50c 5.7354E-06
    92235.50c 1.1422E-08 92238.50c 8.9092E-07
    1001.50c 6.6175E-02 8016.50c 3.3423E-02
    7014.50c 3.0245E-04 $ U233 solution
mt1 lwtr.01t
m2 13027.50c 6.0081E-02 25055.50c 3.7351E-04
    $ Al vessel wall
m3 6000.50c 3.9699E-02 1001.50c 8.2575E-02
    $ paraffin reflector
mt3 poly.01t
print

```

D6.3.2 Base Case B1-af, .50c/MCNP4A

ORNL-2143 TableB1RowAF, cyl, wall=1.27, H:U233=630,
paraffin refl
C Cells

```

1 1 9.909435972E-02 -1 2 -3 imp:n=1
$ U233 solution
2 0 -1 3 -4 imp:n=1
$ void above solution in vessel
3 2 6.0454713E-02 -5 6 -7 (1:-2:4) imp:n=1
$ Al vessel wall
4 3 1.222739E-01 -8 9 -10 (5:-6:7) imp:n=1
$ paraffin reflector
5 0 8:-9:10 imp:n=0
$ void outside system

```

```

C Surfaces
1 cz 15.25 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 23.8 $ U233 solution level
4 pz 30.5 $ vessel inner top
5 cz 16.52 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 pz 31.77 $ vessel outer top
8 cz 36.96 $ reflector outer radius
9 pz -21.59 $ reflector outer bottom
10 pz 52.09 $ reflector outer top

```

```

C Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 10.55 $ start near soln center
C Data: materials and nuclide densities
m1 92233.50c 1.0337E-04 92234.50c 5.2140E-07
92235.50c 1.0383E-08 92238.50c 8.0993E-07
1001.50c 6.5121E-02 8016.50c 3.3595E-02
7014.50c 2.7495E-04 $ U233 solution
mt1 lwtr.01t
m2 13027.50c 6.0081E-02 25055.50c 3.7351E-04
$ Al vessel wall
m3 6000.50c 3.9699E-02 1001.50c 8.2575E-02
$ paraffin reflector
mt3 poly.01t
print

```

D6.3.3 Base Case B1-ag, .50c/MCNP4A

ORNL-2143 TableB1RowAG, cyl, wall=1.27, H:U233=757, paraffin refl

```

C Cells
1 1 9.799811952E-02 -1 2 -3 imp:n=1
$ U233 solution
2 0 -1 3 -4 imp:n=1
$ void above solution in vessel
3 2 6.0454713E-02 -5 6 -7 (1:-2:4) imp:n=1
$ Al vessel wall
4 3 1.222739E-01 -8 9 -10 (5:-6:7) imp:n=1
$ paraffin reflector
5 0 8:-9:10 imp:n=0
$ void outside system

```

```

C Surfaces
1 cz 15.25 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 30.4 $ U233 solution level
4 pz 30.5 $ vessel inner top
5 cz 16.52 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 pz 31.77 $ vessel outer top
8 cz 36.96 $ reflector outer radius
9 pz -21.59 $ reflector outer bottom
10 pz 52.09 $ reflector outer top

```

```

C Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 15.2 $ start near soln center
C Data: materials and nuclide densities
m1 92233.50c 8.5277E-05 92234.50c 4.3015E-07
92235.50c 8.5663E-09 92238.50c 6.6819E-07
1001.50c 6.4555E-02 8016.50c 3.3131E-02
7014.50c 2.2684E-04 $ U233 solution
mt1 lwtr.01t
m2 13027.50c 6.0081E-02 25055.50c 3.7351E-04
$ Al vessel wall
m3 6000.50c 3.9699E-02 1001.50c 8.2575E-02
$ paraffin reflector

```

```

mt3 poly.01t
print

```

D6.3.4 Base Case B1-ah, .50c/MCNP4A

ORNL-2143

TableB1RowAH, sph, wall=1.27, H:U233=405, H2Orefl

```

C Cells
1 1 9.93581836E-02 -1 imp:n=1
$ U233 solution
3 2 6.0454713E-02 -2 1 imp:n=1
$ Al vessel wall
4 3 1.222739E-01 2 (-3 4 -5) imp:n=1
$ H2O reflector
5 0 3:-4:5 imp:n=0
$ void outside system

```

```

C Surfaces
1 so 13.2 $ vessel inner radius
2 so 14.57 $ vessel outer radius
3 cz 36.96 $ reflector outer radius
4 pz -34.89 $ reflector outer bottom
5 pz 34.89 $ reflector outer top

```

```

C Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 10 $ start near soln center
C Data: materials and nuclide densities
m1 92233.50c 1.6022E-04 92234.50c 8.0817E-07
92235.50c 1.6094E-08 92238.50c 1.2554E-06
1001.50c 6.4888E-02 8016.50c 3.4047E-02
7014.50c 4.2618E-04 $ U233 solution
mt1 lwtr.01t
m2 13027.50c 6.0081E-02 25055.50c 3.7351E-04
$ Al vessel wall
m3 1001.60c 6.6742E-02 8016.60c 3.3371E-02
$ H2O reflector
mt3 lwtr.01t
print

```

D6.3.5 Base Case B2-o, .60c/MCNP4A

ORNL-2143

TableB2RowO, cyl, wall=1.27cm, H:U233=45.9, paraffinRef1

```

C Cells
1 1 9.909821E-02 -1 2 -3 imp:n=1
$ U233 solution
2 0 -1 3 -4 imp:n=1
$ void above solution in vessel
3 2 6.045471E-02 -5 6 -7 (1:-2:4) imp:n=1
$ Al vessel wall
4 3 1.222739E-01 -8 9 -10 (5:-6:7) imp:n=1
$ paraffin reflector
5 0 8:-9:10 imp:n=0
$ void outside system

```

```

C Surfaces
1 cz 8.38 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 16.9 $ U233 solution level
4 pz 91.44 $ vessel inner top
5 cz 9.65 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 pz 92.71 $ vessel outer top
8 cz 36.96 $ reflector outer radius
9 pz -21.59 $ reflector outer bottom
10 pz 113.03 $ reflector outer top

```

```

C Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 10.25 $ start near soln center
C Data: materials and nuclide densities
m1 92233.60c 1.3412E-03 92234.60c 7.3063E-06
92235.60c 5.3890E-07 92238.60c 9.5777E-06
1001.60c 6.1560E-02 8016.60c 3.3497E-02
7014.60c 2.7031E-03 $ U233 solution
mt1 lwtr.01t
m2 13027.60c 6.0081E-02 25055.60c 3.7351E-04
$ Al vessel wall

```



```

m3      6000.60c 3.9699E-02 1001.60c 8.2575E-02
      $ paraffin reflector
mt3      poly.01t
print

```

D6.3.6 Base Case B2-s, .60c/MCNP4A

```

ORNL-2143
TableB2RowS,cyl,wall=1.27cm,H:U233=154,paraffinRef1
C      Cells
1      1 1.00606877E-01 -1 2 -3      imp:n=1
$ U233 solution
2      0      -1 3 -4      imp:n=1
$ void above solution in vessel
3      2 6.045471E-02 -5 6 -7 (1:-2:4)      imp:n=1
$ Al vessel wall
4      3 1.222739E-01 -8 9 -10 (5:-6:7)      imp:n=1
$ paraffin reflector
5      0      8:-9:10      imp:n=0
$ void outside system

```

```

C      Surfaces
1      cz 9.55 $ vessel inner radius
2      pz 0.0 $ vessel inner bottom
3      pz 18.4 $ U233 solution level
4      pz 19.1 $ vessel inner top
5      cz 10.82 $ vessel outer radius
6      pz -1.27 $ vessel outer bottom
7      pz 20.37 $ vessel outer top
8      cz 36.96 $ reflector outer radius
9      pz -21.59 $ reflector outer bottom
10     pz 40.69 $ reflector outer top

```

```

C      Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 10.25 $ start near soln center

```

```

C      Data: materials and nuclide densities
m1 92233.60c 4.2638E-04 92234.60c 2.3228E-06
92235.60c 1.7133E-07 92238.60c 3.0449E-06
1001.60c 6.5663E-02 8016.60c 3.3696E-02
7014.60c 8.1808E-04 $ U233 solution
mt1 lwtr.01t
m2 13027.60c 6.0081E-02 25055.60c 3.7351E-04
$ Al vessel wall
m3 6000.60c 3.9699E-02 1001.60c 8.2575E-02
$ paraffin reflector
mt3 poly.01t
print

```

D6.3.7 Base Case B2-aa, .60c/MCNP4A

```

ORNL-2143
TableB2RowAA,sph,wall=1.27,H:U233=419,H2Oref1
C      Cells
1      1 9.996005E-02 -1 -6      imp:n=1
$ U233 solution
2      0      -1 +6      imp:n=1
$ void above solution in vessel
3      2 6.0454713E-02 -2 1      imp:n=1
$ Al vessel wall
4      3 1.222739E-01 2 (-3 4 -5)      imp:n=1
$ H2O reflector
5      0      3:-4:5      imp:n=0
$ void outside system

```

```

C      Surfaces
1      so 13.3 $ vessel inner radius
2      so 14.57 $ vessel outer radius
3      cz 36.96 $ reflector outer radius
4      pz -34.89 $ reflector outer bottom
5      pz 34.89 $ reflector outer top
6      pz 12.872 $ solution top surface inside
vessel

```

```

C      Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 0 $ start near soln center
C      Data: materials and nuclide densities
m1 92233.60c 1.5763E-04 92234.60c 8.5874E-07

```

```

92235.60c 6.3339E-08 92238.60c 1.1257E-06
1001.60c 6.6048E-02 8016.60c 3.3344E-02
7014.60c 4.0845E-04 $ U233 solution
mt1 lwtr.01t
m2 13027.60c 6.0081E-02 25055.60c 3.7351E-04
$ Al vessel wall
m3 1001.60c 6.6742E-02 8016.60c 3.3371E-02
$ H2O reflector
mt3 lwtr.01t
print

```

D6.3.8 Base Case B2-ab, .60c/MCNP4A

```

ORNL-2143
TableB2RowAB,sph,wall=1.27,H:U233=390,H2Oref1
C      Cells
1      1 1.00455E-01 -1 -6      imp:n=1
$ U233 solution
2      0      -1 +6      imp:n=1
$ void above solution in vessel
3      2 6.0454713E-02 -2 1      imp:n=1
$ Al vessel wall
4      3 1.222739E-01 2 (-3 4 -5)      imp:n=1
$ H2O reflector
5      0      3:-4:5      imp:n=0
$ void outside system

```

```

C      Surfaces
1      so 13.3 $ vessel inner radius
2      so 14.57 $ vessel outer radius
3      cz 36.96 $ reflector outer radius
4      pz -34.89 $ reflector outer bottom
5      pz 34.89 $ reflector outer top
6      pz 11.3587 $ solution top surface inside
vessel

```

```

C      Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 0 0 0 $ start near soln center
C      Data: materials and nuclide densities
m1 92233.60c 1.7055E-04 92234.60c 9.2913E-07
92235.60c 6.8531E-08 92238.60c 1.2180E-06
1001.60c 6.6616E-02 8016.60c 3.3604E-02
7014.60c 1.6258E-04 $ U233 solution
mt1 lwtr.01t
m2 13027.60c 6.0081E-02 25055.60c 3.7351E-04
$ Al vessel wall
m3 1001.60c 6.6742E-02 8016.60c 3.3371E-02
$ H2O reflector
mt3 lwtr.01t
print

```

Appendix E

ORNL-4280 Experiments and Calculations

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E1 Experiments

During 1967 and 1968 several sets of ^{233}U solution experiments were performed at ORNL to establish criticality safety limits for various hypothetical but representative processing, handling, storage, and transport conditions. Thomas provided confirmation of and corrections to experiment descriptions reported in part 2.16 of ORNL-4280.^a Only critical, single-unit experiments are considered here. These experiments are not included in the *Benchmark Handbook*.

Idealized experiment descriptions are used here. As shown in Figures 4 and 5 (page 15), each experiment consisted of a uranyl nitrate solution in a spherical aluminum solution vessel in a 9-ft.-diameter stainless-steel reflector vessel or of a uranyl nitrate solution in an open-top cylindrical aluminum solution vessel, supported by styrafoam in the same reflector vessel. Thomas indicated in 1983 that items neglected in Figures 4 and 5 (page 15) had negligible effect on results and were therefore not recorded in notes he had readily available.^a Tables E-1 through E-4 summarize additional descriptive information. Measured k_{eff} s are reported to be 1.0000 ± 0.0005 .

With exception of measured k_{eff} , ORNL-4280 does not specify experiment uncertainties.

Table E-1 ORNL-4280 Uranium Isotopic Composition			
Isotope	ppm	wt% ^a	
		ORNL-4280	adjusted
^{232}U	6.47	not specified	0.00
^{233}U	not specified	97.54 ^b	97.5302
^{234}U		1.05	1.0499
^{235}U		0.03	0.0300
^{236}U		<0.01	0.00
^{238}U		1.39	1.3899

a ORNL-4280 does not specify wt% or atom%. As a more commonly occurring unit, wt% is assumed. Values are adjusted because sum of reported values exceeds 100%.

b ORNL-4280 text indicates 97.59% but its Table 2.16.1 indicates 97.54%. On February 10, 1983, Thomas indicated 97.54% is correct value.

^a Joseph T. Thomas, telephone conversations based on experimenter notebooks, February 10 and 28, 1983.

Table E-2 ORNL-4280 Nonfissionable Materials				
Material	Application	Density (g/cm ³)	Nuclide SCALE # [MCNP #]	N _n (particles/b-cm)
Styrafoam ^a (C ₆ H ₅ CH-CH ₂)	Cylindrical-solution-vessel support	0.024	C [6000]	5.5508E-04
			H [1001]	5.5508E-04
Aluminum ^b	Solution vessels	2.6989	Al [13027]	6.0238E-02
Stainless steel: ^c SS304 (69.5 wt% Fe, 19 wt% Cr, 9.5 wt% Ni, 2 wt% Mn)	Reflector vessel	7.92	CR [24000]	1.7429E-02
			MN [25055]	1.7363E-03
			FE [26000]	5.9358E-02
			NI [28000]	7.7207E-03

a As described by Thomas on February 24, 1983.

b Pure aluminum assumed based on conversations with Thomas because readily available notes did not provide better information. Aluminum and most aluminum alloys are relatively weak neutron absorbers and reflectors. Theoretical density assumed.

c SS304 assumed based on conversations with Thomas but notes do not specify type. Composition and density from SCALE libraries.

Table E-3 ORNL-4280 Solution and Spherical Experiment Critical Parameters						
Experiment # and Solution #	UO ₂ (NO ₃) ₂ Solution Parameters			Sphere Experiment (1.22-mm-thick aluminum wall)		
	Uranium Density (g/l)	Specific Gravity	H: ²³³ U	Inner Radius (cm)	Uranium Mass (kg)	Reflector (Figure 5, page 15)
A	333	1.468	73.	no associated spherical experiments		
B	204	1.280	119. ^a			
C	131	1.183	195.	14.579	1.70	air
D	102	1.144	253.	15.078	1.46	
E	74.6	1.106 ^b	349.	15.821	1.24	
F	44.6	1.050	581.	18.378	1.16	
G	132	1.186	194.	11.170	0.769	water
H	95.0	1.135	273.	11.847	0.662	
I	47.9	1.068	540.	14.579	0.621	

a Value reported in ORNL-4280, 122, corrected to 119 by Thomas on February 10, 1983. Correction makes solution consistent with data reported in ORNL-4280 Table 2.16.2, for apparently the same solution.

b Value might be typographical error for 1.061, which is consistent with ORNL-2143 experiments (Table D-1, page D-4), and which was considered because other solution values here are consistent with ORNL-2143 experiments. However, Thomas confirmed 1.106 value on February 10, 1983

Table E-4 ORNL-4280 Cylinder Experiment Critical Parameters

Reflector ^a (Figure 5, page 15)	Solution # (Table E-3, page E-4)	Exp #	Open-top Cylinder Experiments ^b (aluminum vessel, 1.5-mm-thick wall, 1.27-cm-thick bottom)			
			ID (cm)	IR (cm)	Critical Height ^c (cm)	U Mass (kg)
air	A	A1	50.8	25.40	13.36	9.02
	B	B1	50.8	25.40	13.51	5.59
		B2	38.1	19.05	15.14	3.52
		B3	25.3	12.65	24.69	2.53
	C	C1	50.8	25.40	14.07	3.74
		C2	38.1	19.05	16.33	2.44
		C3	25.3	12.65	28.52	1.88
	D	D2	38.1	19.05	17.60	2.05
		D3	25.3	12.65	33.40	1.71
	E	E2	38.1	19.05	19.35	1.65
		E3	25.3	12.65	43.69	1.64
	F	F2	38.1	19.05	26.37	1.34
water	G	G2	38.1	19.05	13.42	2.02 ^d
		G3	25.3	12.65	17.22	1.14
		G4	20.3	10.15	22.86	0.976
	H	H3	25.3	12.65	19.67	0.939
		H4	20.3	10.15	27.02 ^e	0.824
	I	I2	38.1	12.65	19.6	1.07
		I3	25.3	19.05	31.53	0.757

a Reflector vessel is a 9-foot-diameter open-top stainless-steel cylinder with 7/16-inch-thick walls and 17/16-inch-thick bottom. Neither vessel height nor stainless steel type are known but there was only one 9-foot diameter vessel at the facility. Y-CDC-8 provides the most complete known vessel description.

b Solution vessel supported by a 24.3-cm-high styrafoam cylinder with unspecified outer radius. Thomas indicated styrafoam similar to solution vessel in cross-section shape and size. Solution vessel bottom modelled as styrafoam in all base cases.

c ORNL-4280 indicates critical height corrected to simulate lateral reflection only (specifically corrected so solution vessel bottom does not contribute to system reactivity).

d Value reported in ORNL-4280, 1.72, corrected to 2.02 by Thomas on February 10, 1983.

e Value reported in ORNL-4280, 20.02, corrected to 27.02 by Thomas on February 10, 1983. ORNL-4280 reported value is apparently a typographical error.

E2 Models

Base-case models combine idealized and actual experiment configurations, as shown in Figure 2 (page 12). Figure 2 and Tables E-3 and E-4 list base case dimensions. Table E-5 lists base-case atom densities, which were calculated using given solution specific gravities and, because these densities indicate seven of the nine solutions were acid deficient ($N:U < 2$), atom densities calculated assuming no free acid or acid deficiency ($N:U = 2$). Except one solution, atom densities are affected only slightly (for example, 1.1% or less difference in hydrogen densities and WWF). The exception is Solution B with a 2.4% increase in hydrogen density and WWF, which warrants further investigation.

Table E-5 ORNL-4280 Fissionable Solution Atom Densities

Sol'n #	Nuclide # and Density (particles/b-cm)							N:U	WVF
	H [1001]	O [8016]	N [7014]	U-233 [92233]	U-234 [92234]	U-235 [92235]	U-238 [92238]		
base case: atom densities calculated using solution specific gravity, U density, and H: ²³³ U									
A	6.1267E-2	3.7317E-2	1.6544E-3	8.3927E-4	8.9959E-6	2.5593E-7	1.1708E-5	1.9231	0.9180
B	6.1184E-2	3.5452E-2	1.2687E-3	5.1415E-4	5.5110E-6	1.5679E-7	7.1727E-6	2.4074	0.9167
C	6.4382E-2	3.4878E-2	6.7002E-4	3.3016E-4	3.5389E-6	1.0068E-7	4.6060E-6	1.9799	0.9646
D	6.5040E-2	3.4597E-2	5.1669E-4	2.5707E-4	2.7555E-6	7.8393E-8	3.5863E-6	1.9609	0.9745
E	6.5618E-2	3.4295E-2	3.6695E-4	1.8802E-4	2.0153E-6	5.7334E-8	2.6229E-6	1.9041	0.9832
F	6.5308E-2	3.3486E-2	2.0036E-2	1.1241E-4	1.2049E-6	3.4278E-8	1.5681E-6	1.7391	0.9785
G	6.4541E-2	3.4947E-2	6.6500E-4	3.3268E-4	3.5660E-6	1.0145E-7	4.6411E-6	1.9502	0.9670
H	6.5365E-2	3.4552E-2	4.5953E-4	2.3943E-4	2.5664E-6	7.3013E-8	3.3402E-6	1.8725	0.9794
I	6.5191E-2	3.3910E-2	3.5548E-4	1.2072E-4	1.2940E-6	3.6814E-8	1.6842E-6	2.8728	0.9768
atom densities calculated using uranyl nitrate molecular formula, U density, and H: ²³³ U									
A	6.0812E-2	3.7288E-2	1.7205E-3	8.3927E-4	8.9959E-6	2.5593E-7	1.1708E-5	2	0.9111
B	6.2662E-2	3.5547E-2	1.0540E-3	5.1415E-4	5.5110E-6	1.5679E-7	7.1727E-6	2	0.9389
C	6.4335E-2	3.4875E-2	6.7682E-4	3.3016E-4	3.5389E-6	1.0068E-7	4.6060E-6	2	0.9639
D	6.4969E-2	3.4592E-2	5.2699E-4	2.5707E-4	2.7555E-6	7.8393E-8	3.5863E-6	2	0.9734
E	6.5491E-2	3.4287E-2	3.8542E-4	1.8802E-4	2.0153E-6	5.7334E-8	2.6229E-6	2	0.9813
F	6.5101E-2	3.3472E-2	2.3043E-4	1.1241E-4	1.2049E-6	3.4278E-8	1.5681E-6	2	0.9754
G	6.4424E-2	3.4940E-2	6.8198E-4	3.3268E-4	3.5660E-6	1.0145E-7	4.6411E-6	2	0.9653
H	6.5149E-2	3.4538E-2	4.9082E-4	2.3943E-4	2.5664E-6	7.3013E-8	3.3402E-6	2	0.9761
I	6.5934E-2	3.3957E-2	2.4748E-2	1.2072E-4	1.2940E-6	3.6814E-8	1.6842E-6	2	0.9879

E3 Uncertainty and Sensitivity Effects

Tables E-6 and E-7 list base case results with .50c/MCNP4A library-and-code combination, respectively grouped by solution and by vessel shape and diameter. Results indicate Solution B data are suspect and should not be used without further information, although Thomas's correction (Table E-3 footnote) might be an error source. Results indicate Experiment I2 (Solution I in Cylindrical Vessel 2) is also suspect but experiments with Solution I in other vessels, and other solutions in Cylindrical Vessel 2, do not support deleting Experiment I2.

Cumulative-experimental-uncertainty effects are estimated to be $\pm 0.019 \Delta k_{\text{eff}}$, as shown in Table E-8. Tables E-9 through E-17 list results to confirm basic descriptions and to identify individual, key uncertainty contributors. Most calculations were performed only for spherical experiments because they are expected to be most sensitive to model changes and should envelope effects of similar variations in cylindrical experiments. Typical uncertainties were chosen for analysis because ORNL-4280 does not report cumulative or individual contributor uncertainties, except a ± 0.0005 measured k_{eff} uncertainty.

- ^{233}U enrichment uncertainty is assumed to be $\pm 0.5\%$ because isotopic analysis methods were well established and such an uncertainty is typical for fuel fabrication specifications and ORNL ^{235}U solutions. Table E-9 lists calculation results.
- Specific gravity is assumed to be $\pm 0.5\%$ because it is a directly-measured value for which measurement methods were well established and because this uncertainty value seems typical for experiments performed in the 1960s. This assumed uncertainty does not envelope a possible typographical correction for solution E because Thomas confirmed the reported value (Table E-3 footnote). Table E-10 lists calculation results.
- H: ^{233}U atom ratio is an experimenter calculated value dependent on several direct and indirect measurements, which would have been performed with the best precision and accuracy available because of the parameter's importance in criticality safety. A $\pm 2.5\%$ uncertainty is assumed based on Thomas's correction for solution B (Table E-3 footnote), 1960s measurement precisions when subject parameters are considered key to understanding experiment results. Table E-11 lists calculation results.
- Atom-density-calculation-method (using specific gravity vs. molecular formula) effects were investigated because many atom density calculation methodologies preferentially use molecular formulas whether or not excess acid information is reported. Table E-12 lists calculation results. These effects are not explicitly included in the estimated cumulative uncertainties because they are redundant to parts of the specific-gravity- and H: ^{233}U -uncertainty effects.
- Solution-vessel-wall-thickness uncertainty is assumed to be $\pm 12.5\%$, a typical manufacturing tolerance for thin sheet metal, thin-walled pipes, and tubes. I assume this uncertainty envelopes wall-material uncertainty because aluminum and most aluminum alloys are relatively weak neutron absorbers. Table E-13 lists calculation results.

Table E-6 .50c/MCNP4A Base Cases Grouped by Solution			
Experiment # ^a	k _{eff} ± 1σ	Solution Average	Solution Trend
A1 **	1.0373 ± 0.0022	1.0373 ± 0.0022	none: insufficient sample size
B1	0.9761 ± 0.0025	0.9765 ± 0.0082	results consistently low >2σ each, which is statistically significant. effects: 3.4% nonconservative bias
B2 **	0.9685 ± 0.0025		
B3	0.9849 ± 0.0024		
C	1.0192 ± 0.0023	1.0022 ± 0.0130	none, k _{eff} + 2σ would provide conservative results in all cases
C1	0.9887 ± 0.0023		
C2	0.9965 ± 0.0024		
C3	1.0044 ± 0.0024		
D	1.0173 ± 0.0022	1.0113 ± 0.0057	results consistently high, >2σ each, which is statistically significant; effects: 0.6% conservative bias
D2	1.0105 ± 0.0023		
D3	1.0060 ± 0.0024		
E	1.0074 ± 0.0022	1.0045 ± 0.0041	results consistently high but not statistically significant
E2	1.0016 ± 0.0021		
E3	1.0010 ± 0.0022	1.0057 ± 0.0041	results consistently high but not statistically significant
F	1.0087 ± 0.0020		
F2	1.0072 ± 0.0021		
G	1.0179 ± 0.0021	0.9966 ± 0.0212	none, k _{eff} + 2σ would NOT provide conservative results in all cases
G2	0.9694 ± 0.0022		
G3	0.9907 ± 0.0022		
G4	1.0076 ± 0.0022		
H	1.0082 ± 0.0019	1.0046 ± 0.0003	results consistently high but not statistically significant
H3	1.0018 ± 0.0021		
H4	1.0038 ± 0.0020		
I	0.9976 ± 0.0017	0.9883 ± 0.0012	results consistently low but not statistically significant, k _{eff} + 2σ would NOT provide conservative results in all cases
I2	0.9749 ± 0.0019		
I3	0.9924 ± 0.0019		
Average	1.0000 ± 0.0162		
Ave. w/o Sol'n B	1.0031 ± 0.0143		

a A double asterisk (**) indicates case was run 10 times, each with different starting random number. First run results listed because all results within 0.5σ of each other.

Table E-7 .50c/MCNP4A Base Cases Grouped by Vessel Shape and Size

Exp # ^a	k _{eff} ± 1σ	Vessel(s) Ave	Vessel Trends
C	1.0192 ± 0.0023	1.0109 ± 0.0077 with Solution I; 1.0131 ± 0.0055 without Solution I	k _{eff} + 2σ would provide conservative results in all cases; with one exception, results consistently high >2σ each, which is probably statistically significant. Exception is Solution I. However, its vessel is the same spherical vessel used for Solution C.
D	1.0173 ± 0.0022		
E	1.0074 ± 0.0022		
F	1.0087 ± 0.0020		
G	1.0179 ± 0.0021		
H	1.0082 ± 0.0019		
I	0.9976 ± 0.0017		
A1 **	1.0373 ± 0.0022	1.0007 ± 0.0032 with Solution B; 1.0013 ± 0.0034 without Solution B	k _{eff} + 2σ would NOT provide conservative results in all cases
B1	0.9761 ± 0.0025		
C1	0.9887 ± 0.0023		
B2 **	0.9685 ± 0.0025	0.9898 ± 0.0183 w/ Solutions B & I; 0.9934 ± 0.0172 without Solution B; 0.9970 ± 0.0164 w/o Solutions B & I	air-reflected cases (B2 - F2), except experiment B2, provide excellent or very conservative results; water-reflected cases (G2 and I2) perform less well
C2	0.9965 ± 0.0024		
D2	1.0105 ± 0.0023		
E2	1.0016 ± 0.0021		
F2	1.0072 ± 0.0021		
G2	0.9694 ± 0.0022		
I2	0.9749 ± 0.0019		
B3	0.9849 ± 0.0024	0.9973 ± 0.0080 w/ Solutions B & I; 0.9994 ± 0.0063 without Solution B; 1.0078 ± 0.0060 w/o Solutions B & I	excellent or very conservative results for all cases except experiment B3; air-reflected cases (B3 - E3), except experiment B3, provide more conservative results than water-reflected cases (G3-I3); k _{eff} + 2σ would provide conservative results in all cases except experiment B3
C3	1.0044 ± 0.0024		
D3	1.0060 ± 0.0024		
E3	1.0010 ± 0.0022		
G3	0.9907 ± 0.0022		
H3	1.0018 ± 0.0021		
I3	0.9924 ± 0.0019		
G4	1.0076 ± 0.0022	1.0057 ± 0.0027	results consistently high >2σ each, which is statistically significant; effects: 0.3% conservative bias
H4	1.0038 ± 0.0020		
Average	1.0000 ± 0.0162		
Ave w/o Sol'n B	1.0031 ± 0.0143		

a A double asterisk (**) indicates case was run 10 times, each with different starting random number. First run results listed because all results within 0.5σ of each other.

Table E-8 Estimated Cumulative ORNL-4280 Experiment-Uncertainty Effects				
Parameter q	Δq	experiment $\Delta k_{eff,ave}$ ^a		Internal Reference
		cylinders	spheres	
Measure k_{eff} (reported)	NA	± 0.0005		part E1
^{233}U enrichment (wt%)	$\pm 0.5\%$	± 0.0010		Table E-9
Solution specific gravity	$\pm 0.5\%$	± 0.0007		Table E-10
H: ^{233}U atom ratio	$\pm 2.5\%$	± 0.0139		Table E-11
Solution vessel wall thickness (cm)	$\pm 12.5\%$	± 0.0011		Table E-13
Solution vessel inner radius (cm)	$\pm 1.0\%$	± 0.0088		Table E-14
Solution critical height (cm)	± 0.5 cm	± 0.0112	Not applicable	Table E-16
Reflector vessel presence	$\pm$	± 0.0019		Table E-17
Cumulative Total ^b		± 0.0201	± 0.0166	

a Δk_{eff} s of averaged k_{eff} s listed here. Δk_{eff} calculation method described in Appendix B.

b Cumulative uncertainty for this experiment series is ± 0.019 , considering there are seven spherical-core experiments and 16 cylindrical-core experiments, without including experiments involving Solution B.

Table E-9 Estimated ORNL-4280 ^{233}U -Enrichment-Uncertainty Effects ^a				
Exp #	$k_{eff} \pm 1\sigma$ (.50c/MCNP4A)			Δk_{eff} ^b
	- 0.5%	nominal, 97.5302% (Table E-6, page E-8)	+ 0.5%	
C	1.0177 ± 0.0022	1.0192 ± 0.0023	1.0189 ± 0.0024	± 0.0015 *
D	1.0152 ± 0.0024	1.0173 ± 0.0022	1.0156 ± 0.0022	± 0.0021 *
E	1.0078 ± 0.0022	1.0074 ± 0.0022	1.0091 ± 0.0024	± 0.0017 *
F	1.0091 ± 0.0019	1.0087 ± 0.0020	1.0102 ± 0.0020	± 0.0015 *
G	1.0144 ± 0.0022	1.0179 ± 0.0021	1.0121 ± 0.0022	± 0.0012 *
H	1.0065 ± 0.0021	1.0082 ± 0.0019	1.0095 ± 0.0020	± 0.0030
I	0.9989 ± 0.0019	0.9976 ± 0.0017	1.0002 ± 0.0017	± 0.0026
Ave	1.0099 ± 0.0064	1.0109 ± 0.0077	1.0108 ± 0.059	- 0.0010 *

a ^{233}U and ^{238}U atom densities are varied respectively by $\pm 0.5\%$ and $\mp 0.5\%$, typical for uranium enrichment uncertainties if one assumes variation in other uranium isotopes and resultant effects are negligible.

b Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other).

Table E-10 Estimated ORNL-4280 Specific-Gravity-Uncertainty Effects					
Exp #	nominal spg (Table E-3, page E-4)	$k_{\text{eff}} \pm 1\sigma$ (.50c/MCNP4A)			Δk_{eff}^a
		- 0.5%	nominal (Table E-6, page E-8)	+ 0.5%	
C	1.183	1.0159 ± 0.0023	1.0192 ± 0.0023	1.0170 ± 0.0023	0.0033
D	1.144	1.0147 ± 0.0024	1.0173 ± 0.0022	1.0167 ± 0.0024	0.0026
E	1.106	1.0072 ± 0.0023	1.0074 ± 0.0022	1.0109 ± 0.0021	$\pm 0.0017^*$
F	1.050	1.0094 ± 0.0020	1.0087 ± 0.0020	1.0092 ± 0.0022	0.0007 *
G	1.186	1.0161 ± 0.0021	1.0179 ± 0.0021	1.0121 ± 0.0023	0.0058
H	1.135	1.0090 ± 0.0020	1.0082 ± 0.0019	1.0079 ± 0.0021	$\mp 0.0006^*$
I	1.068	0.9992 ± 0.0018	0.9976 ± 0.0017	1.0008 ± 0.0018	0.0032
Average		1.0102 ± 0.0061	1.0109 ± 0.0077	1.0107 ± 0.0056	0.0007 *

Table E-11 Estimated ORNL-4280 H: ^{233}U -Uncertainty Effects					
Exp #	nominal H: ^{233}U (Table E-3, page E-4)	$k_{\text{eff}} \pm 1\sigma$ as a function of H: ^{233}U (.50c/MCNP4A)			Δk_{eff}^a
		- 2.5%	nominal (Table E-6, page E-8)	+ 2.5%	
C	195.	0.9979 ± 0.0023	1.0192 ± 0.0023	1.0385 ± 0.0023	± 0.0203
D	253.	0.9988 ± 0.0016	1.0173 ± 0.0022	1.0371 ± 0.0022	± 0.0192
E	349.	0.9923 ± 0.0022	1.0074 ± 0.0022	1.0213 ± 0.0020	± 0.0145
F	581.	0.9914 ± 0.0019	1.0087 ± 0.0020	1.0051 ± 0.0019^b	0.0173
G	194.	0.9977 ± 0.0022	1.0179 ± 0.0021	1.0258 ± 0.0020	± 0.0141
H	273.	0.9959 ± 0.0021	1.0082 ± 0.0019	1.0199 ± 0.0020	± 0.0120
I	540.	0.9895 ± 0.0019	0.9976 ± 0.0017	1.0105 ± 0.0017	± 0.0105
Average		0.9948 ± 0.0037	1.0109 ± 0.0077	1.0226 ± 0.0125	0.0139

a Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other).

b Atom densities based on molecular formula (Table E-12, page E-12) rather than increased H: ^{233}U because otherwise an impossible solution, with a negative nitrate molecular density, results.

Table E-12 ORNL-4280 Nuclide-Density-Calculation Effects ^a				
Exp #	$k_{\text{eff}} \pm 1\sigma$ (.50c/MCNP4A)		Δk_{eff}^b	ΔN_N %
	specific gravity ^c (Table E-6, page E-8)	molecular formula		
A1	$1.0373 \pm 0.0022^{**}$	1.0324 ± 0.0023	- 0.0049	1.02
C	1.0192 ± 0.0023	1.0168 ± 0.0021	- 0.0024	
C1	0.9887 ± 0.0023	0.9874 ± 0.0023	- 0.0013 *	
C2	0.9965 ± 0.0024	0.9987 ± 0.0022	+ 0.0022 *	
C3	1.0044 ± 0.0024	1.0070 ± 0.0022	+ 0.0026	1.99
D	1.0173 ± 0.0022	1.0193 ± 0.0021	+ 0.0020 *	
D2	1.0105 ± 0.0023	1.0080 ± 0.0022	- 0.0025	
D3	1.0060 ± 0.0024	1.0127 ± 0.0021	+ 0.0060	
E	1.0074 ± 0.0022	1.0041 ± 0.0022	- 0.0033	5.04
E2	1.0016 ± 0.0021	1.0031 ± 0.0023	+ 0.0015 *	
E3	1.0010 ± 0.0022	1.0021 ± 0.0019	+ 0.0011 *	
F	1.0087 ± 0.0020	1.0051 ± 0.0019	- 0.0036	15.0
F2	1.0072 ± 0.0021	1.0063 ± 0.0019	- 0.0009 *	
G	1.0179 ± 0.0021	1.0119 ± 0.0019	- 0.0060	2.55
G2	0.9694 ± 0.0022	0.9652 ± 0.0023	- 0.0042	
G3	0.9907 ± 0.0022	0.9898 ± 0.0020	- 0.0009 *	
G4	1.0076 ± 0.0022	1.0098 ± 0.0022	+ 0.0022 *	
H	1.0082 ± 0.0019	1.0066 ± 0.0022	- 0.0016 *	6.81
H3	1.0018 ± 0.0021	1.0027 ± 0.0022	+ 0.0009 *	
H4	1.0038 ± 0.0020	1.0096 ± 0.0021	+ 0.0058	
Ave.	1.0053 ± 0.0135	1.0049 ± 0.0135	- 0.0004 *	

a Incorporated but not explicitly included in cumulative-uncertainty effects (Table E-8, page E-10).

Effect is incorporated in cumulative effects of H.²³³U and solution specific gravity uncertainties.

b Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other).

c A double asterisk (**) indicates case was run 10 times, each with different starting random number. First run results listed because all results within 0.5σ of each other.

Table E-13 ORNL-4280 Solution-Vessel Wall-Thickness-Uncertainty Effects				
Exp #	$k_{\text{eff}} \pm 1\sigma$ as a function of solution vessel wall thickness (.50c/MCNP4A)			Δk_{eff}^a
	- 12.5% (- 0.15 mm)	nominal, 1.22 mm (Table E-6, page E-8)	+ 12.5% (+ 0.15 mm)	
C	1.0190 ± 0.0022	1.0192 ± 0.0023	1.0178 ± 0.0022	- 0.0006 *
D	1.0168 ± 0.0022	1.0173 ± 0.0022	1.0174 ± 0.0024	+ 0.0006 *
E	1.0086 ± 0.0022	1.0074 ± 0.0022	1.0084 ± 0.0023	0.0012 *
F	1.0067 ± 0.0021	1.0087 ± 0.0020	1.0068 ± 0.0020	0.0020 *
G	1.0104 ± 0.0021	1.0179 ± 0.0021	1.0105 ± 0.0021	0.0075
H	1.0091 ± 0.0022	1.0082 ± 0.0019	1.0096 ± 0.0020	0.0014 *
I	0.9981 ± 0.0019	0.9976 ± 0.0017	1.0008 ± 0.0018	0.0032
Ave	1.0098 ± 0.0069	1.0109 ± 0.0077	1.0102 ± 0.0060	0.0011 *

Table E-14 ORNL-4280 Solution-Vessel Radius-Uncertainty Effects					
Exp #	nominal IR (cm) (Table E-3, page E-4)	$k_{\text{eff}} \pm 1\sigma$ as a function of solution vessel radius (.50c/MCNP4A)			Δk_{eff}^a
		- 1%	nominal (Table E-6, page E-8)	+ 1%	
C	14.579	1.0085 ± 0.0024	1.0192 ± 0.0023	1.0263 ± 0.0023	+ 0.0089
D	15.078	1.0066 ± 0.0024	1.0173 ± 0.0022	1.0275 ± 0.0023	+ 0.0105
E	15.821	1.0022 ± 0.0022	1.0074 ± 0.0022	1.0204 ± 0.0023	+ 0.0091
F	18.378	0.9952 ± 0.0020	1.0087 ± 0.0020	1.0174 ± 0.0019	+ 0.0111
G	11.170	1.0034 ± 0.0021	1.0179 ± 0.0021	1.0180 ± 0.0021	+ 0.0073
H	11.847	1.0000 ± 0.0021	1.0082 ± 0.0019	1.0159 ± 0.0020	+ 0.0080
I	14.579	0.9946 ± 0.0018	0.9976 ± 0.0017	1.0082 ± 0.0018	+ 0.0068
Average		1.0015 ± 0.0053	1.0109 ± 0.0077	1.0191 ± 0.0065	0.0088

^a Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other).

Table E-15 ORNL-4280 Solution-Vessel-Floor Effects ^a			
Experiment #	$k_{\text{eff}} \pm 1\sigma$ (.50c/MCNP4A)		Δk_{eff} ^b
	styrafoam floor ^c (Table E-6, page E-8)	aluminum floor	
A1	1.0373 ± 0.0022 **	1.0604 ± 0.0022	+ 0.0203
B1	0.9761 ± 0.0025	0.9957 ± 0.0023	+ 0.0196
B2	0.9685 ± 0.0025 **	0.9873 ± 0.0025	+ 0.0188
B3	0.9849 ± 0.0024	0.9945 ± 0.0023	+ 0.0096
C1	0.9887 ± 0.0023	1.0028 ± 0.0021	+ 0.0141
C2	0.9965 ± 0.0024	1.0096 ± 0.0025	+ 0.0131
C3	1.0044 ± 0.0024	1.0071 ± 0.0024	+ 0.0027
D2	1.0105 ± 0.0023	1.0173 ± 0.0022	+ 0.0068
D3	1.0060 ± 0.0024	1.0124 ± 0.0023	+ 0.064
E2	1.0016 ± 0.0021	1.0146 ± 0.0021	+ 0.0130
E3	1.0010 ± 0.0022	1.0004 ± 0.0020	- 0.0006 *
F2	1.0072 ± 0.0021	1.0097 ± 0.0021	+ 0.0025
G2	0.9694 ± 0.0022	0.9874 ± 0.0022	+ 0.0180
G3	0.9907 ± 0.0022	1.0005 ± 0.0020	+ 0.0098
G4	1.0076 ± 0.0022	1.0096 ± 0.0020	+ 0.0020
H3	1.0018 ± 0.0021	1.0106 ± 0.0023	+ 0.0088
H4	1.0038 ± 0.0020	1.0068 ± 0.0021	+ 0.0030
I2	0.9749 ± 0.0019	0.9847 ± 0.0019	+ 0.0098
I3	0.9924 ± 0.0019	0.9963 ± 0.0019	+ 0.0039
Average	0.9960 ± 0.0167	1.0057 ± 0.0164	- 0.0097
Ave. w/o Sol'n B	0.9996 ± 0.0154	1.0081 ± 0.0166	- 0.0085

- a Results indicate reported critical heights were indeed corrected for solution-vessel-floor effects. These effects are incorporated as critical-height uncertainty but not explicitly included in cumulative-uncertainty effects (Table E-8, page E-10).
- b Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other).
- c A double asterisk (**) indicates case was run 10 times, each with different starting random number. First run results listed because all results within 0.5σ of each other.

Table E-16 ORNL-4280 Critical-Height-Uncertainty Effects

Exp #	nominal height (cm) (Table E-4, page E-5)	$k_{eff} \pm 1\sigma$ (.50c/MCNP4A)			Δk_{eff}^a
		- 0.50 cm	nominal ^b (Table E-6, page E-8)	+ 0.50 cm	
A1	13.36	1.0095 ± 0.0018	$1.0373 \pm 0.0022^{**}$	1.0649 ± 0.0017	± 0.0277
B1	13.51	0.9544 ± 0.0016	0.9761 ± 0.0025	1.0081 ± 0.0017	± 0.0269
B2	15.14	0.9505 ± 0.0017	$0.9685 \pm 0.0025^{**}$	0.9922 ± 0.0017	± 0.0209
B3	24.69	0.9805 ± 0.0016	0.9849 ± 0.0024	0.9923 ± 0.0018	± 0.0059
C1	14.07	0.9610 ± 0.0016	0.9887 ± 0.0023	1.0111 ± 0.0016	± 0.0251
C2	16.33	0.9787 ± 0.0017	0.9965 ± 0.0024	1.0154 ± 0.0017	± 0.0184
C3	28.52	1.0031 ± 0.0017	1.0044 ± 0.0024	1.0145 ± 0.0016	± 0.0057
D2	17.60	0.9904 ± 0.0016	1.0105 ± 0.0023	1.0216 ± 0.0016	± 0.0156
D3	33.40	1.0082 ± 0.0016	1.0060 ± 0.0024	1.0146 ± 0.0016	± 0.0032
E2	19.35	0.9891 ± 0.0015	1.0016 ± 0.0021	1.0154 ± 0.0016	± 0.0132
E3	43.69	0.9990 ± 0.0015	1.0010 ± 0.0022	1.0008 ± 0.0014	0.0020 *
F2	26.37	0.9975 ± 0.0013	1.0072 ± 0.0021	1.0120 ± 0.0014	± 0.0613
G2	13.42	0.9446 ± 0.0015	0.9694 ± 0.0022	0.9959 ± 0.0016	± 0.0805
G3	17.22	0.9798 ± 0.0016	0.9907 ± 0.0022	1.0043 ± 0.0016	± 0.0123
G4	22.86	1.0003 ± 0.0016	1.0076 ± 0.0022	1.0153 ± 0.0015	± 0.0075
H3	19.67	0.9899 ± 0.0015	1.0018 ± 0.0021	1.0111 ± 0.0015	± 0.0106
H4	27.02	1.0015 ± 0.0015	1.0038 ± 0.0020	1.0113 ± 0.0014	± 0.0049
I2	19.6	0.9649 ± 0.0013	0.9749 ± 0.0019	0.9920 ± 0.0013	± 0.0136
I3	31.53	0.9908 ± 0.0014	0.9924 ± 0.0019	1.0002 ± 0.0013	± 0.0047
Average		0.9839 ± 0.0200	0.9960 ± 0.0167	1.0102 ± 0.0161	± 0.0132
Average w/o Solution B		0.9866 ± 0.0179	0.9996 ± 0.0154	1.0090 ± 0.0084	± 0.0112

a Δk_{eff} calculation method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other).

b A double asterisk (**) indicates case was run 10 times, each with different starting random number. First run results listed because all results within 0.5σ of each other.

Table E-17 ORNL-4280 Reflector-Vessel Effects

Experiment #	$k_{\text{eff}} \pm 1\sigma$ (.50c/MCNP4A)		Δk_{eff}^a
	with vessel (Table E-6) ^b	without vessel	
A1	$1.0373 \pm 0.0022^{**}$	1.0307 ± 0.0026	- 0.0066
B1	0.9761 ± 0.0025	0.9747 ± 0.0023	- 0.0014 *
B2	$0.9685 \pm 0.0025^{**}$	0.9688 ± 0.0025	+ 0.0003 *
B3	0.9849 ± 0.0024	0.9793 ± 0.0024	+ 0.0056
C	1.0192 ± 0.0023	1.0136 ± 0.0024	- 0.0056
C1	0.9887 ± 0.0023	0.9796 ± 0.0023	- 0.0091
C2	0.9965 ± 0.0024	0.9951 ± 0.0023	- 0.0014 *
C3	1.0044 ± 0.0024	1.0052 ± 0.0024	+ 0.0008 *
D	1.0173 ± 0.0022	1.0156 ± 0.0023	- 0.0017 *
D2	1.0105 ± 0.0023	1.0042 ± 0.0025	- 0.0063
D3	1.0060 ± 0.0024	1.0056 ± 0.0023	- 0.0004 *
E	1.0074 ± 0.0022	1.0099 ± 0.0023	+ 0.0025
E2	1.0016 ± 0.0021	1.0037 ± 0.0022	+ 0.0021 *
E3	1.0010 ± 0.0022	1.0024 ± 0.0023	+ 0.0014 *
F	1.0087 ± 0.0020	1.0068 ± 0.0021	- 0.0019 *
F2	1.0072 ± 0.0021	1.0005 ± 0.0019	- 0.0067
G	1.0179 ± 0.0021	1.0179 ± 0.0021	0.0000 *
G2	0.9694 ± 0.0022	0.9638 ± 0.0022	- 0.0056
G3	0.9907 ± 0.0022	0.9877 ± 0.0022	- 0.0030
G4	1.0076 ± 0.0022	1.0103 ± 0.0023	0.0094
H	1.0082 ± 0.0019	1.0082 ± 0.0019	0.0000 *
H3	1.0018 ± 0.0021	0.9962 ± 0.0019	- 0.0056
H4	1.0038 ± 0.0020	1.0068 ± 0.0021	+ 0.0030
I	0.9976 ± 0.0017	0.9976 ± 0.0017	0.0000 *
I2	0.9749 ± 0.0019	0.9728 ± 0.0020	- 0.0021
I3	0.9924 ± 0.0019	0.9931 ± 0.0018	+ 0.0007 *
Average	1.0000 ± 0.0162	0.9981 ± 0.0165	- 0.0019 *
Ave w/o Solution B	1.0031 ± 0.0143	1.0012 ± 0.0148	- 0.0019 *

a Δk_{eff} method described in Appendix B. An asterisk (*) indicates results are essentially the same (within 1σ of each other).

b A double asterisk (**) indicates case was run 10 times with different starting random numbers. First run results listed because all results within 0.5σ of each other.

- Solution-vessel-radius uncertainty is assumed to be $\pm 1.0\%$ because of precision possible at the time, known parameter importance, and relatively small diameters (20 inches for the largest vessel). This uncertainty should envelope affects of minor deviations in vessel shape (slightly aspherical or non-circular surfaces). Table E-14 list calculation results.
- ORNL-4280 indicates reported critical heights were corrected to incorporate solution-vessel-floor effects. Table E-15 list calculation results which confirm this description. Floor thickness and material composition uncertainties are therefore incorporated into solution critical height uncertainties described next.
- Solution-critical-height uncertainty is assumed to be ± 0.5 cm to envelope uncertainties typical of direct measurements (± 0.2 cm) and estimated uncertainties in correcting for small solution-vessel-floor effects. Table E-16 lists calculation results.
- Reflector-vessel-wall uncertainties were investigated by deleting vessel material. Table E-17 lists calculation results. There is essentially no difference between results for air- and water-reflected experiments. Although neutron absorption in the vessel floor causes most of the difference between results, Δk_{eff} range from 0.1 to 0.3% indicating the vessel wall is not necessarily negligible. The averaged k_{eff} difference, $\pm 0.0019 \Delta k$, envelopes other reflector-vessel uncertainties because its nominal thicknesses are sufficiently large that effects of different stainless steel types and of thickness uncertainties should be several orders of magnitude less than the vessel's presence.

E4 Library-and-Code Combination Effects

Summarized in Table 7 (page 16), Tables E-18 through E-23 list calculation results for various library-and-code combinations. Relatively high individual and average σ s for calculated k_{eff} s mostly reflect difficulties in obtaining calculation convergence in reasonable run times. Most results are conservative and all subject combinations except calculations with the *Hansen-Roach* cross-sections perform well. *Hansen-Roach* calculations produce k_{eff} s an average 2% low with one value 4% low. This result is consistent with differences between these thermal experiments and the fast system basis for *Hansen-Roach* cross-sections.

E5 Analysis Conclusions

Table 8 (page 16) lists recommended biases for calculations validated with these experiments. Recommended biases incorporate an assumed 50% weighting factor for statistical variation of individual k_{eff} s from their respective averaged k_{eff} . This assumption attributes half the variation to calculation methodology and half to experiment-description uncertainty. The weighting factor value is based on typical cumulative experiment uncertainties for well described ^{235}U and ^{233}U experiments, compared to experiment uncertainty effects for these experiments. However, experiment uncertainties are atypically large and must be considered further if these experiments are used to validate criticality safety evaluations.

Table E-18 Calculations with <i>Hansen-Roach</i> Cross Section Library (<i>Hansen-Roach/CSAS25/SCALE4.3</i>)			
Experiment #	$k_{\text{eff}} \pm 1\sigma^a$	ale (ev)	Comments ^a
A1	1.0025 ± 0.0015	0.5031 ± 0.0016	Not fully converged
B1	0.9558 ± 0.0015	0.1799 ± 0.0004	
B2	0.9461 ± 0.0015	0.1803 ± 0.0004	Not converged
B3	0.9574 ± 0.0015	0.1774 ± 0.0004	Not fully converged
C	0.9986 ± 0.0015	0.0762 ± 0.0001	
C1	0.9671 ± 0.0015	0.0779 ± 0.0001	
C2	0.9786 ± 0.0016	0.0772 ± 0.0001	Not fully converged
C3	0.9832 ± 0.0016	0.0772 ± 0.0001	
D	1.0013 ± 0.0016	0.0540 ± 0.0001	Not fully converged
D2	0.9919 ± 0.0014	0.5442 ± 0.0001	
D3	0.9912 ± 0.0015	0.0542 ± 0.0001	
E	0.9919 ± 0.0015	0.0382 ± 0.0000	Not fully converged
E2	0.9911 ± 0.0014	0.0384 ± 0.0000	
E3	0.9880 ± 0.0015	0.0382 ± 0.0000	Not fully converged
F	0.9978 ± 0.0013	0.0253 ± 0.0000	
F2	0.9977 ± 0.0013	0.0254 ± 0.0000	Not fully converged
G	0.9958 ± 0.0014	0.0519 ± 0.0001	
G2	0.9543 ± 0.0014	0.0635 ± 0.0001	Not fully converged
G3	0.9750 ± 0.0014	0.0582 ± 0.0001	
G4	0.9185 ± 0.0014	0.0839 ± 0.0001	
H	0.9966 ± 0.0013	0.0374 ± 0.0000	
H3	0.9874 ± 0.0014	0.0404 ± 0.0001	Not fully converged
H4	0.9906 ± 0.0014	0.0386 ± 0.0001	
I	0.9922 ± 0.0013	0.0235 ± 0.0000	
I2	0.9696 ± 0.0019	0.0250 ± 0.0000	Not fully converged
I3	0.9851 ± 0.0016	0.0239 ± 0.0000	
Average	0.9810 ± 0.0204	Averages include only converged cases	
Ave w/o Sol'n B	0.9839 ± 0.0208		

^a It is not cost-effective to recalculate because *Hansen-Roach* is rarely used at the INEEL today.

Table E-19 27GROUPNDF4 and 218GROUPNDF4 Cross-Section-Library Effects

Experiment # ^a	27GROUPNDF4/CSAS25/SCALE4.3		218GROUPNDF4/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma$	ale (ev)	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
A1 **	1.0551 ± 0.0016	0.6202 ± 0.0017	1.0521 ± 0.0015	0.6165 ± 0.0017
B1	0.9970 ± 0.0016	0.2428 ± 0.0006	0.9963 ± 0.0016	0.2414 ± 0.0006
B2	0.9915 ± 0.0015	0.2430 ± 0.0006	0.9887 ± 0.0016	0.2403 ± 0.0006
B3	1.0039 ± 0.0016	0.2399 ± 0.0006	0.9988 ± 0.0015	0.2389 ± 0.0006
C	1.0293 ± 0.0016	0.1108 ± 0.0002	1.0277 ± 0.0015	0.1099 ± 0.0002
C1	1.0033 ± 0.0014	0.1126 ± 0.0002	1.0028 ± 0.0015	0.1120 ± 0.0002
C2	1.0125 ± 0.0016	0.1118 ± 0.0002	1.0135 ± 0.0016	0.1110 ± 0.0002
C3	1.0212 ± 0.0016	0.1111 ± 0.0002	1.0204 ± 0.0017	0.1105 ± 0.0002
D	1.0305 ± 0.0015	0.0804 ± 0.0001	1.0475 ± 0.0015	0.0800 ± 0.0001
D2	1.0213 ± 0.0014	0.0810 ± 0.0001	1.0215 ± 0.0015	0.0805 ± 0.0001
D3	1.0230 ± 0.0014	0.0806 ± 0.0001	1.0210 ± 0.0015	0.0803 ± 0.0001
E	1.0187 ± 0.0015	0.0585 ± 0.0001	1.0186 ± 0.0015	0.0580 ± 0.0001
E2	1.0153 ± 0.0015	0.0587 ± 0.0001	1.0135 ± 0.0015	0.0584 ± 0.0001
E3	1.0132 ± 0.0015	0.0586 ± 0.0001	1.0128 ± 0.0014	0.0583 ± 0.0001
F	1.0156 ± 0.0012	0.0402 ± 0.0000	1.0161 ± 0.0013	0.0398 ± 0.0000
F2	1.0143 ± 0.0013	0.0403 ± 0.0000	1.0130 ± 0.0013	0.0399 ± 0.0000
G	1.0284 ± 0.0014	0.0808 ± 0.0001	1.0251 ± 0.0014	0.0801 ± 0.0001
G2	0.9868 ± 0.0014	0.0957 ± 0.0002	0.9897 ± 0.0015	0.0948 ± 0.0002
G3	1.0045 ± 0.0015	0.0890 ± 0.0002	1.0019 ± 0.0015	0.0888 ± 0.0002
G4 **	0.9425 ± 0.0014	0.1206 ± 0.0003	0.9433 ± 0.0014	0.1196 ± 0.0002
H	1.0194 ± 0.0014	0.0591 ± 0.0001	1.0185 ± 0.0015	0.0589 ± 0.0001
H3	1.0129 ± 0.0014	0.0629 ± 0.0001	1.0133 ± 0.0014	0.0626 ± 0.0001
H4	1.0192 ± 0.0014	0.0605 ± 0.0001	1.0151 ± 0.0014	0.0603 ± 0.0001
I	1.0087 ± 0.0012	0.0381 ± 0.0000	1.0070 ± 0.0012	0.0377 ± 0.0000
I2	0.9864 ± 0.0012	0.0400 ± 0.0000	0.9876 ± 0.0012	0.0396 ± 0.0000
I3	1.0016 ± 0.0017	0.0386 ± 0.0001	0.9991 ± 0.0013	0.0382 ± 0.0000
Average	1.0106 ± 0.0203		1.0102 ± 0.0207	
Ave w/o Solution B	1.0123 ± 0.0209		1.0122 ± 0.0211	

a A double asterisk (**) indicates case was run 10 times with different starting random numbers. First run results listed because all results within 0.5σ of each other.

Table E-20 44GROUPNDF5 and 238GROUPNDF5 Cross-Section-Library Effects				
Experiment # ^a	44GROUPNDF5/CSAS25/SCALE4.3		238GROUPNDF5/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma$	ale (ev)	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
A1 **	1.0432 ± 0.0016	0.6693 ± 0.0017	1.0277 ± 0.0016	0.6915 ± 0.0019
B1	0.9874 ± 0.0016	0.2762 ± 0.0005	0.9735 ± 0.0015	0.2862 ± 0.0006
B2	0.9773 ± 0.0015	0.2760 ± 0.0006	0.9646 ± 0.0015	0.2858 ± 0.0006
B3	0.9871 ± 0.0017	0.2733 ± 0.0006	0.9770 ± 0.0017	0.2821 ± 0.0006
C	1.0183 ± 0.0016	0.1335 ± 0.0002	1.0117 ± 0.0015	0.1376 ± 0.0002
C1	0.9906 ± 0.0016	0.1353 ± 0.0002	0.9835 ± 0.0014	0.1403 ± 0.0002
C2	0.9993 ± 0.0016	0.1346 ± 0.0002	0.9893 ± 0.0015	0.1393 ± 0.0002
C3	1.0054 ± 0.0015	0.1338 ± 0.0002	0.9985 ± 0.0015	0.1384 ± 0.0002
D	1.0322 ± 0.0015	0.0996 ± 0.0001	1.0276 ± 0.0016	0.1034 ± 0.0001
D2	1.0107 ± 0.0015	0.0998 ± 0.0001	1.0017 ± 0.0015	0.1039 ± 0.0001
D3	1.0155 ± 0.0016	0.0996 ± 0.0001	1.0006 ± 0.0015	0.1038 ± 0.0001
E	1.0090 ± 0.0015	0.0741 ± 0.0001	1.0027 ± 0.0015	0.0773 ± 0.0001
E2	1.0062 ± 0.0014	0.0745 ± 0.0001	0.9991 ± 0.0014	0.0777 ± 0.0001
E3	1.0011 ± 0.0015	0.0744 ± 0.0001	0.9928 ± 0.0015	0.0777 ± 0.0001
F	1.0085 ± 0.0013	0.0527 ± 0.0000	1.0161 ± 0.0013	0.0398 ± 0.0000
F2	1.0047 ± 0.0013	0.0529 ± 0.0000	1.0011 ± 0.0013	0.0553 ± 0.0000
G	1.0165 ± 0.0014	0.0992 ± 0.0015	1.0052 ± 0.0015	0.1029 ± 0.0002
G2	0.9765 ± 0.0015	0.1160 ± 0.0002	0.9679 ± 0.0015	0.1198 ± 0.0002
G3	0.9937 ± 0.0014	0.1087 ± 0.0017	0.9802 ± 0.0015	0.1128 ± 0.0002
G4 **	0.9366 ± 0.0015	0.1441 ± 0.0002	0.9258 ± 0.0015	0.1496 ± 0.0003
H	1.0106 ± 0.0014	0.0747 ± 0.0001	1.0026 ± 0.0014	0.0777 ± 0.0001
H3	1.0032 ± 0.0015	0.0791 ± 0.00001	0.9936 ± 0.0014	0.0822 ± 0.0001
H4	1.0103 ± 0.0015	0.0764 ± 0.0001	1.0009 ± 0.0014	0.0793 ± 0.0001
I	1.0005 ± 0.0012	0.0500 ± 0.0000	0.9929 ± 0.0012	0.0523 ± 0.0000
I2	0.9788 ± 0.0012	0.0524 ± 0.0000	0.9717 ± 0.0012	0.0549 ± 0.0000
I3	0.9978 ± 0.0015	0.0507 ± 0.0001	0.9892 ± 0.0012	0.5306 ± 0.0000
Average	1.0008 ± 0.0203		0.9922 ± 0.0212	
Average w/o Solution B	1.0030 ± 0.0205		0.9949 ± 0.0211	

a A double asterisk (**) indicates case was run 10 times with different starting random numbers. First run results listed because all results within 0.5σ of each other.

Table E-21 27-Group Library-Processing Effects

Experiment # ^a	27Grev/CSAS25/SCALE4.0		27GROUPNDF4/CSAS25/SCALE4.3 (Table E-19, page E-19)	
	$k_{\text{eff}} \pm 1\sigma$	afg	$k_{\text{eff}} \pm 1\sigma$	afg
A1 **	1.0547 ± 0.0016	19.6829 ± 0.0046	1.0551 ± 0.0016	19.6842 ± 0.0044
B1	0.9987 ± 0.0015	21.1664 ± 0.0037	0.9970 ± 0.0016	21.1651 ± 0.0038
B2	0.9867 ± 0.0015	21.1609 ± 0.0036	0.9915 ± 0.0015	21.1637 ± 0.0037
B3	1.0009 ± 0.0016	21.1792 ± 0.0037	1.0039 ± 0.0016	21.1835 ± 0.0036
C	1.0331 ± 0.0015	22.4092 ± 0.0027	1.0293 ± 0.0016	22.4037 ± 0.0027
C1	1.0028 ± 0.0015	22.3781 ± 0.0029	1.0033 ± 0.0014	22.3779 ± 0.0029
C2	1.0106 ± 0.0015	22.3901 ± 0.0027	1.0125 ± 0.0016	22.3899 ± 0.0028
C3	1.0212 ± 0.0016	22.4033 ± 0.0027	1.0212 ± 0.0016	22.3992 ± 0.0027
D	1.0301 ± 0.0015	22.9060 ± 0.0024	1.0305 ± 0.0015	22.9085 ± 0.0022
D2	1.0218 ± 0.0015	22.8938 ± 0.0022	1.0213 ± 0.0014	22.8970 ± 0.0023
D3	1.0228 ± 0.0015	22.9031 ± 0.0023	1.0230 ± 0.0014	22.9028 ± 0.0023
E	1.0217 ± 0.0014	23.4135 ± 0.0019	1.0187 ± 0.0015	23.4106 ± 0.0018
E2	1.0157 ± 0.0014	23.404 ± 0.0018	1.0153 ± 0.0015	23.4038 ± 0.0019
E3	1.0136 ± 0.0014	23.4069 ± 0.0018	1.0132 ± 0.0015	23.4052 ± 0.0019
F	1.0148 ± 0.0012	24.0020 ± 0.0012	1.0156 ± 0.0012	23.9972 ± 0.0012
F2	1.0156 ± 0.0013	23.9956 ± 0.0013	1.0143 ± 0.0013	23.9945 ± 0.0013
G	1.0257 ± 0.0014	22.9254 ± 0.0027	1.0284 ± 0.0014	22.9232 ± 0.0026
G2	0.9882 ± 0.0015	22.6556 ± 0.0027	0.9868 ± 0.0014	22.6503 ± 0.0028
G3	1.0058 ± 0.0014	22.7655 ± 0.0028	1.0045 ± 0.0015	22.7674 ± 0.0028
G4 **	0.9463 ± 0.0014	22.2632 ± 0.0031	0.9425 ± 0.0014	22.2659 ± 0.0029
H	1.0210 ± 0.0013	23.4065 ± 0.0020	1.0194 ± 0.0014	23.4107 ± 0.0021
H3	1.0145 ± 0.0015	23.3097 ± 0.0021	1.0129 ± 0.0014	23.3082 ± 0.0020
H4	1.0160 ± 0.0014	23.3714 ± 0.0022	1.0192 ± 0.0014	23.3735 ± 0.0021
I	1.0077 ± 0.0012	24.0959 ± 0.0013	1.0087 ± 0.0012	24.0920 ± 0.0013
I2	0.9881 ± 0.0012	24.0105 ± 0.0013	0.9864 ± 0.0012	24.0104 ± 0.0014
I3	1.0032 ± 0.0017	24.0707 ± 0.0017	1.0016 ± 0.0017	24.0673 ± 0.0017
Average	1.0108 ± 0.0199		1.0106 ± 0.0203	
Average w/o Solution B	1.0128 ± 0.0202		1.0123 ± 0.0209	

^a A double asterisk (**) indicates case was run 10 times with different starting random numbers. First run results listed because all results within 0.5σ of each other.

Table E-22 DANT and KENO Va Code Effects		
Experiment #	k_{eff}^a SCALE4.3/TWODANT 27GROU/PNDF4/CSAS/	$k_{eff} \pm 1\sigma^b$ (Table E-19, page E-19) 27GROU/PNDF4/CSAS25/SCALE4.3
A1	1.0488	1.0551 $\pm$ 0.0016 **
B1	0.9935	0.9970 $\pm$ 0.0016
B2	0.9871	0.9915 $\pm$ 0.0015
B3	1.0014	1.0039 $\pm$ 0.0016
C	1.0344	1.0293 $\pm$ 0.0016
C1	0.9983	1.0033 $\pm$ 0.0014
C2	1.0105	1.0125 $\pm$ 0.0016
C3	1.0204	1.0212 $\pm$ 0.0016
D ^c	1.0701	1.0305 $\pm$ 0.0015
D2 ^c	1.0557	1.0213 $\pm$ 0.0014
D3	1.0243 *	1.0230 $\pm$ 0.0014
E	-- d	1.0187 $\pm$ 0.0015
E2	1.0190 *	1.0153 $\pm$ 0.0015
E3	1.0185 *	1.0132 $\pm$ 0.0015
F	1.0188	1.0156 $\pm$ 0.0012
F2	1.0193 *	1.0143 $\pm$ 0.0013
G	1.0261	1.0284 $\pm$ 0.0014
G2	0.9955 *	0.9868 $\pm$ 0.0014
G3	1.0106	1.0045 $\pm$ 0.0015
G4 ^c	1.0196	0.9425 $\pm$ 0.0014 **
H	1.0211	1.0194 $\pm$ 0.0014
H3	1.0117	1.0129 $\pm$ 0.0014
H4	1.0181	1.0192 $\pm$ 0.0014
I	1.0096	1.0087 $\pm$ 0.0012
I2	0.9841	0.9864 $\pm$ 0.0012
I3	1.0023	1.0016 $\pm$ 0.0017
Average	1.0168 $\pm$ 0.0202	1.0106 $\pm$ 0.0203
Ave w/o Solution B	1.0185 $\pm$ 0.0188	1.0123 $\pm$ 0.0209

a An asterisk (*) indicates convergence criteria changed from 1×10^{-6} to 1×10^{-4} .

b A double asterisk (**) indicates case was run 10 times with different starting random numbers. First run results listed because all results within 0.5% of each other.

c Result difference unexpectedly large but independent review did not identify errors.

d Convergence not attained in reasonable time & mesh size. TWODANT averages do not include this experiment.

Table E-23 .50c and .60c Cross-Section-Library Effects		
Experiment # ^a	$k_{eff} \pm 1\sigma$	
	.50c/MCNP4A	.60c/MCNP4A
A1 **	1.0373 $\pm$ 0.0022	1.0323 $\pm$ 0.0024
B1	0.9761 $\pm$ 0.0025	0.9761 $\pm$ 0.0024
B2 **	0.9685 $\pm$ 0.0025	0.9658 $\pm$ 0.0022
B3	0.9849 $\pm$ 0.0024	0.9839 $\pm$ 0.0022
C	1.0192 $\pm$ 0.0023	1.0136 $\pm$ 0.0025
C1	0.9887 $\pm$ 0.0023	0.9801 $\pm$ 0.0022
C2	0.9965 $\pm$ 0.0024	0.9979 $\pm$ 0.0024
C3	1.0044 $\pm$ 0.0024	1.0005 $\pm$ 0.0023
D	1.0173 $\pm$ 0.0022	1.0080 $\pm$ 0.0022
D2	1.0105 $\pm$ 0.0023	1.0072 $\pm$ 0.0022
D3	1.0060 $\pm$ 0.0024	1.0013 $\pm$ 0.0023
E	1.0074 $\pm$ 0.0022	1.0044 $\pm$ 0.0021
E2	1.0016 $\pm$ 0.0021	0.9996 $\pm$ 0.0023
E3	1.0010 $\pm$ 0.0022	0.9979 $\pm$ 0.0021
F	1.0087 $\pm$ 0.0020	1.0055 $\pm$ 0.0020
F2	1.0072 $\pm$ 0.0021	1.0037 $\pm$ 0.0019
G	1.0179 $\pm$ 0.0021	1.0061 $\pm$ 0.0021
G2	0.9694 $\pm$ 0.0022	0.9639 $\pm$ 0.0023
G3	0.9907 $\pm$ 0.0022	0.9873 $\pm$ 0.0018
G4	1.0076 $\pm$ 0.0022	0.9977 $\pm$ 0.0022
H	1.0082 $\pm$ 0.0019	1.0037 $\pm$ 0.0021
H3	1.0018 $\pm$ 0.0021	0.9977 $\pm$ 0.0019
H4	1.0038 $\pm$ 0.0020	1.0009 $\pm$ 0.0021
I	0.9976 $\pm$ 0.0017	0.9956 $\pm$ 0.0017
I2	0.9749 $\pm$ 0.0019	0.9739 $\pm$ 0.0019
I3	0.9924 $\pm$ 0.0019	0.9931 $\pm$ 0.0020
Average	1.0000 $\pm$ 0.0162	0.9961 $\pm$ 0.0151
Average without Solution B	1.0031 $\pm$ 0.0143	0.9988 $\pm$ 0.0136

^a A double asterisk (**) indicates case was run 10 times with different starting random numbers. First run results listed because all results within 0.5 σ of each other.

E6 Sample Inputs

Some single lines of input are listed here on multiple lines due to report's column width. Use caution in regenerating code inputs from these listings.

E6.1 SCALE Input

Most SCALE calculations were performed with 605 generations, 900 neutrons per generation, skipping 20 generations before averaging k_{eff} values. Most results are therefore based on 526,500 neutron histories, which is typically more than sufficient to achieve eigenvalue convergence. Several cases used more neutron histories, none used fewer.

E6.1.1 Base Case A1, Hansen-Roach/CSAS25/SCALE4.3

```
=CSAS25
ORNL-4280, Experiment A1, no reflector
HANSEN-ROACH INFHOMMEDIUM
' mtl 1 is fissile solution A
H      1 0 6.1267E-02 END
O      1 0 3.7317E-02 END
N      1 0 1.6544E-03 END
U-233  1 0 8.3927E-04 END
U-234  1 0 8.9959E-06 END
U-235  1 0 2.5593E-07 END
U-238  1 0 1.1708E-05 END
' mtl 2 is styrafoam support for cylindrical vessels
H      2 0 5.5508E-04 END
C      2 0 5.5508E-04 END
' mtl 3 is aluminum solution vessel, type not
specified
AL     3 0 6.0238E-02 END
' mtl 4 is water reflector, not needed with solns A-F
H2O    4 1.0 END
' mtl 5 is SS reflector vessel, type not specified
SS304  5 1.0 END
END COMP
KENOV.A
READ PARAM
TME=120 GEN=605 NPG=900 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=20
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 25.40 13.36 0.
CYLINDER 0 1 25.40 37.66 0.
CYLINDER 3 1 25.415 37.66 0.0
CYLINDER 2 1 25.415 37.66 -25.57
CYLINDER 0 1 137.16 37.66 -25.57
CYLINDER 5 1 138.2713 37.66 -28.2688
END GEOMETRY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

E6.1.2 Base Case B1, 27Grev/CSAS25/SCALE4.0

```
=CSAS25
ORNL-2480, Experiment B1, no reflector
27G INF
' mtl 1 is fissile solution B
H      1 0 6.1184E-02 END
O      1 0 3.5452E-02 END
N      1 0 1.2687E-03 END
U-233  1 0 5.1415E-04 END
U-234  1 0 5.5110E-06 END
```

```
U-235  1 0 1.5679E-07 END
U-238  1 0 7.1727E-06 END
' mtl 2 is styrafoam support for cylindrical vessels
H      2 0 5.5508E-04 END
C      2 0 5.5508E-04 END
' mtl 3 is aluminum solution vessel, type not
specified
AL     3 0 6.0238E-02 END
' mtl 4 is water reflector, not needed with solns A-F
H2O    4 1.0 END
' mtl 5 is SS reflector vessel, type not specified
SS304  5 1.0 END
END COMP
KENOV.A
READ PARAM
TME=120 GEN=605 NPG=900 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=20
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 25.40 13.51 0.
CYLINDER 0 1 25.40 37.81 0.
CYLINDER 3 1 25.415 37.81 0.0
CYLINDER 2 1 25.415 37.81 -25.57
CYLINDER 0 1 137.16 37.81 -25.57
CYLINDER 5 1 138.2713 37.81 -28.2688
END GEOMETRY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

E6.1.3 Base Case B2, 27GROUPNDF4/CSAS25/SCALE4.3

```
=CSAS25
ORNL-4280, Experiment B2, no reflector
44GROUPNDF5 INF
' mtl 1 is fissile solution B
H      1 0 6.1184E-02 END
O      1 0 3.5452E-02 END
N      1 0 1.2687E-03 END
U-233  1 0 5.1415E-04 END
U-234  1 0 5.5110E-06 END
U-235  1 0 1.5679E-07 END
U-238  1 0 7.1727E-06 END
' mtl 2 is styrafoam support for cylindrical vessels
H      2 0 5.5508E-04 END
C      2 0 5.5508E-04 END
' mtl 3 is aluminum solution vessel, type not
specified
AL     3 0 6.0238E-02 END
' mtl 4 is water reflector, not needed with solns A-F
H2O    4 1.0 END
' mtl 5 is SS reflector vessel, type not specified
SS304  5 1.0 END
END COMP
KENOV.A
READ PARAM
TME=120 GEN=605 NPG=900 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=20
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 19.05 15.14 0.
CYLINDER 0 1 19.05 39.44 0.
CYLINDER 3 1 19.065 39.44 0.0
CYLINDER 2 1 19.065 39.44 -25.57
CYLINDER 0 1 137.16 39.44 -25.57
CYLINDER 5 1 138.2713 39.44 -28.2688
END GEOMETRY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

**E6.1.4 Base Case B3, 218GROUPNDF4/CSAS25/
SCALE4.3**

```
=CSAS25      PARM=SIZE=1000000
ORNL-4280, Experiment B3, no reflector
218GROUPNDF4 INF
' mtl 1 is fissile solution B
H      1 0 6.1184E-02 END
O      1 0 3.5452E-02 END
N      1 0 1.2687E-03 END
U-233  1 0 5.1415E-04 END
U-234  1 0 5.5110E-06 END
U-235  1 0 1.5679E-07 END
U-238  1 0 7.1727E-06 END
' mtl 2 is styrafoam support for cylindrical vessels
H      2 0 5.5508E-04 END
C      2 0 5.5508E-04 END
' mtl 3 is aluminum solution vessel, type not
specified
AL     3 0 6.0238E-02 END
' mtl 4 is water reflector, not needed with solns A-F
H2O    4 1.0 END
' mtl 5 is SS reflector vessel, type not specified
SS304  5 1.0 END
END COMP
KENOV.A
READ PARAM
TME=120 GEN=605 NPG=900 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=20
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 12.65 24.69 0.
CYLINDER 0 1 12.65 48.99 0.
CYLINDER 3 1 12.665 48.99 0.0
CYLINDER 2 1 12.665 48.99 -25.57
CYLINDER 0 1 137.16 48.99 -25.57
CYLINDER 5 1 138.2713 48.99 -28.2688
END GEOMETRY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

**E6.1.5 Base Case C1, 238GROUPNDF5/CSAS25/
SCALE4.3**

```
=CSAS25      PARM=SIZE=1000000
ORNL-4280, Experiment C1, no reflector
238GROUPNDF5 INF
' mtl 1 is fissile solution C
H      1 0 6.4382E-02 END
O      1 0 3.4878E-02 END
N      1 0 6.7002E-04 END
U-233  1 0 3.3016E-04 END
U-234  1 0 3.5389E-06 END
U-235  1 0 1.0068E-07 END
U-238  1 0 4.6060E-06 END
' mtl 2 is styrafoam support for cylindrical vessels
H      2 0 5.5508E-04 END
C      2 0 5.5508E-04 END
' mtl 3 is aluminum solution vessel, type not
specified
AL     3 0 6.0238E-02 END
' mtl 4 is water reflector, not needed with solns A-F
H2O    4 1.0 END
' mtl 5 is SS reflector vessel, type not specified
SS304  5 1.0 END
END COMP
KENOV.A
READ PARAM
TME=120 GEN=605 NPG=900 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=20
END PARAM
READ GEOM
BOX TYPE 1
CYLINDER 1 1 25.40 14.07 0.
```

```
CYLINDER 0 1 25.40 38.37 0.
CYLINDER 3 1 25.415 38.37 0.0
CYLINDER 2 1 25.415 38.37 -25.57
CYLINDER 0 1 137.16 38.37 -25.57
CYLINDER 5 1 138.2713 38.37 -28.2688
```

```
END GEOMETRY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

E6.2 DANTSYS Input

All DANT calculations were performed with S_{16} quadrature and P_3 scattering. Most calculations were also performed with a 10^{-6} convergence criteria.

**E6.2.1 Base Case C, 27GROUPNDF4/CSASI/
SCALE4.3/ONEDANT****Cross Section Processing Input:**

```
=CSASI
ORNL-4280, Experiment C, no reflector
27GROUPNDF4 INF
' mtl 1 is fissile solution C
H      1 0 6.4382E-02 END
O      1 0 3.4878E-02 END
N      1 0 6.7002E-04 END
U-233  1 0 3.3016E-04 END
U-234  1 0 3.5389E-06 END
U-235  1 0 1.0068E-07 END
U-238  1 0 4.6060E-06 END
' mtl 2 is styrafoam support for cylindrical vessels
H      2 0 5.5508E-04 END
C      2 0 5.5508E-04 END
' mtl 3 is aluminum solution vessel, type not
specified
AL     3 0 6.0238E-02 END
' mtl 4 is water reflector, not needed with solns A-F
H2O    4 1.0 END
' mtl 5 is SS reflector vessel, type not specified
SS304  5 1.0 END
END COMP
MORE DATA axs=07 END
END
```

 k_{eff} Calculation Input:

```
1 0 0
ORNL-4280, Experiment C, no reflector
/ Block 1
igeom=sphere ngroup=27 isn=16 niso=5 mt=5 nzone=5
im=4 it=46
maxscm=280000 maxlcm=2600000
T
/ Block 2 (geometry)
xmesh= 0.0 14.579 14.701 39.001 39.636
xints= 30 2 12 2
zones= 1 3 0 5
T
/ Block 3 (cross sections)
lib=f27 writmxs=macbcd
chivec= 0.020 0.195 0.219 0.126 0.164 0.172 0.088
0.014 0.001 0.000001 17z
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lpl=1
T
/ Block 4 (material mixing and assignments)
matls=isos assign=matls
T
/ Block 5 (solver control)
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
```

T
/ Block 6
zned= 1
T

E6.2.2 Base Case I3, 27GROUPNDF4/CSASI/ SCALE4.3/TWODANT

Cross Section Processing Input:

```
=CSASI
ORNL-4280, Experiment I, H2O reflector
27GROUPNDF4 INF
' mtl 1 is fissile solution 1
H      1 0 6.5191E-02 END
O      1 0 3.3909E-02 END
N      1 0 3.5548E-04 END
U-233  1 0 1.2072E-04 END
U-234  1 0 1.2940E-06 END
U-235  1 0 3.6814E-08 END
U-238  1 0 1.6842E-06 END
' mtl 2 is styrafoam support for cylindrical vessels
H      2 0 5.5508E-04 END
C      2 0 5.5508E-04 END
' mtl 3 is aluminum solution vessel, type not
specified
AL      3 0 6.0238E-02 END
' mtl 4 is water reflector, not needed with solns A-F
H2O     4 1.0 END
' mtl 5 is SS reflector vessel, type not specified
SS304   5 1.0 END
END COMP
MORE DATA axs=07 END
END
```

k_{eff} Calculation Input:

```
1 0 0
ORNL-4280, Experiment I3, H2O reflector
/ Block 1
igeom=r-z ngroup=27 isn=16 niso=5 mt=5 nzone=5
im=4 it=171 jm=5 jt=104
maxscm=350000 maxlcm=2600000
T
/ Block 2 (geometry)
xmesh= 0.0 12.65 12.665 137.16 137.795
ymesh= -26.205 -25.57 -1.25 0.0 31.53
55.83
xints= 30 2 137 2
yints= 2 25 2 63 12
zones=
          2R2 4 5;
          2R2 4 5;
          1 3 4 5;
          0 3 4 5
T
/ Block 3 (cross sections)
lib=f27 writmxs=macbcd
chivec= 0.020 0.195 0.219 0.126 0.164 0.172 0.088
0.014 0.001 0.000001 17z
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1
T
/ Block 4 (material mixing and assignments)
matls=isos assign=matls
T
/ Block 5 (solver control)
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
T
/ Block 6
zned= 1
T
```

E6.3 MCNP Input

Most MCNP calculations were performed with 250 generations, 1000 neutrons per generation, skipping the first 15 generations before averaging k_{eff} values. Most MCNP results are therefore based on 235,000 neutron histories. Some cases used more neutron histories, none used fewer.

E6.3.1 97% Enriched in ²³³U Case D, .50c/ MCNP4A

```
ORNL-2480, Exp D, U233-.5%, no reflector
c Cells
1 1 1.00417-01 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 0 +2 -3 -4 +5 imp:n=1
$ void reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

c Surfaces
1 so 15.078 $ vessel inner radius
2 so 15.200 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 39.5 $ reflector vessel (open) top
5 pz -39.5 $ reflector vessel inner bottom
6 cz 137.795 $ reflector vessel outer radius
7 pz -40.135 $ reflector vessel outer bottom

c Data: materials and nuclide densities
m1 92233.50c 2.5579-04 92234.50c 2.7555-06
92235.50c 7.8393-08 92238.50c 3.6042-06
1001.50c 6.5040-02 8016.50c 3.4597-02
7014.50c 5.1669-04 $ U233 solution
mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
$ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304

c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print
```

E6.3.2 98% Enriched in ²³³U Case E, .50c/ MCNP4A

```
ORNL-2480, Exp E, U233+.5%, no reflector
c Cells
1 1 1.00473-01 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 0 +2 -3 -4 +5 imp:n=1
$ void reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

c Surfaces
1 so 15.821 $ vessel inner radius
2 so 15.943 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 40.243 $ reflector vessel (open) top
```

```

5 pz -40.243 $ reflector vessel inner bottom
6 cz 137.795 $ reflector vessel outer radius
7 pz -40.87 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.50c 1.8896-04 92234.50c 2.0153-06
    92235.50c 5.7334-08 92238.50c 2.6098-06
    1001.50c 6.5618-02 8016.50c 3.4295-02
    7014.50c 3.6695-04 $ U233 solution

```

```

mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
    $ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304

```

```

c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print

```

E6.3.3 Specific Gravity -0.5% Case F, .50c/ MCNP4A

ORNL-4280, sp.g.-0.5%, Exp F, no reflector

```

c Cells
1 1 9.8906-02 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 0 +2 -3 -4 +5 imp:n=1
$ void reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 so 18.378 $ vessel inner radius
2 so 18.5 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 42.8 $ reflector vessel (open) top
5 pz -42.8 $ reflector vessel inner bottom
6 cz 137.795 $ reflected vessel outer radius
7 pz -43.435 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.50c 1.1241-04 92234.50c 1.2049-06
    92235.50c 3.4278-08 92238.50c 1.5681-06
    1001.50c 6.5308-02 8016.50c 3.3333-02
    7014.50c 1.4947-04 $ U233 solution

```

```

mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
    $ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304

```

```

c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print

```

E6.3.4 Specific Gravity +0.5% Case G, .50c/ MCNP4A

ORNL-4280, sp.g.+0.5%, Exp G, H2O reflector

```

c Cells
1 1 1.00724-01 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall

```

```

3 4 -0.9982 +2 -3 -4 +5 imp:n=1
$ H2O reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 so 11.17 $ vessel inner radius
2 so 11.292 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 35.592 $ reflector vessel (open) top
5 pz -35.592 $ reflector vessel inner bottom
6 cz 137.795 $ reflected vessel outer radius
7 pz -36.227 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.50c 3.3268-04 92234.50c 3.5660-06
    92235.50c 1.0145-07 92238.50c 4.6411-06
    1001.50c 6.4541-02 8016.50c 3.5120-02
    7014.50c 7.2249-04 $ U233 solution

```

```

mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
    $ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304

```

```

c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print

```

E6.3.5 H: ²³³U -2.5% Case H, .50c/MCNP4A

ORNL-4280, H: ²³³U -2.5%, Exp H, H2O reflector

```

c Cells
1 1 9.91198-02 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 4 -0.9982 +2 -3 -4 +5 imp:n=1
$ H2O reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 so 11.847 $ vessel inner radius
2 so 11.969 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 36.269 $ reflector vessel (open) top
5 pz -36.269 $ reflector vessel inner bottom
6 cz 137.795 $ reflector vessel outer radius
7 pz -36.904 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.50c 2.3943-04 92234.50c 2.5664-06
    92235.50c 7.3013-08 92238.50c 3.3402-06
    1001.50c 6.3731-02 8016.50c 3.4447-02
    7014.50c 6.9690-04 $ U233 solution

```

```

mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
    $ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304

```

```

c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print

```


E6.3.6 H:²³³U +2.5% Case I, .50c/MCNP4A

ORNL-4280, H:²³³U+2.5%, Exp I, H₂O reflector

```

c Cells
1 1 1.01077-01 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 4 -0.9982 +2 -3 -4 +5 imp:n=1
$ H2O reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 so 14.579 $ vessel inner radius
2 so 14.701 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 39.001 $ reflector vessel (open) top
5 pz -39.001 $ reflector vessel inner bottom
6 cz 137.795 $ reflector vessel outer radius
7 pz -39.636 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.50c 1.2072-04 92234.50c 1.2940-06
92235.50c 3.6814-08 92238.50c 1.6842-06
1001.50c 6.6821-02 8016.50c 3.4014-02
7014.50c 1.1874-04 $ U233 solution

```

```

mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
$ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print

```

E6.3.7 1.07 mm Solution Vessel Wall Thickness Case C, .50c/MCNP4A

ORNL-2480, wall-12.5%, Exp C, no reflector

```

c Cells
1 1 1.00268-01 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 0 +2 -3 -4 +5 imp:n=1
$ void reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 so 14.579 $ vessel inner radius
2 so 14.686 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 39.001 $ reflector vessel (open) top
5 pz -39.001 $ reflector vessel inner bottom
6 cz 137.795 $ reflector vessel outer radius
7 pz -39.636 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.50c 3.3016-04 92234.50c 3.5389-06
92235.50c 1.0068-07 92238.50c 4.6060-06
1001.50c 6.4382-02 8016.50c 3.4878-02
7014.50c 6.7002-04 $ U233 solution

```

```

mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
$ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel

```

```

m4 1001.50c 2 8016.50c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print

```

E6.3.8 1.37 mm Solution Vessel Wall Thickness Case D, .50c/MCNP4A

ORNL-2480, wall+12.5%, Exp D, no reflector

```

c Cells
1 1 1.00417-01 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 0 +2 -3 -4 +5 imp:n=1
$ void reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 so 15.078 $ vessel inner radius
2 so 15.215 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 39.5 $ reflector vessel (open) top
5 pz -39.5 $ reflector vessel inner bottom
6 cz 137.795 $ reflector vessel outer radius
7 pz -40.135 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.50c 2.5707-04 92234.50c 2.7555-06
92235.50c 7.8393-08 92238.50c 3.5863-06
1001.50c 6.5040-02 8016.50c 3.4597-02
7014.50c 5.1669-04 $ U233 solution

```

```

mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
$ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 1. $ start near soln center
print

```

E6.3.9 Solution Vessel Radius -1% Case E, .50c/MCNP4A

ORNL-2480, Exp E, IR-1%, no reflector

```

c Cells
1 1 1.00473-01 -1 imp:n=1
$ U233 solution
2 3 -2.6989 +1 -2 imp:n=1
$ Al vessel wall
3 0 +2 -3 -4 +5 imp:n=1
$ void reflector
4 5 -7.92 -4 -6 +7 (+3:-5) imp:n=1
$ SS reflector vessel
5 0 +4:+6:-7 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 so 15.663 $ vessel inner radius
2 so 15.785 $ vessel outer radius
3 cz 137.16 $ reflector vessel inner radius
4 pz 40.243 $ reflector vessel (open) top
5 pz -40.243 $ reflector vessel inner bottom

```

```

6  cz  137.795  $ reflector vessel outer radius
7  pz  -40.87   $ reflector vessel outer bottom

```

```

c  Data: materials and nuclide densities
m1 92233.50c 1.8802-04 92234.50c 2.0153-06
    92235.50c 5.7334-08 92238.50c 2.6229-06
    1001.50c 6.5618-02 8016.50c 3.4295-02
    7014.50c 3.6695-04 $ U233 solution

```

```

mt1 lwtr.01t
m2  1001.50c 1      6000.50c 1
    $ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4  1001.50c 2      8016.50c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304

```

```

c  Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc  1. 1. 1. $ start near soln center
print

```

E6.3.10 Solution Vessel Radius+1% Case F, .50c/ MCNP4A

ORNL-2480, Exp F, IR+1%, no reflector

```

c  Cells
1  1  9.91096-02  -1      imp:n=1 $
U233 solution
2  3  -2.6989     +1 -2    imp:n=1 $ Al
vessel wall
3  0              +2 -3 -4 +5 imp:n=1 $
void reflector
4  5  -7.92       -4 -6 +7 (+3:-5) imp:n=1 $ SS
reflector vessel
5  0              +4:+6:-7    imp:n=0 $
void outside reflector vessel

```

```

c  Surfaces
1  so  18.562  $ vessel inner radius
2  so  18.684  $ vessel outer radius
3  cz  137.16  $ reflector vessel inner radius
4  pz  42.8    $ reflector vessel (open) top
5  pz  -42.8   $ reflector vessel inner bottom
6  cz  137.795 $ reflector vessel outer radius
7  pz  -43.435 $ reflector vessel outer bottom

```

```

c  Data: materials and nuclide densities
m1 92233.50c 1.1241-04 92234.50c 1.2049-06
    92235.50c 3.4278-08 92238.50c 1.5681-06
    1001.50c 6.5308-02 8016.50c 3.3486-02
    7014.50c 2.0036-04 $ U233 solution

```

```

mt1 lwtr.01t
m2  1001.50c 1      6000.50c 1
    $ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4  1001.50c 2      8016.50c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304

```

```

c  Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc  1. 1. 1. $ start near soln center
print

```

E6.3.11 Solution Vessel Bottom Case C2, .50c/ MCNP4A

ORNL-2480, Experiment C2, no reflector

```

c  Cells
1  1  1.00268-01  -1 +2 -3    imp:n=1
2  0              -1 +3 -4    imp:n=1
3  3  -2.6989     -5 +6 -4 (+1:-2) imp:n=1
4  2  -0.024      -5 -6 +9    imp:n=1
5  0              -4 -7 +9 (+5)  imp:n=1

```

```

6  5  -7.92       -4 -8 +10 (+7:-9) imp:n=1
7  0              +4:+8:-10    imp:n=0

```

```

c  Surfaces
1  cz  19.05
2  pz  0.0
3  pz  16.33
4  pz  40.63
5  cz  19.065
6  pz  -1.27
7  cz  137.16
8  cz  137.795
9  pz  -25.57
10 pz  -26.205

```

```

c  Data: materials and nuclide densities
m1 92233.50c 3.3016-04 92234.50c 3.5389-06
    92235.50c 1.0068-07 92238.50c 4.6060-06
    1001.50c 6.4382-02 8016.50c 3.4878-02
    7014.50c 6.7002-04

```

```

mt1 lwtr.01t
m2  1001.50c 1      6000.50c 1
m3 13027.50c 6.0238-02
m4  1001.50c 2      8016.50c 1
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03

```

```

c  Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc  1. 1. 8.2 $ start near soln center
print

```

E6.3.12 Solution Height-5mm Case C3, .50c/ MCNP4A

ORNL-2480, ht-5mm, Exp C3, no reflector

```

c  Cells
1  1  1.00268-01  -1 +2 -3    imp:n=1
$ U233 solution
2  0              -1 +3 -4    imp:n=1
$ void above solution in vessel
3  3  -2.6989     -5 -4 +1 +2  imp:n=1
$ Al vessel wall (no bottom)
4  2  -0.024      -5 -2 +9    imp:n=1
$ styrafoam support
5  0              -4 -7 +9 (+5) imp:n=1
$ void reflector
6  5  -7.92       -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7  0              +4:+8:-10    imp:n=0
$ void outside reflector vessel

```

```

c  Surfaces
1  cz  12.65  $ vessel inner radius
2  pz  0.0    $ vessel inner bottom
3  pz  28.02  $ U233 solution level
4  pz  52.82  $ vessel top
5  cz  12.665 $ vessel outer radius
6  pz  -1.27  $ vessel outer bottom
7  cz  137.16 $ reflector vessel inner radius
8  cz  137.795 $ reflector vessel outer radius
9  pz  -25.57 $ reflector vessel inner bottom
10 pz  -26.205 $ reflector vessel outer bottom

```

```

c  Data: materials and nuclide densities
m1 92233.50c 3.3016-04 92234.50c 3.5389-04
    92235.50c 1.0068-07 92238.50c 4.6060-06
    1001.50c 6.4382-02 8016.50c 3.4878-02
    7014.50c 6.7002-04 $ U233 solution

```

```

mt1 lwtr.01t
m2  1001.50c 1      6000.50c 1
    $ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4  1001.50c 2      8016.50c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304

```

```

c  Data: run control

```

```
kcode 1000 1.0 30 500 $ k-eff calc
ksrc 1. 1. 14.25 $ start near soln center
print
```

E6.3.13 Solution Height+5mm Case D2, .50c/ MCNP4A

```
ORNL-2480, ht+5mm, Exp D2, no reflector
c Cells
1 1 1.00417-01 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall (no bottom)
4 2 -0.024 -5 -2 +9 imp:n=1
$ styrafoam support
5 0 -4 -7 +9 (+5) imp:n=1
$ void reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel
```

```
c Surfaces
1 cz 19.05 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 18.10 $ U233 solution level
4 pz 41.90 $ vessel top
5 cz 19.065 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom
```

```
c Data: materials and nuclide densities
m1 92233.50c 2.5707-04 92234.50c 2.7555-06
92235.50c 7.8393-08 92238.50c 3.5863-06
1001.50c 6.5040-02 8016.50c 3.4597-02
7014.50c 5.1669-04 $ U233 solution
mt1 lwtr.01t
m2 1001.50c 1 6000.50c 1
$ Styrafoam support
m3 13027.50c 6.0238-02 $ Al solution vessel
m4 1001.50c 2 8016.50c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.50c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 30 500 $ k-eff calc
ksrc 1. 1. 8.5 $ start near soln center
print
```

E6.3.14 Base Case D3, .60c/MCNP4A

```
ORNL-2480, Experiment D3, no reflector
c Cells
1 1 1.00417-01 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall (no bottom)
4 2 -0.024 -5 -2 +9 imp:n=1
$ styrafoam support
5 0 -4 -7 +9 (+5) imp:n=1
$ void reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel
```

```
c Surfaces
1 cz 12.65 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
```

```
3 pz 33.40 $ U233 solution level
4 pz 57.70 $ vessel top
5 cz 12.665 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom
```

```
c Data: materials and nuclide densities
m1 92233.60c 2.5707-04 92234.60c 2.7555-06
92235.60c 7.8393-08 92238.60c 3.5863-06
1001.60c 6.5040-02 8016.60c 3.4597-02
7014.60c 5.1669-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
$ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2 8016.60c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 16.5 $ start near soln center
print
```

E6.3.15 Base Case E2, .60c/MCNP4A

```
ORNL-2480, Experiment E2, no reflector
c Cells
1 1 1.00473-01 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall (no bottom)
4 2 -0.024 -5 -2 +9 imp:n=1
$ styrafoam support
5 0 -4 -7 +9 (+5) imp:n=1
$ void reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel
```

```
c Surfaces
1 cz 19.05 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 19.35 $ U233 solution level
4 pz 43.65 $ vessel top
5 cz 19.065 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom
```

```
c Data: materials and nuclide densities
m1 92233.60c 1.8802-04 92234.60c 2.0153-06
92235.60c 5.7334-08 92238.60c 2.6229-06
1001.60c 6.5618-02 8016.60c 3.4295-02
7014.60c 3.6695-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
$ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2 8016.60c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 10. $ start near soln center
print
```

E6.3.16 Base Case E3, .60c/MCNP4A

```

ORNL-2480, Experiment E3, no reflector
c  Cells
1  1  1.00473-01  -1 +2 -3      imp:n=1
$ U233 solution
2  0                      -1 +3 -4      imp:n=1
$ void above solution in vessel
3  3  -2.6989      -5 -4 +1 +2      imp:n=1
$ Al vessel wall (no bottom)
4  2  -0.024      -5 -2 +9      imp:n=1
$ styrafoam support
5  0                      -4 -7 +9 (+5)      imp:n=1
$ air reflector
6  5  -7.92      -4 -8 +10 (+7:-9)      imp:n=1
$ SS reflector vessel
7  0                      +4:+8:-10      imp:n=0
$ void outside reflector vessel

```

```

c  Surfaces
1  cz  12.65      $ vessel inner radius
2  pz  0.0      $ vessel inner bottom
3  pz  43.69      $ U233 solution level
4  pz  67.99      $ vessel top
5  cz  12.665      $ vessel outer radius
6  pz  -1.27      $ vessel outer bottom
7  cz  137.16      $ reflector vessel inner radius
8  cz  137.795      $ reflector vessel outer radius
9  pz  -25.57      $ reflector vessel inner bottom
10 pz  -26.205      $ reflector vessel outer bottom

```

```

c  Data: materials and nuclide densities
m1 92233.60c 1.8802-04 92234.60c 2.0153-06
    92235.60c 5.7334-08 92238.60c 2.6229-06
    1001.60c 6.5618-02 8016.60c 3.4295-02
    7014.60c 3.6695-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1      6000.60c 1
    $ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2      8016.60c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304
c  Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 10. $ start near soln center
print

```

E6.3.17 Base Case F2, .60c/MCNP4A

```

ORNL-2480, Experiment F2, no reflector
c  Cells
1  1  9.91096-02  -1 +2 -3      imp:n=1
$ U233 solution
2  0                      -1 +3 -4      imp:n=1
$ void above solution in vessel
3  3  -2.6989      -5 -4 +1 +2      imp:n=1
$ Al vessel wall (no bottom)
4  2  -0.024      -5 -2 +9      imp:n=1
$ styrafoam support
5  0                      -4 -7 +9 (+5)      imp:n=1
$ void reflector
6  5  -7.92      -4 -8 +10 (+7:-9)      imp:n=1
$ SS reflector vessel
7  0                      +4:+8:-10      imp:n=0
$ void outside reflector vessel

```

```

c  Surfaces
1  cz  19.05      $ vessel inner radius
2  pz  0.0      $ vessel inner bottom
3  pz  26.37      $ U233 solution level
4  pz  50.67      $ vessel top
5  cz  19.065      $ vessel outer radius
6  pz  -1.27      $ vessel outer bottom
7  cz  137.16      $ reflector vessel inner radius
8  cz  137.795      $ reflector vessel outer radius

```

```

9  pz  -25.57      $ reflector vessel inner bottom
10 pz  -26.205      $ reflector vessel outer bottom

```

```

c  Data: materials and nuclide densities
m1 92233.60c 1.1241-04 92234.60c 1.2049-06
    92235.60c 3.4278-08 92238.60c 1.5681-06
    1001.60c 6.5308-02 8016.60c 3.3486-02
    7014.60c 2.0036-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1      6000.60c 1
    $ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2      8016.60c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304
c  Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 13.2 $ start near soln center
print

```

E6.3.18 Base Case G2, .60c/MCNP4A

```

ORNL-2480, Experiment G2, H2O reflector
c  Cells
1  1  1.00494-01  -1 +2 -3      imp:n=1
$ U233 solution
2  0                      -1 +3 -4      imp:n=1
$ void above solution in vessel
3  3  -2.6989      -5 -4 +1 +2      imp:n=1
$ Al vessel wall (no bottom)
4  2  -0.024      -5 -2 +9      imp:n=1
$ styrafoam support
5  4  -0.9982      -4 -7 +9 (+5)      imp:n=1
$ H2O reflector
6  5  -7.92      -4 -8 +10 (+7:-9)      imp:n=1
$ SS reflector vessel
7  0                      +4:+8:-10      imp:n=0
$ void outside reflector vessel

```

```

c  Surfaces
1  cz  19.05      $ vessel inner radius
2  pz  0.0      $ vessel inner bottom
3  pz  13.42      $ U233 solution level
4  pz  37.72      $ vessel top
5  cz  19.065      $ vessel outer radius
6  pz  -1.27      $ vessel outer bottom
7  cz  137.16      $ reflector vessel inner radius
8  cz  137.795      $ reflector vessel outer radius
9  pz  -25.57      $ reflector vessel inner bottom
10 pz  -26.205      $ reflector vessel outer bottom

```

```

c  Data: materials and nuclide densities
m1 92233.60c 3.3268-04 92234.60c 3.5660-06
    92235.60c 1.0145-07 92238.60c 4.6411-06
    1001.60c 6.4541-02 8016.60c 3.4947-02
    7014.60c 6.6500-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1      6000.60c 1
    $ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2      8016.60c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304
c  Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 7.5 $ start near soln center
print

```

E6.3.19 Base Case G3, .60c/MCNP4A

```

ORNL-2480, Experiment G3, H2O reflector
c  Cells
1  1  1.00494-01  -1 +2 -3      imp:n=1 $

```

```

U233 solution
2 0 -1 +3 -4 imp:n=1 $
void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1 $
Al vessel wall (no bottom)
4 2 -0.024 -5 -2 +9 imp:n=1 $
styrafoam support
5 4 -0.9982 -4 -7 +9 (+5) imp:n=1 $
H2O reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1 $
SS reflector vessel
7 0 +4:+8:-10 imp:n=0 $
void outside reflector vessel

```

```

c Surfaces
1 cz 12.65 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 17.22 $ U233 solution level
4 pz 41.52 $ vessel top
5 cz 12.665 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.60c 3.3268-04 92234.60c 3.5660-06
    92235.60c 1.0145-07 92238.60c 4.6411-06
    1001.60c 6.4541-02 8016.60c 3.4947-02
    7014.60c 6.6500-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
    $ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2 8016.60c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 8.6 $ start near soln center
print

```

E6.3.20 Base Case G4, .60c/MCNP4A

```

ORNL-2480, Experiment G4, H2O reflector
c Cells
1 1 1.00494-01 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall (no bottom)
4 2 -0.024 -5 -2 +9 imp:n=1
$ styrafoam support
5 4 -0.9982 -4 -7 +9 (+5) imp:n=1
$ H2O reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 cz 10.15 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 22.86 $ U233 solution level
4 pz 47.16 $ vessel top
5 cz 10.165 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.60c 3.3268-04 92234.60c 3.5660-06
    92235.60c 1.0145-07 92238.60c 4.6411-06

```

```

1001.60c 6.4541-02 8016.60c 3.4947-02
7014.60c 6.6500-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
    $ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2 8016.60c
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 5. $ start near soln center
print

```

E6.3.21 Base Case H3, .60c/MCNP4A

```

ORNL-2480, Experiment H3, H2O reflector
c Cells
1 1 1.00622-01 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall (no bottom)
4 2 -0.024 -5 -2 +9 imp:n=1
$ styrafoam support
5 4 -0.9982 -4 -7 +9 (+5) imp:n=1
$ H2O reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel

```

```

c Surfaces
1 cz 12.65 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 19.67 $ U233 solution level
4 pz 43.97 $ vessel top
5 cz 12.665 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom

```

```

c Data: materials and nuclide densities
m1 92233.60c 2.3943-04 92234.60c 2.5664-06
    92235.60c 7.3013-08 92238.60c 3.3402-06
    1001.60c 6.5365-02 8016.60c 3.4552-02
    7014.60c 4.5953-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
    $ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2 8016.60c 1
    $ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
    26000.55c 5.9358-02 28000.50c 7.7207-03
    $ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 8.6 $ start near soln center
print

```

E6.3.22 Base Case H4, .60c/MCNP4A

```

ORNL-2480, Experiment H4, H2O reflector
c Cells
1 1 1.00622-01 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall without bottom
4 2 -0.024 -5 -2 +9 imp:n=1

```

```

$ styrafoam support
5 4 -0.9982 -4 -7 +9 (+5) imp:n=1
$ H2O reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel

c Surfaces
1 cz 10.15 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 27.02 $ U233 solution level
4 pz 51.32 $ vessel top
5 cz 10.165 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom

c Data: materials and nuclide densities
m1 92233.60c 2.3943-04 92234.60c 2.5664-06
92235.60c 7.3013-08 92238.60c 3.3402-06
1001.60c 6.5365-02 8016.60c 3.4552-02
7014.60c 4.5953-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
$ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2 8016.60c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 5.1 $ start near soln center
print

```

E6.3.23 Base Case I2, .60c/MCNP4A

```

ORNL-2480, Experiment I2, H2O reflector
c Cells
1 1 9.95795-02 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall no bottom
4 2 -0.024 -5 -2 +9 imp:n=1
$ styrafoam support
5 4 -0.9982 -4 -7 +9 (+5) imp:n=1
$ H2O reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel

c Surfaces
1 cz 19.05 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 19.60 $ U233 solution level
4 pz 43.90 $ vessel top
5 cz 19.065 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom

c Data: materials and nuclide densities
m1 92233.60c 1.2072-04 92234.60c 1.2940-06
92235.60c 3.6814-08 92238.60c 1.6842-06
1001.60c 6.5191-02 8016.60c 3.3909-02
7014.60c 3.5548-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
$ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel

```

```

m4 1001.60c 2 8016.60c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
3 4 -0.9982 +2 -3 -4 +5 imp:n=1 $
H2O reflector
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 9.8 $ start near soln center
print

```

E6.3.24 Base Case I3, .60c/MCNP4A

```

ORNL-2480, Experiment I3, H2O reflector
c Cells
1 1 9.95795-02 -1 +2 -3 imp:n=1
$ U233 solution
2 0 -1 +3 -4 imp:n=1
$ void above solution in vessel
3 3 -2.6989 -5 -4 +1 +2 imp:n=1
$ Al vessel wall no bottom
4 2 -0.024 -5 -2 +9 imp:n=1
$ styrafoam support
5 4 -0.9982 -4 -7 +9 (+5) imp:n=1
$ H2O reflector
6 5 -7.92 -4 -8 +10 (+7:-9) imp:n=1
$ SS reflector vessel
7 0 +4:+8:-10 imp:n=0
$ void outside reflector vessel

c Surfaces
1 cz 12.65 $ vessel inner radius
2 pz 0.0 $ vessel inner bottom
3 pz 31.53 $ U233 solution level
4 pz 55.83 $ vessel top
5 cz 12.665 $ vessel outer radius
6 pz -1.27 $ vessel outer bottom
7 cz 137.16 $ reflector vessel inner radius
8 cz 137.795 $ reflector vessel outer radius
9 pz -25.57 $ reflector vessel inner bottom
10 pz -26.205 $ reflector vessel outer bottom

c Data: materials and nuclide densities
m1 92233.60c 1.2072-04 92234.60c 1.2940-06
92235.60c 3.6814-08 92238.60c 1.6842-06
1001.60c 6.5191-02 8016.60c 3.3909-02
7014.60c 3.5548-04 $ U233 solution
mt1 lwtr.01t
m2 1001.60c 1 6000.60c 1
$ Styrafoam support
m3 13027.60c 6.0238-02 $ Al solution vessel
m4 1001.60c 2 8016.60c 1
$ H2O reflector
mt4 lwtr.01t
m5 24000.50c 1.7429-02 25055.60c 1.7363-03
26000.55c 5.9358-02 28000.50c 7.7207-03
$ SS reflector vessel, SS304
c Data: run control
kcode 1000 1.0 15 250 $ k-eff calc
ksrc 1. 1. 15.7 $ start near soln center
print

```

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Appendix F

^{233}U Jezebel Experiment and Calculations

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F1 Experiment

Several experiments approximating an ideal, unreflected, metal-sphere system were performed in 1961 with the ^{233}U Jezebel Assembly at Los Alamos. Experiments and analysis were publicly reported in LA-4208, which incorporated several correction factors to provide data for an ideal, unreflected, ^{233}U -metal sphere. Brewer reanalyzed data, corrections, and results for identification number U233-MET-FAST-001 of the *Benchmark Handbook*. Summarized in Figure 6 (page 17) and Tables F-1 and F-2, Brewer's idealized description is used here. The benchmark experiment is reported to have $k_{\text{eff}} = 1.000 \pm 0.001$. Tables F-3 and F-4 respectively list correction factors and impurity information. Additional descriptions are provided in the *Benchmark Handbook* and its references.

Table F-1 ^{233}U Jezebel Experiment Critical Mass and Dimensions		
	Uranium M_c (kg)	Outer Radius (cm) ^a
measured	16.252	5.9495
benchmark minimum ^b	16.469	5.9758
benchmark nominal	16.535	5.9838
benchmark maximum ^b	16.601	5.9918

a Calculated from critical mass and density.

b Uncertainty is $\pm 66\text{g}$, or $\pm 0.40\%$.

Table F-2 ^{233}U Jezebel Material Composition (mass density = 18.424 g/cm^3)		
Nuclide SCALE # [MCNP #]	atom%	N_n (particles/b-cm) ^a
U-233 [92233]	98.13	4.6712E-02
U-234 [92234]	1.24	5.9026E-04
U-235 [92235]	0.03	1.4281E-05
U-238 [92238]	0.60	2.8561E-04

a Values from *Benchmark Handbook*. Independently calculated values were essentially the same, for example, within 0.1% for ^{233}U . Therefore, *Benchmark Handbook* values were used in models here.

Table F-3 ^{233}U Jezebel Corrections to Obtain Benchmark	
Description	Mass (kg)
Critical Mass of Experimental Configuration ($\rho = 18.424 \text{ g/cm}^3$)	16.252
Corrections:	
asphericity	-0.044
internal nickel (surface plating) & homogenization	0.023
equatorial band	0.110
polar supports	0.108
external nickel (surface plating)	0.072
framework	0.002
building-wall reflection	0.008
air reflection	0.004
trace impurities	0
elevated temperatures	0
Critical Mass of Homogeneous Configuration ($\rho = 18.424 \text{ g/cm}^3$)	$16.535 \pm 0.4\%$

Table F-4 ^{233}U Jezebel Uranium Impurities ^a		
Nuclide	ppm	N_n (particles/b-cm)
Carbon	160	1.4780E-5
Silicon	110	4.3455E-5
Iron	70	1.3907E-5
Others (not specified)	60	not specified

^a Included for completeness. Not used in calculational models.

Table F-5 ^{233}U Jezebel Critical-Mass-Uncertainty Effects		
Model	44GROUPNDF5/CSASI/ SCALE4.3/ONEDANT k_{eff}	44GROUPNDF5/ CSAS25/SCALE4.3 $k_{\text{eff}} \pm 1\sigma$
measured M_c and dimensions	0.9914	0.9887 ± 0.0014
benchmark minimum M_c	0.9949	0.9919 ± 0.0014
benchmark nominal M_c (base case, Table F-6, page F-6)	0.9960	0.9925 ± 0.0014
benchmark maximum M_c	0.9971	0.9965 ± 0.0015
Δk_{eff}^a	± 0.0011	± 0.0023

^a Averaged Δk_{eff} here is 0.002, compared to a benchmark experimental $k_{\text{eff}} = 1.000 \pm 0.001$.

F2 Model

The base case model exactly represents the benchmark experiment description. Independently calculated radius and ^{233}U atom density indicate INEEL methods produce essentially the same model, with less than 0.1% difference in the ^{233}U atom density. Therefore, the *Benchmark Handbook* model was used here although its sample input listings were not used.

F3 Uncertainty and Sensitivity Effects

The *Benchmark Handbook* benchmark description incorporates correction factors to idealize the system. Reproduced from the *Benchmark Handbook*, Table F-3 lists correction factors which provide insight into effects of small variations in experiment parameters. Table F-5 summarizes results obtained here over the range of critical mass uncertainty. For this case, averaged uncertainty in calculated k_{eff} (± 0.002) exceeds reported uncertainty in benchmark k_{eff} (1.000 ± 0.001).

F4 Library-and-Code Combination Effects

Tables F-6 and F-7 respectively list calculation results for various library-and-code combinations, and for adjusted base-case models to identify difference sources between results with ENDF/B-IV- and ENDF/B-V-based cross-section libraries.

Hansen-Roach/CSAS25/SCALE4.3 and *.60c/MCNP4A* respectively seem to be the best and second best combinations for this benchmark. Results indicate calculations with libraries based on *Hansen-Roach*, ENDF/B-V, or ENDF/B-VI data are within 1% of critical but calculations with libraries based on ENDF/B-IV data are within 4% of critical. Table F-7 indicates the difference is attributable to ^{233}U cross-section data in SCALE libraries. Based on conversations with code developers and testers, the difference is consistent with differences between this fast experiment and assumptions in building respective SCALE libraries.^a

F5 Analysis Conclusions

Table 11 (page 18) lists recommended biases for calculations validated with this experiment. Recommendations incorporate experimental-uncertainty effects but not calculation-statistical-uncertainty effects so that a traditional $k_{\text{eff}} + 2\sigma + \text{bias}$ formula can be used for criticality safety evaluations. Averaged INEEL-calculated effects of ^{233}U -Jezebel-experiment cumulative uncertainty, ± 0.002 , are not necessarily within typical INEEL-Monte-Carlo-calculation uncertainties because typical σ s exceed ± 0.0014 by only a small amount.

^a Calvin M Hopper, telephone conversations, June and July, 1996; Cecil V. Parks and Lester J. Petrie, separate world-wide internet electronic mail replies, "Re: U233 Cross-Sections," October 21, 1996; and Robert Michael Westfall, telephone conversations, June, 1996.

Table F-6 Library-and-Code-Combination Comparison for ²³³ U Jezebel		
Combination	$k_{\text{eff}} \pm 1\sigma$	Notes
27Grev/CSASI/SCALE4.0/ONEDANT	0.9635	Benchmark Handbook input sample: ²³⁵ U chi, 48 quadrature, 200 points evenly spaced along radius. Benchmark Handbook $k_{\text{eff}} = 0.9635$
27Grev/CSASI/SCALE4.0/ONEDANT	0.9645	16 quadrature, 120 points fairly evenly spaced along r with slightly closer spacing near max radius
27GROUPNDF4/CSASI/SCALE4.3/ONEDANT	0.9645	except for library source, same as 27Grev/CSASI/SCALE4.0/ONEDANT
27Grev/CSAS25/SCALE4.0	0.9634 ± 0.0014	avg = 4.74867 ± 0.0034
27GROUPNDF4/CSAS25/SCALE4.3	0.9635 ± 0.0015	ale (ev) = 950873 ± 2231.98 , avg = 4.75585 ± 0.0035
218G(4.0)/CSAS25/SCALE4.0	0.9633 ± 0.0014	avg = 16.9545 ± 0.0246
218GROUPNDF4/CSAS25/SCALE4.3	0.9613 ± 0.0014	ale (ev) = 996579 ± 2331.83 , avg = 16.9445 ± 0.0240
44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	0.9960	except for library source, same as 27Grev/CSASI/SCALE4.0/ONEDANT
44GROUPNDF5/CSAS26/SCALE4.3	0.9925 ± 0.0014	ale (ev) = 1082320 ± 2406.07 , avg = 7.94599 ± 0.0053
238GROUPNDF5/CSAS25/SCALE4.3	0.9906 ± 0.0014	ale (ev) = 1126680 ± 2540.87 , avg = 22.5160 ± 0.0241
.50c/MCNP4A	0.9916 ± 0.0014	none
.60c/MCNP4A	0.9940 ± 0.0013	except for library source, same as .50c/MCNP4A
Hansen-Roach/CSAS25/SCALE4.3	1.0036 ± 0.0016	ale (ev) = 1003240 ± 2522.70 , avg = 3.09053 ± 0.0029

Table F-7 27GROUPNDF4 and 44GROUPNDF5 Library and Nuclide Effects		
Model Description	Library-and-Code Combination	$k_{\text{eff}} \pm 1\sigma$
Base Case (Table F-6)	27GROUPNDF4/CSAS25/SCALE4.3	0.9635 ± 0.0015
	44GROUPNDF5/CSAS26/SCALE4.3	0.9925 ± 0.0014
Delete ²³⁸ U from Base Case without changing other nuclide densities	27GROUPNDF4/CSAS25/SCALE4.3	0.9638 ± 0.0013
	44GROUPNDF5/CSAS26/SCALE4.3	0.9949 ± 0.0014
Delete ²³⁵ U from Base Case without changing other nuclide densities	27GROUPNDF4/CSAS25/SCALE4.3	0.9645 ± 0.0015
	44GROUPNDF5/CSAS26/SCALE4.3	0.9943 ± 0.0014
Delete ²³⁴ U from Base Case without changing other nuclide densities	27GROUPNDF4/CSAS25/SCALE4.3	0.9556 ± 0.0015
	44GROUPNDF5/CSAS26/SCALE4.3	0.9887 ± 0.0014
Delete ²³³ U from Base Case without changing other nuclide densities	27GROUPNDF4/CSAS25/SCALE4.3	0.0100 ± 0.0001
	44GROUPNDF5/CSAS26/SCALE4.3	0.0106 ± 0.0001

F6 Sample Inputs

Some single lines of input are listed here on multiple lines due to report's column width. Use caution in regenerating code inputs from these listings.

F6.1 SCALE Input: Jezebel, 238GROUPNDF5/CSAS25/SCALE4.3

SCALE calculations were performed with 405 generations, 800 neutrons per generation, skipping 5 generations before averaging k_{eff} values. Results are therefore based on 320,000 neutron histories.

```
=CSAS25      PARM=SIZE=1000000
Jezebel, 16.535 kg sphere, unreflected
238GROUPNDF5 INF
U-233      1 0      4.6712E-02  END
U-234      1 0      5.9026E-04  END
U-235      1 0      1.4281E-05  END
U-238      1 0      2.8561E-04  END
END COMP
KENOV.A
READ PARAM
TME=60      GEN=405  NPG=800  FLX=YES  FDN=YES
PKI=YES     FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE 1 1      5.9838
END GEOMETRY
END DATA
END
```

F6.2 ONEDANT Input: Jezebel, 27Grev/ CSASI/SCALE4.0/ONEDANT

DANT calculations were performed with S_{16} quadrature, P_3 scattering, and a 10^{-6} convergence criteria.

Cross Section Processing Input:

```
=CSASI
Jezebel, 16.535kgSphere, r=5.9838cm, unreflected
27GROUPNDF4 INF
U-233      1 0      4.6712E-02  END
U-234      1 0      5.9026E-04  END
U-235      1 0      1.4281E-05  END
U-238      1 0      2.8561E-04  END
END COMP
END
```

k_{eff} Calculation Input:

```
1 0 0
Jezebel, 16.535U233kgSphere, r=5.9838cm, unreflected
/ Block 1
igeom=sphere ngroup=27 isn=16 niso=1 mt=1 nzone=1
im=12 it=120
maxscm=50000 maxlcm=850000
T
/ Block 2 (geometry)
/ set up 12 course mesh intervals in sphere
xmesh= 0.0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 5.9838
xints= 12R 10
zones= 12R1
T
/ Block 3 (cross sections)
```

```
lib=f27 writmxs=macbcd
chivec= 0.020 0.195 0.219 0.126 0.164 0.172 0.088
        0.014 0.001 0.000001 17z
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1
T
/ Block 4 (material mixing and assignments)
matls=isos assign=matls
T
/ Block 5 (solver control)
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
T
/ Block 6
zned= 1
T
```

F6.3 MCNP Inputs, .50c/MCNP4A

MCNP calculations were performed with 250 generations, 1000 neutrons per generation, skipping the first 15 generations before averaging k_{eff} values. Results are therefore based on 235,000 neutron histories.

```
Jezebel, 16.535 kg sphere, unreflected
C Cells
1 1 4.7602151E-02 -1 imp:n=1 $ U233 core
2 0 +1 imp:n=0 $ void

C Surfaces
1 so 5.9838

C Data: materials and nuclide densities
m1 92233.50c 4.6712E-02 92234.50c 5.9026E-04
    92235.50c 1.4281E-05 92238.50c 2.8561E-04
C Data: calc control
kcode 1000 1.0 15 200 $ k-eff calc
ksrc 0 0 0 $ start neutrons at center
print
```


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Appendix G

^{233}U Flattop Experiment and Calculations

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G1 Experiment

During 1964 an experiment comprised of two critical ^{233}U configurations was performed on the Flattop critical assembly machine. A final critical mass and idealized experiment description were determined by averaging critical configurations. The benchmark experiment is a spherical, ^{233}U metal core enclosed in a tight-fitting, concentric, natural-uranium shell.

Brewer evaluated these configurations and idealization for the *Benchmark Handbook* (evaluation U233-MET-FAST-006), incorporating information from several sources (Barton, et. al.; Hansen and Wood; LA-4208; LA-3067-MS; and LA-CP-92-235) and accumulating experiment-uncertainty affects in a ± 30 g uncertainty in critical mass. The resultant benchmark experiment is reported to have a k_{eff} of 1.0000 ± 0.0014 .

Figure 7 (page 19) and Tables G-1 and G-2 summarize Brewer's revised ^{233}U Flattop benchmark experiment, used here. The *Benchmark Handbook* provides additional information.

Table G-1 ^{233}U Flattop Materials				
Material	ρ (g/cm ³)	Nuclide SCALE # [MCNP #]	wt%	N_n (particles/b-cm) ^a
^{233}U sphere (core)	18.42	U-233 [92233]	98.13	4.6710E-02
		U-234 [92234]	1.24	5.8772E-04
		U-235 [92235]	0.03	1.4158E-05
		U-238 [92238]	0.60	2.7959E-04
normal U shell (reflector)	19.00	U-235 [92235]	0.72	3.5050E-04
		U-238 [92238]	99.28	4.7719E-02

a Values from *Benchmark Handbook*. Independently calculated values were essentially the same. For example, values were within 0.1% for ^{233}U . Therefore, *Benchmark Handbook* are used in models here.

Table G-2 ^{233}U Flattop Mass and Dimensions			
	Total U M_c (kg)	Calculated Outer Radius (cm)	
		Core	Reflector
^{233}U Jezebel mass density, Flattop nominal mass	5.740	4.2055	24.1191
benchmark minimum	5.710	4.1984	24.1120
benchmark nominal	5.740	4.2058	24.1194
benchmark maximum	5.770	4.2131	24.1267

G2 Model

The calculational model exactly represents the benchmark experiment. Table G-1 includes atom densities calculated from the experiment description. Independently calculated radii and ²³³U atom density indicate INEEL methods produce essentially the same model as the *Benchmark Handbook*, with less than 0.1% difference in ²³³U atom density. The *Benchmark Handbook* model is therefore used here but its sample input listings are not used.

G3 Uncertainty and Sensitivity Effects

Table G-3 summarizes calculations to determine critical-mass-uncertainty effects, which incorporates all experiment uncertainties. This cumulative uncertainty effect is less than 0.005 nonconservative in $\Delta k_{\text{eff,calc}}$, slightly greater than the calculation method's statistical uncertainty.

Readers should be aware that, although this ²³³U Flattop core is probably made from the same material as the ²³³U Jezebel core, the *Benchmark Handbook* describes Flattop mass density (18.42 g/cm³) with fewer significant figures than the Jezebel experiment (18.424 g/cm³, Table F-2, page F-3). The *Benchmark Handbook* also describes Flattop core isotopic distribution in weight percent with the same values as used for the Jezebel core in atom percent (Table F-2, page F-3). Table G-2 includes information from which one can conclude that affects of these differences will be well within affects of Flattop's critical mass uncertainty.

G4 Library-and-Code Combination Effects

Table G-4 lists calculation results for various library-and-code combinations. Combinations using the *Hansen-Roach*, ENDF/B-V-based SCALE 4.3 libraries, or the MCNP 4A continuous energy libraries produce results within 1% of critical ($k_{\text{eff}} = 1.0000$). Combinations with ENDF/B-IV-based libraries perform least well (2 to 3% low), consistent with differences between this fast experiments and infinite-dilution assumptions for developing these SCALE libraries. In all cases for which results are low, the deviation exceeds the calculation method's statistical uncertainty.

G5 Analysis Conclusions

Table 14 (page 20) lists recommended biases for calculations validated with this experiment. Recommendations incorporate experimental-uncertainty effects but not calculation-statistical-uncertainty effects so that a traditional $k_{\text{eff}} + 2\sigma + \text{bias}$ formula can be used for criticality safety evaluations. Averaged INEEL-calculated effects of ²³³U-Flattop-experiment cumulative uncertainty, ± 0.002 , are not necessarily within typical INEEL-Monte-Carlo-calculation uncertainties because typical σ s exceed ± 0.0014 by only a slight amount.

Table G-3 ^{233}U Flattop Critical-Mass-Uncertainty Effects		
Critical Mass (M_c uncertainty is $\pm 30\text{g}$)	44GROUPNDF5/CSASI/ SCALE4.3/ONEDANT k_{eff}	44GROUPNDF5/ CSAS25/SCALE4.3 $k_{\text{eff}} \pm 1\sigma$
minimum	0.9932	0.9911 ± 0.0014
nominal (Table G-4, page 5)	0.9946	0.9916 ± 0.0014
maximum	0.9960	0.9962 ± 0.0014
Δk_{eff}^a	± 0.0014	± 0.0026

a Compare with a benchmark $k_{\text{eff}} = 1.0000 \pm 0.0014$.

Table G-4 Library-and-Code-Combination Comparison for ^{233}U Flattop		
Library Data Source	Combination	$k_{\text{eff}} \pm 1\sigma^a$
Hansen-Roach	Hansen-Roach/CSAS25/SCALE4.3	0.9965 ± 0.0016
ENDF/B-IV	27Grev/CSASI/SCALE4.0/ONEDANT	0.9764
	27Grev/CSAS25/SCALE4.0	0.9716 ± 0.0013
	218G(4.0)/CSAS25/SCALE4.0	0.9757 ± 0.0014
	27GROUPNDF4/CSASI/SCALE4.3/ONEDANT	0.9764
	27GROUPNDF4/CSAS25/SCALE4.3	0.9765 ± 0.0014
	218GROUPNDF4/CSAS25/SCALE4.3	0.9742 ± 0.0013
ENDF/B-V	44GROUPNDF5/CSASI/SCALE4.3/ONEDANT	0.9946
	44GROUPNDF5/CSAS25/SCALE4.3	0.9916 ± 0.0014
	238GROUPNDF5/CSAS25/SCALE4.3	1.0000 ± 0.0014
	.50c/MCNP4A	1.0098 ± 0.0016
ENDF/B-VI	.60c/MCNP4A	1.0084 ± 0.0016

a Compare with a benchmark experimental $k_{\text{eff}} = 1.0000 \pm 0.0014$.

G6 Sample Inputs

Some single lines of input are listed here on multiple lines due to report's column width. Use caution in regenerating code inputs from these listings.

G6.1 SCALE Input, 238GROUPNDF5/ CSAS25/SCALE4.3

SCALE calculations were performed with 405 generations, 800 neutrons per generation, skipping 5 generations before averaging k_{eff} values. Results are therefore based on 320,000 neutron histories.

```
=CSAS25      PARM=SIZE=1000000
U233 Flattop Benchmark
238GROUPNDF5 INF
U-233      1  0  4.6710-02  END
U-234      1  0  5.8772-04  END
U-235      1  0  1.4158-05  END
U-238      1  0  2.7959-04  END
U-235      2  0  3.5050-04  END
U-238      2  0  4.7719-02  END
END COMP
KENOV.A
READ PARAM
TME=60  GEN=405  NPG=800  FLX=YES  PDN=YES
PKI=YES  FAR=YES  FMP=YES  NUB=YES  NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE 1 1 4.2058
SPHERE 2 1 24.1194
END GEOMETRY
END DATA
END
```

G6.2 DANTSYS Input, 44GROUPNDF5/ CSASI/SCALE4.3/ONEDANT

DANT calculations were performed with S_{16} quadrature, P_3 scattering, and a 10^{-6} convergence criteria.

Cross Section Processing Input:

```
=CSASI
U233 Flattop Benchmark
44GROUPNDF5 INF
U-233      1  0  4.6710-02  END
U-234      1  0  5.8772-04  END
U-235      1  0  1.4158-05  END
U-238      1  0  2.7959-04  END
U-235      2  0  3.5050-04  END
U-238      2  0  4.7719-02  END
END COMP
MORE DATA axs=07 END
END
```

k_{eff} Calculation Input:

```
1 0 0
U233 Flattop Benchmark
igeom=sphere ngroup=44 isn=48 niso=2 mt=2 nzone=2
im=35 it=350
maxscm=500000 maxlcm=8500000
T
/ Block 2 (geometry)
/ set up 11 course mesh intervals in core, 24 in
```

```
reflector
xmesh= 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 3.75 4.0
4.125
4.2058 4.25 4.5 4.75 5.0 5.5 6.0 6.5 7.0 8.0
9.0
10.0 12.0
15.0 17.0 19.0 21.0 22.0 22.5 23.0 23.25 23.5
23.75
24.0 24.1194
xints= 35R 10
zones= 11R1 24R2
T
/ Block 3 (cross sections)
lib=f27 writmxs=macbcd
chivec= 0.00596 0.01595 0.04804 0.16050 0.08701
0.02460 0.11536 0.12550 0.16072 0.16555
0.07817 0.01102 0.00071 0.00084 0.00006
0.000005 0.0000003 0.00000005 0.00000004
0.000000003 0.000000002 0.000000002 22z
maxord=3 ihm=68 iht=3 ihs=25 itit1=1 ifido=2 i2lp1=1
T
/ Block 4 (material mixing and assignments)
matls=isos assign=matls
T
/ Block 5 (solver control)
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
T
/ Block 6
zned= 1
T
```

G6.3 MCNP Input, .60c/MCNP4A

MCNP calculations were performed with 250 generations, 1000 neutrons per generation, skipping the first 15 generations before averaging k_{eff} values. Results are therefore based on 235,000 neutron histories.

```
U233 Flattop Benchmark
c Cells
c U233 core
1 1 4.816985-02 -1 imp:n=1
c normal U reflector
2 2 4.786702-02 +1 -2 imp:n=1
c void
3 0 +2 imp:n=0

c Surfaces
c core
1 so 4.2058
c reflector
2 so 24.1194

c Data: calc control
c k-eff calc
kcode 1000 1.0 15 200
c start neutrons at center
ksrc 0 0 0
c Data: materials and nuclide densities
m1 $ U233 core, 18.42 g/cc
92233.60c 4.6710-02
92234.60c 5.8772-04
92235.60c 1.4158-05
92238.60c 2.7959-04
m2 $ normal U reflector, 19.00 g/cc
92235.60c 3.5050-04
92238.60c 4.7719-02
print
```


Appendix H

^{233}U Planet Experiments and Calculations

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H1 Experiments

Eight experiments approximating ideal metal-reflected, metal-sphere systems were performed in the late 1950s with the Planet Assembly at Los Alamos. Experiment information was analyzed to determine critical data for ideal experiment configurations. These experiments were analyzed and several times (Plassman and Wood, LA-4208, LA-3067-MS, and *Benchmark Handbook*). Brewer performed the most recent analyses which are reported under identification numbers U233-MET-FAST-002, -003, -004, and -005 of the *Benchmark Handbook*. Figure 8 (page 21) and Tables H-1 and H-2 list benchmark experiment description information.

Table H-1 Idealized ^{233}U Planet Critical Experiment Parameters									
Exp # ^a	Spherical ^{233}U Metal Core				Tight-Fitting Metal Reflector Shell				
	M _c (g)	ρ (g/cm ³)	OD (in.)	OR ^b (cm)	Material	ρ (g/cm ³)	Thickness ^c (cm)		
							min	nom [in.]	max
002a	7601	18.644	3.662	4.599	^{235}U	18.80	1.9689	1.9888 [0.783]	2.0087
002b	10012	18.621	3.972	5.044	^{235}U	18.80	1.2095	1.2217 [0.481]	1.2339
003a	7601	18.644	3.662	4.599	Natural Uranium	18.92	5.2555	5.3086 [2.090]	5.3617
003b	10012	18.621	3.972	5.044	Natural Uranium	18.92	2.2782	2.3012 [0.906]	2.3242
004a	7601	18.644	3.662	4.599	Tungsten Alloy	17.21	5.7333	5.7912 [2.280]	5.8491
004b	10012	18.621	3.972	5.044	Tungsten Alloy	17.21	2.4140	2.4384 [0.960]	2.4628
005a	7601	18.644	3.662	4.599	Beryllium	1.83	4.1541 ^d	4.1961 [1.652]	4.2381 ^d
005b	10012	18.621	3.972	5.044	Beryllium	1.83	2.0243 ^d	2.0447 [0.805]	2.0652 ^d

a Assigned for purposes of this validation, using *Benchmark Handbook* identification number.

b Calculated from M_c and ρ .

c *Benchmark Handbook* specifies uncertainty values for benchmark-model rather than benchmark-experiment descriptions. All uncertainties are incorporated into an assigned $\pm 1\%$ reflector-thickness uncertainty.

d Uncertainty deduced from sensitivity calculations reported in *Benchmark Handbook*.

Table H-2 ²³³ U Planet Experiment Materials					
Experiment #s	Material	Application	Nuclide SCALE # [MCNP #]	wt% ^a	N _n ^b (particles/b-cm)
002a, 003a, 004a, 005a	²³³ U	7.6 kg Core	U-233 [92233]	98.2	4.7312E-02
			U-234 [92234]	1.1	5.2770E-04
			U-238 [92238]	0.7	3.3015E-04
002b, 003b, 004b, 005b	²³³ U	10 kg Core	U-233 [92233]	98.2	4.7253E-02
			U-234 [92234]	1.1	5.2705E-04
			U-238 [92238]	0.7	3.2975E-04
-002a, 002b	²³⁵ U	Reflector	U-235 [92235]	93.2	4.4892E-02
			U-238 [92238]	6.8	3.2340E-03
003a, 003b	Natural U	Reflector	U-235 [92235]	0.72	3.4902E-04
			U-238 [92238]	99.28	4.7518E-02
004a, 004b	Tungsten Alloy	Reflector	TUNGSTEN ^c [74000] ^d	91.3	5.1468E-02
			W-182 ^c	24.01 ^e	1.3528E-02
			W-183 ^c	13.04 ^c	7.3454E-03
			W-184 ^c	28.03 ^c	1.5792E-02
			W-185 ^c	0.09 ^c	nuclide not available
			W-186 ^c	26.11 ^c	1.4711E-02
			Ni [28000]	5.5	9.7124E-03
			Cu [29000]	2.5	4.0774E-03
			Zr [40000]	0.7	7.9528E-04
005a, 005b	Beryllium	Reflector	Be [4009]	98.0	1.1984E-01
			O [8016]	2.0	1.3776E-03

a Values from *Benchmark Handbook*. All were used in *Benchmark Handbook* as weight percent values but in some cases values are more typical of published atom percent values. Comparison of N_n and k_{eff} results indicate difference is negligible in these cases

b Values from *Benchmark Handbook*. Independently calculated values were within 1% for key nuclides and, therefore, *Benchmark Handbook* values were used in models.

c For 44GROUPNDF5 and 238GROUPNDF5 libraries, used for better comparison with .50c.

d .50c as implemented at the INEEL does not include isotopic tungsten. .60c does not include elemental or isotopic tungsten.

e For 27Grev, 218G(4.0), 27GROUPNDF4, 218GROUPNDF4, and Hansen-Roach libraries. Elemental tungsten is 91.3 wt% of the alloy. Natural isotopic distribution (26.3 wt% ¹⁸²W, 14.28 wt% ¹⁸³W, 30.7 wt% ¹⁸⁴W, 0.1 wt% ¹⁸⁵W, and 28.6 wt% ¹⁸⁶W) is assumed for elemental tungsten.

H2 Models

Models here represent benchmark descriptions exactly. Models are of a solid metal spherical core reflected by a tightly-fitting concentric solid metal shell, shown in Figure 8 (page 21). Independently calculated dimensions and nuclide densities for key model components indicate INEEL methods produce essentially the same models, with less than 1% difference in atom densities. Therefore, *Benchmark Handbook* models were used but sample input listings were not used. Tables H-2 and H-3 respectively include model nuclide densities and dimensions.

H3 Uncertainty and Sensitivity Effects

The *Benchmark Handbook* incorporates parameter sensitivity analyses for these experiments, accumulating uncertainty effects in reflector thickness uncertainties. Table H-4 lists calculation results quantifying cumulative experiment-uncertainty effects, both as calculated here and as reported for benchmarks. Results are essentially the same: $k_{\text{eff}} = 1.000 \pm 0.001$.

H4 Library-and-Code Combination Effects

Tables H-5 through H-11 summarize calculations performed to identify best combinations readily available to LMITCO personnel and to determine affects of code and library differences. For these fast-neutron experiments, the .60c/MCNP4A combination performs best. Combinations with ENDF/B-IV-based cross-section libraries perform least well, consistent with differences between these fast experiments and infinite-dilution assumptions for developing these SCALE libraries.

H5 Analysis Conclusions

Table 17 (page 22) lists recommended biases for calculations validated with these experiments. Recommendations do not incorporate calculation-statistical-uncertainty effects so that a traditional $k_{\text{eff}} + 2\sigma + \text{bias}$ formula can be used for criticality safety evaluations. Effects of ^{233}U -Planet-experiment cumulative uncertainty, ± 0.001 , should be within and masked by typical INEEL Monte Carlo calculations because typical σ s exceed ± 0.0014 by a small amount.

Table H-3 ²³³ U Planet Model Dimensions				
Exp #	Core OR, Reflector IR (cm)	Reflector Outer Radius (cm)		
		min	nom	max
002a	4.599	1.9689	1.9888	2.0087
002b	5.044	1.2095	1.2217	1.2339
003a	4.599	5.2555	5.3086	5.3617
003b	5.044	2.2782	2.3012	2.3242
004a	4.599	5.7333	5.7912	5.8491
004b	5.044	2.4140	2.4384	2.4628
005a	4.599	4.1541	4.1961	4.2381
005b	5.044	2.0243	2.0447	2.0651

Table H-4 ²³³ U Planet Reflector-Thickness-Uncertainty Effects 44GROUPNDF5/CSASI/SCALE4.3/ONEDANT ^a					
Exp #	k _{eff} as a Function of Reflector Thickness			Δk _{eff}	
	minimum (-1%)	nominal (Table H-9, page 9)	maximum (+1%)	This Validation	Benchmark Handbook
002a	1.0005	1.0007	1.0023	± 0.0009	± 0.0011
002b	0.9992	0.9981	0.9970	± 0.0011	± 0.0010
003a	0.9927	0.9936	0.9950	± 0.0012	± 0.0010
003b	0.9939	0.9947	0.9955	± 0.0008	± 0.0009
004a	1.0049 ^b	1.0057	1.0066	± 0.0009	± 0.0008
004b	1.0034	1.0042	1.0050	± 0.0008	± 0.0007
005a	1.0039	1.0051	1.0063	± 0.0012	± 0.0013
005b	1.0005 ^b	1.0014 ^b	1.0023 ^b	± 0.0009	± 0.0015
Ave	0.9999 ± 0.0045	1.0004 ± 0.0046	1.0013 ± 0.0048	± 0.001	± 0.001

a 120 mesh points, decreased spacing as a material boundary is approached, convergence criteria 1×10^{-6} unless otherwise noted.

b Convergence criteria changed to 1×10^{-4} .

**Table H-5 Calculations with Hansen-Roach Cross Section Library
(Hansen-Roach/CSAS25/SCALE4.3)**

Experiment #	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
002a	1.0032 ± 0.0016	944188 ± 2256.50
002b	1.0011 ± 0.0016	969946 ± 2397.60
003a	1.0018 ± 0.0017	961499 ± 2560.29
003b	1.0040 ± 0.0016	970498 ± 2280.06
004a	0.9838 ± 0.0017	811025 ± 2169.41
004b	0.9949 ± 0.0016	890360 ± 2467.95
005a	1.0164 ± 0.0017	689127 ± 2415.47
005b	1.0124 ± 0.0018	843366 ± 2236.42
Average	1.0022 ± 0.0100	

Table H-6 27GROUPNDF4 and 218GROUPNDF4 Cross-Section-Library Effects

Experiment #	27GROUPNDF4/CSAS25/SCALE4.3		218GROUPNDF4/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma$	ale (ev)	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
002a	0.9762 ± 0.0012	934890 ± 2102	0.9762 ± 0.0014	968457 ± 2203
002b	0.9698 ± 0.0013	937456 ± 2254	0.9705 ± 0.0014	977674 ± 2333
003a	0.9744 ± 0.0014	916084 ± 2229	0.9714 ± 0.0014	950872 ± 2381
003b	0.9733 ± 0.0014	923857 ± 2164	0.9703 ± 0.0014	961311 ± 2015
004a	0.9715 ± 0.0014	769082 ± 1840	0.9721 ± 0.0015	807439 ± 1892
004b	0.9716 ± 0.0014	844293 ± 2029	0.9725 ± 0.0013	885099 ± 1987
005a	0.9932 ± 0.0015	575914 ± 2182	0.9870 ± 0.0016	657385 ± 2138
005b	0.9795 ± 0.0014	760590 ± 2143	0.9776 ± 0.0014	827877 ± 2086
Average	0.9762 ± 0.0075		0.9747 ± 0.0056	

Table H-7 44GROUPNDF5 and 238GROUPNDF5 Cross Section-Library Effects				
Experiment #	44GROUPNDF5/CSAS25/SCALE4.3		238GROUPNDF5/CSAS25/SCALE4.3	
	$k_{\text{eff}} \pm 1\sigma$	ale (ev)	$k_{\text{eff}} \pm 1\sigma$	ale (ev)
002a	1.0008 ± 0.0014	1019370 ± 2425	0.9971 ± 0.0014	1067090 ± 2311
002b	0.9989 ± 0.0014	1042160 ± 2469	0.9971 ± 0.0014	1093350 ± 2388
003a	0.9954 ± 0.0014	1032530 ± 2309	1.0000 ± 0.0014	1065780 ± 2441
003b	0.9938 ± 0.0014	1044700 ± 2480	0.9987 ± 0.0014	1082190 ± 2381
004a	1.0078 ± 0.0014	825471 ± 2139	1.0053 ± 0.0014	864378 ± 2270
004b	1.0057 ± 0.0014	925284 ± 2368	1.0039 ± 0.0013	965291 ± 2206
005a	1.0059 ± 0.0015	712164 ± 2659	1.0016 ± 0.0015	762758 ± 2481
005b	1.0023 ± 0.0015	891981 ± 2469	0.9994 ± 0.0015	951444 ± 2604
Average	1.0013 ± 0.0051		1.0039 ± 0.0030	

Table H-8 ONEDANT and KENO V.a Code Effects with 27Grev Library		
Experiment #	27Grev/CSASI/SCALE4.0/ ONEDANT ^a	27Grev/CSAS25/SCALE4.0 (Table H-11, page 10)
	k_{eff}	$k_{\text{eff}} \pm 1\sigma$
002a	0.9788	0.9782 ± 0.0013
002b	0.9724	0.9718 ± 0.0012
003a	0.9749	0.9742 ± 0.0014
003b	0.9717	0.9763 ± 0.0014
004a	0.9722	0.9702 ± 0.0015
004b	0.9720	0.9710 ± 0.0014
005a	0.9923	0.9907 ± 0.0015
005b	0.9811	0.9800 ± 0.0014
Average _f	0.9769 ± 0.0071	0.9766 ± 0.0067

a 120 mesh points, decreased spacing as a material boundary is approached.

Table H-9 ONEDANT & KENO V.a Code Effects with 44GROUPNDF5 Library		
Experiment #	44GROUPNDF5/CSASI/SCALE4.3/ ONEDANT ^a k_{eff}	44GROUPNDF5/CSAS25/SCALE4.3 (Table H-7, page 8) $k_{eff} \pm 1\sigma$
002a	1.0007	1.0008 ± 0.0014
002b	0.9981	0.9989 ± 0.0014
003a	0.9936	0.9954 ± 0.0014
003b	0.9947	0.9938 ± 0.0014
004a	1.0057	1.0078 ± 0.0014
004b	1.0042	1.0057 ± 0.0014
005a	1.0051	1.0059 ± 0.0015
005b	1.0014	1.0023 ± 0.0015
Average	1.0004 ± 0.0046	1.0013 ± 0.0051

a 120 mesh points, decreased spacing as a material boundary is approached.

Table H-10 .50c and .60c Cross-Section-Library Effects		
Experiment #	$k_{eff} \pm 1\sigma$	
	.50c/MCNP4A	.60c/MCNP4A
002a	0.9980 ± 0.0013	1.0000 ± 0.0014
002b	0.9989 ± 0.0012	0.9952 ± 0.0014
003a	0.9999 ± 0.0016	0.9991 ± 0.0015
003b	0.9966 ± 0.0015	0.9970 ± 0.0014
004a	1.0044 ± 0.0015	1.0078 ± 0.0015
004b	1.0013 ± 0.0014	1.0051 ± 0.0015
005a	1.0004 ± 0.0015	0.9972 ± 0.0016
005b	0.9942 ± 0.0014	0.9970 ± 0.0015
Average	0.9992 ± 0.0031	0.9998 ± 0.0044

Table H-11 27-Group Library-Processing Effects				
Experiment #	27Grev/CSAS25/SCALE4.0		27GROUPNDF4/CSAS25/SCALE4.3 (Table H-6, page 7)	
	$k_{\text{eff}} \pm 1\sigma$	afg	$k_{\text{eff}} \pm 1\sigma$	afg
002a	0.9782 ± 0.0013	4.7888 ± 0.0036	0.9762 ± 0.0012	4.7849 ± 0.0033
002b	0.9718 ± 0.0012	4.7848 ± 0.0035	0.9698 ± 0.0013	4.7777 ± 0.0035
003a	0.9742 ± 0.0014	4.7719 ± 0.0037	0.9744 ± 0.0014	4.7762 ± 0.0035
003b	0.9763 ± 0.0014	4.7892 ± 0.0036	0.9733 ± 0.0014	4.7847 ± 0.0034
004a	0.9702 ± 0.0015	5.0611 ± 0.0036	0.9715 ± 0.0014	5.0657 ± 0.0034
004b	0.9710 ± 0.0014	4.9432 ± 0.0036	0.9716 ± 0.0014	4.9363 ± 0.0033
005a	0.9907 ± 0.0015	5.2752 ± 0.0042	0.9932 ± 0.0015	5.2718 ± 0.0041
005b	0.9800 ± 0.0014	5.0227 ± 0.0039	0.9795 ± 0.0014	5.0184 ± 0.0036
Average	0.9766 ± 0.0067	4.9296 ± 0.1816	0.9762 ± 0.0075	4.9270 ± 0.1821

Table H-12 218-Group Library-Processing Effects				
Experiment #	218G(4.0)/CSAS25/SCALE4.0		218GROUPNDF4/CSAS25/SCALE4.3 (Table H-6, page 7)	
	$k_{\text{eff}} \pm 1\sigma$	afg	$k_{\text{eff}} \pm 1\sigma$	afg
002a	0.9777 ± 0.0014	17.2337 ± 0.0218	0.9762 ± 0.0014	17.2615 ± 0.0237
002b	0.9684 ± 0.0014	17.1828 ± 0.0245	0.9705 ± 0.0014	17.1584 ± 0.0244
003a	0.9725 ± 0.0013	17.4466 ± 0.0254	0.9714 ± 0.0014	17.4914 ± 0.0255
003b	0.9737 ± 0.0013	17.3409 ± 0.0235	0.9703 ± 0.0014	17.3761 ± 0.0224
004a	0.9702 ± 0.0014	19.2685 ± 0.0236	0.9721 ± 0.0015	19.2201 ± 0.0235
004b	0.9668 ± 0.0014	18.2641 ± 0.0257	0.9725 ± 0.0013	18.2546 ± 0.0232
005a	0.9873 ± 0.0014	20.6189 ± 0.0283	0.9870 ± 0.0016	20.5953 ± 0.0288
005b	0.9758 ± 0.0014	18.7391 ± 0.0253	0.9776 ± 0.0014	18.7674 ± 0.0250
Average	0.9741 ± 0.0065	18.2618 ± 1.2266	0.9747 ± 0.0056	18.2656 ± 1.2080

H6 Sample Inputs

Some single lines of input are listed here on multiple lines due to report's column width. Use caution in regenerating code inputs from these listings.

H6.1 SCALE Inputs

SCALE calculations were performed with 405 generations, 800 neutrons per generation, skipping 5 generations before averaging k_{eff} values. Results are therefore based on 320,000 neutron histories.

H6.1.1 U233-MET-FAST-002a, Hansen-Roach/ CSAS25/SCALE4.3

```
=CSAS25
PLANET 7.6kg d=3.622" U233 sphere, t=0.783" U235 refl
HANSEN-ROACH INFHOMMEDIUM
U-233      1 0  4.7312E-02 END
U-234      1 0  5.2770E-04 END
U-238      1 0  3.3015E-04 END
U-235      2 0  4.4892E-02 END
U-238      2 0  3.2340E-03 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE 1 1 4.5999
SPHERE 2 1 6.5887
END GEOMETRY
END DATA
END
```

H6.1.2 U233-MET-FAST-002b, 27Grev/CSAS25/ SCALE4.0 and 27GROUPNDF4/CSAS25/ SCALE4.3

```
=CSAS25
PLANET 10kg d=3.972" U233 sphere, t=0.481" U235 refl
27G INF
U-233      1 0  4.7253E-02 END
U-234      1 0  5.2705E-04 END
U-238      1 0  3.2975E-04 END
U-235      2 0  4.4892E-02 END
U-238      2 0  3.2340E-03 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE 1 1 5.0444
SPHERE 2 1 6.2661
END GEOMETRY
END DATA
END
```

H6.1.3 U233-MET-FAST-003a, 218G(4.0)/CSAS25/ SCALE4.0 and 218GROUPNDF4/CSAS25/ SCALE4.3

```
=CSAS25 PARM=SIZE=1000000
PLANET 7.6kg d=3.622" U233 sphere, t=5.0836cm Unat
refl
218GROUPNDF4 INF
U-233      1 0  4.7312E-02 END
U-234      1 0  5.2770E-04 END
U-238      1 0  3.3015E-04 END
U-235      2 0  3.4902E-04 END
U-238      2 0  4.7518E-02 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE 1 1 4.5999
SPHERE 2 1 9.9085
END GEOMETRY
END DATA
END
```

H6.1.4 U233-MET-FAST-003b, 44GROUPNDF5/ CSAS26/SCALE4.3

```
=CSAS25
PLANET 10kg d=3.972" U233 sphere, t=2.3012cm Unat
refl
44GROUPNDF5 INF
U-233      1 0  4.7253E-02 END
U-234      1 0  5.2705E-04 END
U-238      1 0  3.2975E-04 END
U-235      2 0  3.4902E-04 END
U-238      2 0  4.7518E-02 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE 1 1 5.0444
SPHERE 2 1 7.3456
END GEOMETRY
END DATA
END
```

H6.1.5 U233-MET-004a, 238GROUPNDF5/ CSAS25/SCALE4.3

```
=CSAS25 PARM=SIZE=1000000
PLANET 7.6kg d=3.622" U233 sphere, t=5.7912cm
Tungsten refl
238GROUPNDF5 INF
U-233      1 0  4.7312E-02 END
U-234      1 0  5.2770E-04 END
U-238      1 0  3.3015E-04 END
TUNGSTEN 2 0  5.1468E-02 END
NI         2 0  9.7124E-03 END
CU         2 0  4.0774E-03 END
ZR         2 0  7.9528E-04 END
END COMP
KENOV.A
READ PARAM
TME=60 GEN=405 NPG=800 FLX=YES FDN=YES
PKI=YES FAR=YES FMP=YES NUB=YES NSK=5
END PARAM
READ GEOM
BOX TYPE 1
SPHERE 1 1 4.5999
```

```
SPHERE 2 1 10.3911
END GEOMETRY
END DATA
END
```

H6.2 ONEDANT Inputs

All DANT calculations were performed with S_{16} quadrature and P_3 scattering. Most calculations were performed with a 10^{-6} convergence criteria.

H6.2.1 U233-MET-FAST-004a, 27Grev/CSASI/SCALE4.0/ONEDANT

Cross Section Processing Input:

```
=CSASI
PLANET 7.6kg d=3.622" U233 sphere, t=5.7912cm
Tungsten refl
44GROUPNDF5 INF
U-233 1 0 4.7312E-02 END
U-234 1 0 5.2770E-04 END
U-238 1 0 3.3015E-04 END
W-182 2 0 1.3528E-02 END
W-183 2 0 7.3454E-03 END
W-184 2 0 1.5792E-02 END
W-186 2 0 1.4711E-02 END
NI 2 0 9.7124E-03 END
CU 2 0 4.0774E-03 END
ZR 2 0 7.9528E-04 END
END COMP
MORE DATA axs=07 END
END
```

k_{eff} Calculation Input:

```
1 0 0
PLANET 7.6kg d=3.622" U233 sphere, t=5.7912cm
Tungsten refl
/ Block 1
igeom=sphere ngrou=27 isn=48 niso=2 mt=2 nzone=2
im=27 it=270
maxscm=50000 maxlcm=850000
T
/ Block 2 (geometry)
/ set up 11 course mesh intervals in core, 16 in
reflector
xmesh= 0.0 0.5 1 1.5 2 2.5 3 3.5 4 4.25 4.5 4.5999
4.75 5 5.25 5.5 6 6.5 7 7.5 8 8.5 9 9.5 9.75
10 10.25 10.3911
xints= 27R 10
zones= 11R1 16R2
T
/ Block 3 (cross sections)
lib=f27 writmxs=macbcd
chivec= 0.020 0.195 0.219 0.126 0.164 0.172 0.088
0.014 0.001 0.000001 17z
maxord=3 ihm=42 iht=3 ihs=16 ititl=1 ifido=2 i2lp1=1
T
/ Block 4 (material mixing and assignments)
matls=isos assign=matls
T
/ Block 5 (solver control)
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
T
/ Block 6
zned= 1
T
```

H6.2.2 U233-MET-FAST-004b, 44GROUPNDF5/CSASI/SCALE4.3/ONEDANT

Cross Section Processing Input:

```
=CSASI
PLANET 10kg d=3.972" U233 sphere, t=2.4384cm
Tungsten refl
44GROUPNDF5 INF
U-233 1 0 4.7253E-02 END
U-234 1 0 5.2705E-04 END
U-238 1 0 3.2975E-04 END
W-182 2 0 1.3528E-02 END
W-183 2 0 7.3454E-03 END
W-184 2 0 1.5792E-02 END
W-186 2 0 1.4711E-02 END
NI 2 0 9.7124E-03 END
CU 2 0 4.0774E-03 END
ZR 2 0 7.9528E-04 END
END COMP
MORE DATA axs=07 END
END
```

k_{eff} Calculation Input:

```
1 0 0
PLANET 10kg d=3.972" U233 sphere, t=2.4384cm
Tungsten refl
/ Block 1
igeom=sphere ngrou=44 isn=48 niso=2 mt=2 nzone=2
im=21 it=210
maxscm=50000 maxlcm=850000
T
/ Block 2 (geometry)
/ set up 12 course mesh intervals in core, 9 in
reflector
xmesh= 0.0 0.5 1 1.5 2 2.5 3 3.5 4 4.25 4.5 4.75
5.0444
5.25 5.5 5.75 6 6.5 6.75 7 7.25 7.4828
xints= 21R 10
zones= 12R1 9R2
T
/ Block 3 (cross sections)
lib=f27 writmxs=macbcd
chivec= 0.00596 0.01595 0.04804 0.16050 0.08701
0.02460 0.11536 0.12550 0.16072 0.16555
0.07817 0.01102 0.00071 0.00084 0.00006
0.000005 0.0000003 0.00000005 0.000000004
0.000000003 0.000000002 0.000000002 22z
maxord=3 ihm=68 iht=3 ihs=25 ititl=1 ifido=2 i2lp1=1
T
/ Block 4 (material mixing and assignments)
matls=isos assign=matls
T
/ Block 5 (solver control)
ievt=1 isct=3 ith=0 ibr=0 epsi=1E-6 iitm=40 oitm=60
T
/ Block 6
zned= 1
T
```

H6.3 MCNP Input

MCNP calculations were performed with 250 generations, 1000 neutrons per generation, skipping the first 15 generations before averaging k_{eff} values. Results are therefore based on 235,000 neutron histories.

H6.3.1 U233-MET-FAST-005a, .50c/MCNP4A

```
PLANET 7.6kg d=3.622" U233 sphere, t=1.652" Be ref
C Cells
1 1 4.816985E-02 -1 imp:n=1 $ U233 core
2 2 1.212176E-01 +1 -2 imp:n=1 $ Be reflector
3 0 +2 imp:n=0 $ void

C Surfaces
1 so 4.5999 $ U233 core
2 so 8.7960 $ Be reflector

C Data: materials and nuclide densities
m1 92233.50c 4.7312E-02 92234.50c 5.2770E-04
92238.50c 3.3015E-04 $ U233 core
m2 4009.50c 1.1984E-01 8016.50c 1.3776E-03
$ Be reflector
mt2 be.01t
C Data: calc control
kcode 1000 1.0 15 200 $ k-eff calc
ksrc 0 0 0 $ start neutrons at center
print
```

H6.3.2 U233-MET-FAST-005b, .60c/MCNP4A

```
PLANET 10kg d=3.972" U233 sphere, t=0.805" Be refl
C Cells
1 1 4.81098E-02 -1 imp:n=1 $ U233 core
2 2 1.212176E-01 +1 -2 imp:n=1 $ Be reflector
3 0 +2 imp:n=0 $ void

C Surfaces
1 so 5.0444 $ U233 core
2 so 7.0891 $ Be reflector

C Data: materials and nuclide densities
m1 92233.60c 4.7253E-02 92234.60c 5.2705E-04
92238.60c 3.2975E-04 $ U233 core
m2 4009.60c 1.1984E-01 8016.60c 1.3776E-03
$ Be reflector
mt2 be.01t
C Data: calc control
kcode 1000 1.0 15 200 $ k-eff calc
ksrc 0 0 0 $ start neutrons at center
print
```

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