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Updates to SNL Nuclear Criticality Safety Benchmark Suite for MCNP

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ABSTRACT

Members of the Nuclear Criticality Safety (NCS) Program at Sandia National Laboratories (SNL) have updated the suite of benchmark problems developed to validate MCNP6 Version 2.0 for use in NCS applications. The updated NCS benchmark suite adds approximately 600 new benchmarks and includes peer review of all input files by two different NCS engineers (or one NCS engineer and one candidate NCS engineer). As with the originally released benchmark suite, the updated suite covers a broad range of fissile material types, material forms, moderators, reflectors, and neutron energy spectra. The benchmark suite provides a basis to establish a bias and bias uncertainty for use in NCS analyses at SNL.

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ACRONYMS AND TERMS

Acronym/Term	Definition
ANS	American Nuclear Society
ANSI	American National Standards Institute
CEE	Common Engineering Environment
COMP	Compound system
CSA	Criticality Safety Analysis
DOE	Department of Energy
EALF	Energy Corresponding to the Average Neutron Lethargy Causing Fission
ECF	Average Neutron Energy Causing Fission
FAST	Fast neutron energy system
HEU	Highly Enriched Uranium
IEU	Intermediate and Mixed Enrichment Uranium
ICSBEP	International Criticality Safety Benchmark Evaluation Project
INTER	Intermediate neutron energy system
k_{eff}	Effective neutron multiplication factor
k_{USL}	Upper subcritical limit for k_{eff}
LEU	Low Enriched Uranium
MCNP	Monte Carlo N-Particle radiation transport code
MET	Metal system
MIX	Mixed Uranium / Plutonium Systems
MIXED	Mixed neutron energy system
NCS	Nuclear Criticality Safety
PU	Plutonium
SNL	Sandia National Laboratories
SOL	Solution system
SVVR	Software Verification and Validation Report
THERM	Thermal neutron energy system
USL	Upper subcritical limit

1. INTRODUCTION

During 2014 and 2015, DePriest and Miller [1] created and documented a suite of benchmark models for use in the validation of the MCNP6 computer code [2] with ENDF/B-VII cross sections [3] for nuclear criticality safety (NCS) applications at Sandia National Laboratories (SNL). Since the original publication of the SNL NCS benchmark suite, members of the NCS Program at SNL have expanded the original benchmark suite while removing a few cases that were deemed inappropriate for the activities that NCS engineers at SNL were analyzing (for example, ^{233}U benchmark models were not viewed as relevant to SNL NCS activities). The SNL NCS benchmark suite now contains 882 criticality benchmark models (up from 265 cases in the original release). This report describes the update to the original suite of benchmark problems developed by NCS engineers at SNL for the purpose of NCS validation of the MCNP6 Version 2.0 [4] with the ENDF/B-VII.1 cross sections.

The SNL NCS benchmark suite currently contains highly enriched uranium systems, intermediate and mixed enrichment uranium systems, low enriched uranium systems, mixed uranium / plutonium systems, and plutonium systems. The systems in the suite include reflectors of natural uranium, nickel, tungsten carbide, water, molybdenum, beryllium – molybdenum, beryllium, molybdenum – beryllium, polyethylene, beryllium oxide, boron – beryllium, boron – beryllium oxide, aluminum, steel, depleted uranium, graphite, paraffin, steel – polyethylene, lead, concrete, tungsten, thorium, and copper. The moderators encompassed by the benchmark suite include polyethylene, Plexiglas, Teflon, beryllium, water, uranyl nitrate (water), UO_2F_2 solution (water), heavy water (D_2O), and plutonium nitrate (water).

While the cases in the original suite were reviewed prior to publication, the updated suite includes peer review of all input files by two different NCS engineers (or one NCS engineer and one candidate NCS engineer). The peer review included a check to ensure that each input file resulted in a calculation that satisfied the Los Alamos National Laboratory MCNP6 best practices [5]. These best practices require that the models use a minimum of 10,000 neutron per cycle, specify a minimum of 50 source settling cycles prior to accumulating statistics on effective neutron multiplication factor (k_{eff}), and use at least 100 active cycles. Additionally, the peer reviewers verified that the results satisfied all source entropy convergence checks.

Within the NCS benchmark suite, the NCS engineers insured that the current version of the cases used the ENDF/B-VII.1 cross sections. Before the materials are defined for each benchmark model case, the card for defining a default cross section set (that is, `M0`) was inserted, and the MCNP6 cross section designation for the END/B-VII.1 (that is, `NLIB=80`) was used. This step in the building and peer review of the benchmark models accomplishes two things: (1) all materials in the model will use the defined cross section set and (2) the cross section set for the entire benchmark suite can be updated by changing one line in the input file using a simple script.

The benchmark experiments selected as part of the SNL NCS benchmark suite are found in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook [6]. The current set of benchmarks in the suite is now considered complete. While we consider the suite comprehensive, a NCS engineer may supplement the fully developed benchmark suite with additional cases to encompass the unique materials or geometries of a special analysis situation.

2. SOFTWARE VALIDATION FOR NCS

NCS engineers at SNL are tasked with ensuring that fissionable material operations outside of reactor operations and critical experiments will be safely subcritical under both normal and credible abnormal conditions. In performing the duties associated with this responsibility, NCS engineers frequently utilize computer codes that calculate the k_{eff} of fissionable systems under analysis. In these cases, the computer code (or codes) used must be validated to meet the requirements found in DOE-STD-3007-2017 [7], ANSI/ANS-8.1-2014 (R2018) [8], and ANSI/ANS 8.24-2017 [9].

The NCS program at SNL assumes that any NCS engineer or candidate NCS engineer has the requisite skills needed to install MCNP6 software correctly on the machine that he/she intends to use for NCS analysis. Thus, the process of verifying that the code is installed according to the software distribution instructions is omitted in this document. In addition, configuration control of the MCNP software or the evaluation of system updates to the computer with respect to code validation are not discussed as part of the software validation process defined within this report.

Prior to inclusion in the ICSBEP Handbook, critical experiments undergo a rigorous selection and review process to determine if the experiment meets the requirements to be defined as a benchmark. Each benchmark in the ICSBEP Handbook includes the following items: (1) Detailed description of the experiment, (2) Evaluation of the experimental data, (3) Benchmark specification (often uses idealization of actual experiment), (4) Results of sample calculations, (5) References, and (6) Typical input listings for computer codes. While there are typical input listings for computer codes, the "Introduction" to the ICSBEP Handbook also contains the following statement:

> "**Sample input listings are not intended to be used directly for validation efforts and should be verified by the user**. Since it is impractical to describe in detail the code input used to model each benchmark critical experiment, computer input listings are given for typical calculations of accepted benchmark configurations. From these listings, a user can identify which options were used to obtain the reported results. This is the sole purpose for inclusion of the input listings. The user of any code system has the responsibility to ensure that the particular calculational tools and options used to solve a problem are properly validated. It is the responsibility of the user to ensure that use of these listings for any other purpose is consistent with proper criticality safety practices."

At SNL, the NCS Program has interpreted the statement to mean that each benchmark experiment description included in the benchmark handbook must be reviewed by an NCS engineer (or candidate NCS engineer) and an input listing created based on that description. The SNL NCS Program has taken the additional step to require the peer review of each input listing included in the benchmark suite.

2.1. Establishment of Bias & Bias Uncertainty

The most basic reason for comparing neutron transport code calculations with criticality benchmark experiment results is to establish the bias associated with the calculation of k_{eff}. The intent of bias determination is to allow the NCS engineer to further understand the limitations associated with modeling a physical system with the neutron transport code being used. By convention, a positive bias occurs when the results of the calculated k_{eff} is greater than the experimentally measured k_{eff}.

The bias calculated for a given neutron transport code depends on the specifics of the selected benchmarks, the details contained in the benchmark modeling such as the accuracy of the cross sections, the modeling match to experiment, and the computational methodology. The bias uncertainty accounts for the combined effects of uncertainties in the benchmark critical experiments, the models of the benchmarks, and the calculation method. The bias for each benchmark experiment is calculated using the following equation:

$$Bias = k_{Calc} - k_{Bench} \qquad \text{Eq (1)}$$

A positive bias means that the analysis method is conservative (that is, k_{Calc} is greater than k_{Bench}), and a negative bias means that the analysis method is non-conservative. According to ANSI/ANS-8.24 Section 6.1.3, the use of a positive bias shall be justified if it is used in the determination of the calculational margin. Thus, the validation process at SNL will not take credit for a positive bias. The total uncertainty in the bias is given by the following equation:

$$\sigma_t = \sqrt{\sigma_{Calc}^2 + \sigma_{Bench}^2} \qquad \text{Eq (2)}$$

To assign the bias and bias uncertainty for a benchmark suite, an average bias ($\overline{Bias}$) is first computed using the following equation:

$$\overline{Bias} = \frac{\sum_{i=1}^{N} \frac{1}{\sigma_{t_i}^2} \cdot Bias_i}{\sum_{i=1}^{N} \frac{1}{\sigma_{t_i}^2}} \qquad \text{Eq (3)}$$

The sample variance for the average bias is computed in this manner:

$$s^2 = \frac{\left(\frac{1}{N-1}\right) \cdot \sum_{i=1}^{N} \frac{1}{\sigma_{t_i}^2} \cdot \left(Bias_i - \overline{Bias}\right)^2}{\left(\frac{1}{N}\right) \cdot \sum_{i=1}^{N} \frac{1}{\sigma_{t_i}^2}} \qquad \text{Eq (4)}$$

The average total uncertainty is computed using the following technique:

$$\overline{\sigma}_t^2 = \frac{N}{\sum_{i=1}^{N} \frac{1}{\sigma_{t_i}^2}} \qquad \text{Eq (5)}$$

The computed average bias, the sample variance in the average bias, and the average total uncertainty are quantities used in one of the statistical methods for establishing an upper subcritical limit (USL). The statistical techniques will be described in a later chapter.

2.1.1. *Trends in Bias*

Since the intent of the benchmark comparison is to understand the limitations of the calculational technique, an NCS engineer examines trends in the bias to understand where the system or systems under analysis fit within the coverage of the benchmark suite. For instance, the bias for the benchmarks is plotted as function of the average lethargy energy causing fission (or uranium concentration, moderation ratio, etc.). The bias trend plots inform the NCS engineer where the regions of concern when interpolating or extrapolating to the physics regime of a particular criticality safety analysis. At SNL, the bias trend plots are also examined to determine whether there are regions of sparse benchmark data that might be filled with additional benchmarks (in some cases the benchmark experiments in that physics regime may not exist).

2.2. Validation Report

One of the most time-consuming aspects of validating neutron transport codes for use in NCS analysis is the requirement of generating a validation report. There is a requirement that each time a change is made (for example, a new version of the code or a new cross section set), a new validation report must be generated to account for the changes. One of the goals of the SNL NCS benchmark suite described in this report is to create a methodology that allows for the preparation of a validation report for a new machine or code version with relatively little effort on the part of the NCS engineer. The scripting for this automation is complete and was based on the framework of the regression comparison suite of the Neutron Gamma Energy Transport (NuGET) [10] ASC code developed at SNL.

2.3. Benefits of a Unified Benchmark Set

During the peer review process for a criticality safety analysis (CSA), the reviewing NCS engineer examines the adequacy of the benchmark set selected by their colleague for validating the neutron transport code. If performed properly, the review of the selected benchmarks will encompass a significant amount of time.

The adoption of a unified benchmark set within the SNL NCS Program eliminates this time consuming (but highly important) step from the peer review process. If a single benchmark suite for validating a neutron transport code is established, then the NCS engineer writing a CSA need only state that the program defined benchmark set was used and verify that the benchmark suite covers the application space of the CSA.

An additional benefit of establishing a common validation suite for SNL is that it focuses the NCS engineer responsible for the peer review on the cases needed for the CSA. The NCS engineer will have more time to determine if the excursions and upsets are adequate, if the NCS engineer does not have to go through hundreds of cases to determine if the proper benchmarks were included to establish bias & bias uncertainty. Essentially, a common benchmark suite moves a significant effort ***from*** the determination of whether the right set of benchmarks experiments are calculated to be close enough to k_{eff} of 1.000 ***to*** the determination if the processes/operations described in the CSA are safe.

2.4. Current Status of SNL NCS Benchmark Suite

The SNL NCS benchmark suite was designed to make configuration management seamless and relatively simple to the NCS engineers in the NCS Program. The creation of a git [11] repository allowed each NCS engineer to control their own clone and update the benchmark suite during the peer review process. If additional benchmarks are identified by an NCS engineer, those models can be added and distributed to all NCS engineers at SNL with little effort. The current benchmark suite is based on 166 benchmark descriptions from the ICSBEP Handbook with 882 computational cases. The ENDF/B-VII.1 cross sections are used in the benchmark suite and all elements (except carbon and platinum) are now described by isotopic cross sections.

The git repository structure for the benchmark is discussed in the next chapter. In addition, Chapter 3 describes scripts that can be used to run the benchmark suite automatically and includes a process for obtaining the benchmark repository for SNL staff members. Chapter 4 describes the contents of the benchmark suite while Chapter 5 will provide the USL found using the benchmark suite. The USL obtained here is the starting recommended maximum value prior to establishing any applicability margin for CSAs performed at SNL using a version of MCNP6 with a Software Verification & Validation Report (SVVR) generated through the process described in this report. Chapter 5 also shows the bias trends for the benchmark suite with respect to a few parameters important to criticality safety analysis (e.g., neutron lethargy causing fission). Chapter 6 summarizes the SNL NCS benchmark suite and discusses future work.

3. SNL BENCHMARK REPOSITORY STRUCTURE

3.1. Changes in Repository Hosting

The NCS Program at SNL uses a git-based system to maintain configuration management and change control of the NCS benchmark suite. As originally implemented, the git repository was hosted on a server maintain by the Applied Nuclear Technologies department located in Tech Area V. Since the launch of the git repository in 2014 for the NCS benchmark suite, the Applied Nuclear Technologies group has been reorganized (split into two organizations) and the staff member maintaining the NCS portion of the git hosting on the server moved on to new assignments at SNL. As a result of these organizational changes, the SNL NCS Program decided that the git repository should be hosted on a SNL Corporate resource and suggested a restructure of the original implementation.

Using a newly created entity account for the NCS Program (NCSe, ncse@sandia.gov), a fresh repository was created on the SNL Common Engineering Environment (CEE) GitLab Enterprise Edition site [12]. The SNL CEE GitLab site does not rely on any underlying operating system, allows for change control and configuration management by the NCSe account (managed by the NCS Program), and provides for a nightly backup of the repository. By design, the git software allows for a distributed management of the repository. This means that a clone (that is, an exact copy at a point in repository history) has equal status with the repository that was cloned. In addition to the equal status of each clone, a complete repository history (change history) accompanies the cloning process. Although the design of git provides a distributed capability, the CEE GitLab repository provides NCS engineers with a central location to publish modifications to the repository and to obtain any changes that others have made.

3.2. Structure of SNL NCS Benchmark Suite Repository

The git repository for the SNL NCS benchmark suite is divided in two parts: (1) Benchmarks and (2) Whisper Data. A schematic of the structure is found below in Figure 1. As pointed out in the figure, the 882 MCNP6 input files that contain the benchmark models are found in the Benchmarks directory. Whisper [13] is a sensitivity/uncertainty-based calculation technique created by Los Alamos National Laboratory to assist NCS engineers with determining the USL values given a set of criticality benchmarks models. The Whisper Data directory contains data related to using Whisper with the SNL NCS benchmark suite.

3.2.1. Whisper Data

The Whisper code ships with MCNP 6.2 and uses sensitivity/uncertainty based computational methods to investigate the applicability of a calculation model (i.e., application) against a suite of benchmarks. Whisper assigns a correlating coefficient value (ck) between 0 and 1 to each calculation model. Benchmarks with ck values closer to 1 correlate better to the compared modeled application. At SNL benchmarks identified by Whisper with ck values below 0.80 are judged to not correlate well with the application. While benchmarks that have poor correlation can still be used, their use requires a justification and a proper understanding of the cause(s) of the poor correlation.

The Whisper code ships with a default suite of ~1100 benchmarks and are heavy in plutonium experiments. It has been discovered that the default benchmarks contain errors in the provided referenced experimental k_{eff} value (i.e., not correct to the value found in the ICSBEP Handbook). Additionally, they have not been reviewed as required by Sandia's NCS Program. Therefore, none of the default benchmarks are used and instead just the SNL NCS benchmark suite is used for Whisper calculations. New sensitivities were calculated, Covariance Data was adjusted, and a new benchmark Table of Contents (TOC) was built for the SNL suite. The provided Whisper Exclude file was removed and no new file was established. It is the decision of the NCS program to not exclude any of the modelled benchmarks for Whisper calculations.

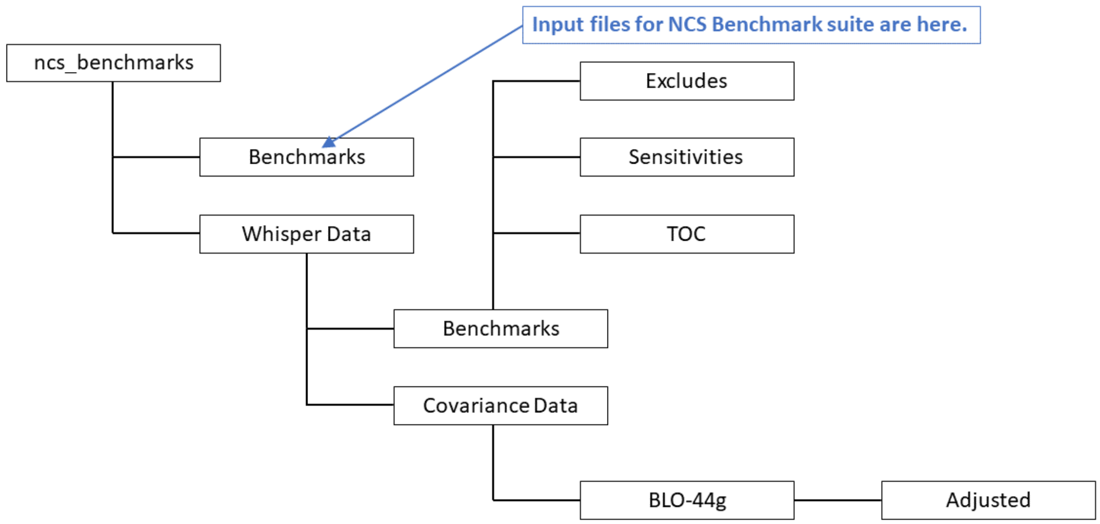

Figure 1 - Directory Structure for NCS Benchmark Repository

3.3. Benchmark Comparison Utility

In the original description of the SNL NCS benchmark suite, a set of comparison scripts was described to assist with the preparation of a SVVR when changing software versions, updating cross section sets, or obtaining a new computer that will be used for NCS analysis. The initial version of the benchmark comparison utility was based on a similar application with the NuGET code developed at SNL [10]. The NuGET code runs nightly automatic regression tests to determine if any changes to the software produced unexpected differences in the baseline output of a calculation. The key in this comparison is that the developer knows that some software modifications are expected to produce changes in the output, and they can distinguish those changes from the ones that are unexpected. The NuGET code is structured in such a way that essentially the entire output file from the current (changed) version of the software is compared with the approved or baseline version of the same output.

3.3.1. Directory Structure

For the purposes of the SNL NCS benchmark suite, the criticality summary data from the current version of MCNP (or from a new computer) is compared with the criticality summary with the same summary data from those benchmarks stored in the repository. The NCS engineer should not expect any differences if the MCNP6 code version and operating system are the same for the baseline and new installation of the software. Additionally, the modifications associated with most code version updates should not impact the criticality calculations. However, small differences can be expected if the comparison between the baseline and the new installation are done with different operating systems or sometimes a different version of MCNP6 (versions declared by Los Alamos National Laboratory to have “non-tracking” changes).

A schematic of the structure for the benchmark comparison utility is found below in Figure 2. The git repository for utility is named "svvr_cee" because it was developed to assist with the production of a SVVR on the SNL Common Engineering Environment (CEE). As with the previous version of the utility, there is a top-level directory for MCNP6 (directory name is "mcnp") that allows for expansion to other codes such as KENO. The directory for MCNP6 contains the input files in a directory named "input" while the comparison utility scripts are found in the "compare" directory.

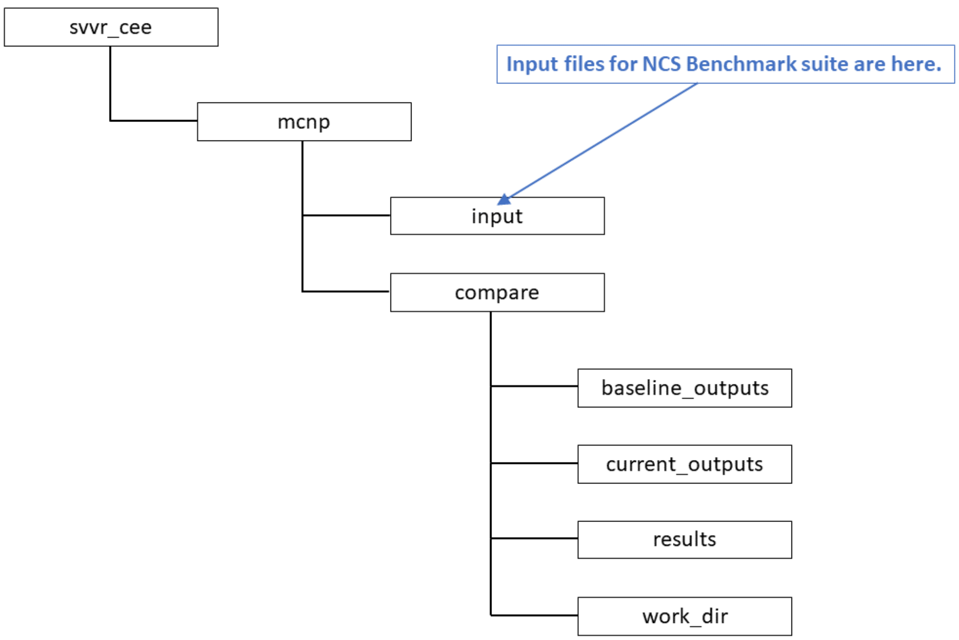

Figure 2 – Repository Structure for the Benchmark Comparison Utility

The compare directory contains four subdirectories:

- "baseline_outputs"
  - Contains the criticality summary information of the accepted benchmark model outputs
- "current_outputs"
  - Holds the full outputs from the current run of the benchmark comparison utility
- "results"
  - Contains the criticality summary information for the current run of the benchmark comparison utility
  - Contains the "diff" file between the current run and the accepted benchmark model criticality summary information
- "work_dir"
  - The working directory used by the benchmark comparison script

3.3.2. Script Flow Logic

The benchmark comparison utility is initialized by a Linux/Unix C-shell start-up script called "compare". The compare script performs the following set of actions:

- Sets an environment variable called SYSTEMTYPE to the value of "unix"

- Purges any system modules, and then loads the proper modules for running MCNP6 on the CEE Engineering Workstations
- Sets the PATH to include the path to the MCNP6 executable that is to be used by the script
- Sets the DATAPATH variable to the location of the MCNP6 cross sections on the machine
- Initiates a call to the perl script ("ncs_comp.prl") that executes MCNP6 for all the benchmark models
  - By default (that is, no arguments), 5 tasks are used in the MCNP6 calculations
  - If an argument is provided, MCNP6 is initiated with the number of tasks specified in the argument

Once the call to the perl script is made, the start-up script has performed its duties. However, it will remain active until the benchmark calculations and comparisons are completed.

The perl script called by the start-up script is the engine that performs the multitude of different operations within the SNL NCS benchmark suite calculations. Here is a high-level overview of the various operations performed by the perl script:

- The script cleans up the "results" and "current_outputs" directories
  - This is done to ensure that the calculations performed later do not conflict with an older run of the benchmark suite
- The script copies the MCNP6 input files for the benchmarks from their storage location into the "work_dir" directory
  - The calculations are performed in a working directory to prevent contamination and conflicts with other calculations
- The script starts spawning the MCNP6 calculations
- When each MCNP6 calculation is completed, the following steps are performed on the output that was generated:
  - The appropriate criticality summary data is extracted from the output file
  - The output file is moved to the "current_outputs" directory
- When all the cases have been completed, the script compares the data extracted from the current execution of the script to the "results" stored in the repository
- The outcome of the comparison is stored in the "results" subdirectory
- The script moves the file containing the extracted benchmark data to the "results" subdirectory

3.3.3. Benchmark Comparison Utility k_{eff} Results

To have baseline k_{eff} results for the SNL NCS benchmark suite, a set of results from a version of MCNP on a given computer operating system was produced with the benchmark comparison utility. The baseline k_{eff} results were produced using MCNP6 Version 2.0 on the CEE Engineering Workstation EWS00838 running 64-bit Red Hat Enterprise Linux Workstation version 7.7.

When a user has completed running the SNL NCS benchmark suite, they will have the following items:

- A summary file that contains the k_{eff} values, standard deviations, and other critical system parameters of interest to an NCS engineer

    - The summary file is an ASCII file named "Current_Outputs.keff"
- A file that summarizes the differences between the current run and the baseline results for the benchmark suite
    - The difference file is name "NCS_Benchmark.dif".
- A complete MCNP output for each of the benchmark model calculations
    - The user should keep these as the archived output for the SVVR

3.4. Obtaining the git Repositories

Obtaining the SNL NCS benchmark suite can be done by simply performing a "git clone" operation. If you are at SNL, contact one of the authors to obtain the appropriate URL for the git repositories maintained by the NCS Program. Questions and comments on this installation process should be directed to K. Russell DePriest (krdepri@sandia.gov) or Shawn J. Henderson (sjhende@sandia.gov).

4. BENCHMARK SUITE

As mentioned earlier, the SNL NCS benchmark suite is a set of benchmark models that have been constructed by a qualified NCS engineer (or a candidate NCS engineer). Each input file was peer reviewed for completeness and accuracy by a two qualified NCS engineers or one qualified NCS engineer and one candidate NCS engineer. Each of the benchmark cases in the suite described in this report has been included in multiple SVVR documents.

Full descriptions of the benchmarks are not provided in this report because that level of detail is available in the individual benchmark reports associated with the experiments found in the ICSBEP Handbook. The naming convention used for the various benchmark cases below should point the reader directly to the benchmark in the ICSBEP Handbook. That is, the full characterization name of the benchmark experiment report is used and concatenated with a descriptor to allow for easy identification. For example, the benchmark case #2 (002) for the highly enriched uranium (HEU), metal (MET), fast energy (FAST) experiment series #16 (016) has the name, HEU-MET-FAST-016-002. The IHESCBE descriptions of an experiment often contain multiple choices for the model of a single benchmark experiment. For example, the Godiva sphere (HEU-MET-FAST-001) has a solid sphere model and a spherical shell model of the same experiment. To prevent a single experiment from providing multiple inputs to a bias determination, we select only one of the benchmark models (usually the more detailed description of the benchmark experiment) for the benchmark suite.

4.1. Highly Enriched Uranium Systems

The SNL NCS benchmark suite contains 366 HEU benchmark cases that were obtained from 62 ICSBEP Handbook descriptions. In the original publication of the SNL NCS benchmark suite, there were 152 HEU benchmark cases from 34 ICSBEP Handbook series descriptions. The HEU benchmark cases included in the suite are found in Table 1. The HEU segment of the benchmark suite is the most extensive because many NCS engineers will use HEU (or pure ^{235}U) for a conservative bounding assumption in their analyses. The HEU benchmark cases include composite intermediate energy experiments, composite mixed energy experiments, metal fast energy experiments, metal intermediate energy experiments, metal thermal energy experiments, and solution thermal energy experiments.

Table 1 – Highly Enriched Uranium Systems in the SNL NCS Benchmark Suite

Case Name	Benchmark Description
HEU-COMP-INTER-003-001 HEU-COMP-INTER-003-002 HEU-COMP-INTER-003-003 HEU-COMP-INTER-003-004 HEU-COMP-INTER-003-005 HEU-COMP-INTER-003-006 HEU-COMP-INTER-003-007	Reflected Uranium-Hydride Cylindrical Assemblies

Case Name	Benchmark Description
HEU-COMP-MIXED-001-002 HEU-COMP-MIXED-001-004 HEU-COMP-MIXED-001-005 HEU-COMP-MIXED-001-006 HEU-COMP-MIXED-001-008 HEU-COMP-MIXED-001-010 HEU-COMP-MIXED-001-011 HEU-COMP-MIXED-001-014 HEU-COMP-MIXED-001-017 HEU-COMP-MIXED-001-018 HEU-COMP-MIXED-001-019 HEU-COMP-MIXED-001-021 HEU-COMP-MIXED-001-022 HEU-COMP-MIXED-001-023 HEU-COMP-MIXED-001-024 HEU-COMP-MIXED-001-025	Arrays of Cans of Highly Enriched Uranium Dioxide Reflected by Polyethylene
HEU-MET-FAST-001-001	Bare, Highly Enriched Uranium Sphere (Godiva)
HEU-MET-FAST-002-001 HEU-MET-FAST-002-002 HEU-MET-FAST-002-003 HEU-MET-FAST-002-004 HEU-MET-FAST-002-005 HEU-MET-FAST-002-006	Topy 8-Inch-Tuballoy-Reflected Oralloy Assemblies
HEU-MET-FAST-003-001 HEU-MET-FAST-003-002 HEU-MET-FAST-003-003 HEU-MET-FAST-003-004 HEU-MET-FAST-003-005 HEU-MET-FAST-003-006 HEU-MET-FAST-003-007 HEU-MET-FAST-003-008 HEU-MET-FAST-003-009 HEU-MET-FAST-003-010 HEU-MET-FAST-003-011 HEU-MET-FAST-003-012	Reflected Oralloy Spherical Assemblies
HEU-MET-FAST-004-001	Water-Reflected, Highly Enriched Uranium Sphere
HEU-MET-FAST-005-001 HEU-MET-FAST-005-002 HEU-MET-FAST-005-003 HEU-MET-FAST-005-004 HEU-MET-FAST-005-005 HEU-MET-FAST-005-006	Beryllium- and Molybdenum-Reflected Cylinders of Highly Enriched Uranium
HEU-MET-FAST-006-001 HEU-MET-FAST-006-002	Lattices of Oralloy Cubes in Water

Case Name	Benchmark Description
HEU-MET-FAST-007-001 HEU-MET-FAST-007-002 HEU-MET-FAST-007-003 HEU-MET-FAST-007-004 HEU-MET-FAST-007-005 HEU-MET-FAST-007-006 HEU-MET-FAST-007-007 HEU-MET-FAST-007-008 HEU-MET-FAST-007-009 HEU-MET-FAST-007-010 HEU-MET-FAST-007-011 HEU-MET-FAST-007-012 HEU-MET-FAST-007-013 HEU-MET-FAST-007-014 HEU-MET-FAST-007-015 HEU-MET-FAST-007-016 HEU-MET-FAST-007-017 HEU-MET-FAST-007-018 HEU-MET-FAST-007-019 HEU-MET-FAST-007-020 HEU-MET-FAST-007-021 HEU-MET-FAST-007-022 HEU-MET-FAST-007-023 HEU-MET-FAST-007-024 HEU-MET-FAST-007-025 HEU-MET-FAST-007-026 HEU-MET-FAST-007-027 HEU-MET-FAST-007-028 HEU-MET-FAST-007-029 HEU-MET-FAST-007-030 HEU-MET-FAST-007-031 HEU-MET-FAST-007-032 HEU-MET-FAST-007-033 HEU-MET-FAST-007-034 HEU-MET-FAST-007-035 HEU-MET-FAST-007-036 HEU-MET-FAST-007-037 HEU-MET-FAST-007-038 HEU-MET-FAST-007-039 HEU-MET-FAST-007-040 HEU-MET-FAST-007-041 HEU-MET-FAST-007-042 HEU-MET-FAST-007-043	Uranium Metal Slabs Moderated with Polyethylene, Plexiglas, and Teflon
HEU-MET-FAST-008-001	Bare Sphere of Highly Enriched Uranium
HEU-MET-FAST-009-001 HEU-MET-FAST-009-002	Spheres of Highly Enriched Uranium Reflected by Beryllium or Beryllium Oxide
HEU-MET-FAST-010-001 HEU-MET-FAST-010-002	Spheres of Highly Enriched Uranium Reflected by Boron + Beryllium or Boron + Beryllium Oxide
HEU-MET-FAST-011-001	Sphere of Highly Enriched Uranium Reflected by Polyethylene
HEU-MET-FAST-012-001	Sphere of Highly Enriched Uranium Reflected by Aluminum

Case Name	Benchmark Description
HEU-MET-FAST-013-001	Sphere of Highly Enriched Uranium Reflected by Steel
HEU-MET-FAST-014-001	Sphere of Highly Enriched Uranium Reflected by Depleted Uranium
HEU-MET-FAST-015-001	Unreflected Cylinder of Highly Enriched Uranium
HEU-MET-FAST-016-001 HEU-MET-FAST-016-002	Beryllium-Reflected and Beryllium Oxide-Reflected Cylinders of Highly Enriched Uranium
HEU-MET-FAST-017-001	Beryllium-Moderated and Reflected Cylinder of Highly Enriched Uranium
HEU-MET-FAST-018-001	Bare Spherical Assembly of ^{235}U(90%)
HEU-MET-FAST-019-001	Graphite-Reflected Spherical Assembly of ^{235}U(90%)
HEU-MET-FAST-020-001	Polyethylene-Reflected Spherical Assembly of ^{235}U(90%)
HEU-MET-FAST-021-001	Steel-Reflected Spherical Assembly of ^{235}U(90%)
HEU-MET-FAST-022-001	Duralumin-Reflected Spherical Assembly of ^{235}U(90%)
HEU-MET-FAST-023-002 HEU-MET-FAST-023-003 HEU-MET-FAST-023-004 HEU-MET-FAST-023-005 HEU-MET-FAST-023-006 HEU-MET-FAST-023-007 HEU-MET-FAST-023-008 HEU-MET-FAST-023-009 HEU-MET-FAST-023-010 HEU-MET-FAST-023-012 HEU-MET-FAST-023-013 HEU-MET-FAST-023-014 HEU-MET-FAST-023-015 HEU-MET-FAST-023-016 HEU-MET-FAST-023-017 HEU-MET-FAST-023-018 HEU-MET-FAST-023-019 HEU-MET-FAST-023-020 HEU-MET-FAST-023-021 HEU-MET-FAST-023-022	Tinkertoy: Unmoderated Uranium Metal (93.2) Arrays with Cylinders of 10.5 kg Mass
HEU-MET-FAST-024-001	Sphere of Highly Enriched Uranium Reflected by Steel and Polyethylene
HEU-MET-FAST-027-001	Spherical Assembly of ^{235}U(90%) with a 3.25-cm Lead Reflector
HEU-MET-FAST-029-001	Spherical Assembly of ^{235}U(90%) with 4.7-cm Depleted Uranium Reflector
HEU-MET-FAST-030-001	Heterogeneous Cylinder of Highly Enriched Uranium with Beryllium Moderator and Depleted-Uranium Reflector
HEU-MET-FAST-031-001	Spherical Assembly of ^{235}U(90%) with Central Area of Polyethylene ad 17.45-cm Polyethylene Reflector
HEU-MET-FAST-038-001 HEU-MET-FAST-038-002	Two Heterogeneous Cylinders of Highly Enriched Uranium with Beryllium and Beryllium Oxide Moderators and Depleted-Uranium Reflector

Case Name	Benchmark Description
HEU-MET-FAST-041-001 HEU-MET-FAST-041-002 HEU-MET-FAST-041-003 HEU-MET-FAST-041-004 HEU-MET-FAST-041-005 HEU-MET-FAST-041-006	^{235}U(94%) Spheres Surrounded by Beryllium or Graphite Reflectors
HEU-MET-FAST-048-001 HEU-MET-FAST-048-002 HEU-MET-FAST-048-003 HEU-MET-FAST-048-004 HEU-MET-FAST-048-005 HEU-MET-FAST-048-006 HEU-MET-FAST-048-007 HEU-MET-FAST-048-008 HEU-MET-FAST-048-009 HEU-MET-FAST-048-010 HEU-MET-FAST-048-011 HEU-MET-FAST-048-012 HEU-MET-FAST-048-013 HEU-MET-FAST-048-014 HEU-MET-FAST-048-015 HEU-MET-FAST-048-016 HEU-MET-FAST-048-017	Oil Reflected Spheres and Hemispheres of Highly Enriched Uranium (93.1% ^{235}U) Metal with Oil or Steel Moderator
HEU-MET-FAST-058-001 HEU-MET-FAST-058-002 HEU-MET-FAST-058-003 HEU-MET-FAST-058-004 HEU-MET-FAST-058-005	Highly Enriched Uranium Metal Spheres with Beryllium Reflectors
HEU-MET-FAST-061-001	ZPPR-21 Phase F: A Cylindrical Assembly of U Metal Reflected by Graphite
HEU-MET-FAST-063-001 HEU-MET-FAST-063-002	Cylindrical Experiments Using HEU Plates Reflected by Lithium Deuteride
HEU-MET-FAST-066-001 HEU-MET-FAST-066-002 HEU-MET-FAST-066-003 HEU-MET-FAST-066-004 HEU-MET-FAST-066-005 HEU-MET-FAST-066-006 HEU-MET-FAST-066-007 HEU-MET-FAST-066-008 HEU-MET-FAST-066-009	Metal Spherical Shells of Highly Enriched Uranium Moderated and Reflected by Beryllium
HEU-MET-FAST-084-003 HEU-MET-FAST-084-016 HEU-MET-FAST-084-026 HEU-MET-FAST-084-027	HEU Metal Cylinders with Magnesium, Titanium, Aluminum, Graphite, Mild Steel, Nickel Copper, Cobalt, Molybdenum, Natural Uranium, Tungsten, Beryllium, Aluminum Oxide, Molybdenum Carbide, and Polyethylene Reflectors
HEU-MET-INTER-001-001	The Uranium/Iron Benchmark Assembly: A ^{235}(93%)/Iron Cylinder Reflector by Stainless Steel
HEU-MET-INTER-009-001 HEU-MET-INTER-009-002	‘SPADE’ Assemblies Part II: Highly Enriched Uranium Metal Foils Moderated by Beryllium Oxide

Case Name	Benchmark Description
HEU-MET-THERM-003-001 HEU-MET-THERM-003-002 HEU-MET-THERM-003-003 HEU-MET-THERM-003-004 HEU-MET-THERM-003-006 HEU-MET-THERM-003-007	Lattices of Oralloy Cubes in Water
HEU-MET-THERM-006-001 HEU-MET-THERM-006-002 HEU-MET-THERM-006-003 HEU-MET-THERM-006-004 HEU-MET-THERM-006-005 HEU-MET-THERM-006-006 HEU-MET-THERM-006-007 HEU-MET-THERM-006-008 HEU-MET-THERM-006-009 HEU-MET-THERM-006-010 HEU-MET-THERM-006-011 HEU-MET-THERM-006-012 HEU-MET-THERM-006-015 HEU-MET-THERM-006-023	Critical Experiments of Spert-D Fuel in Water, Dilute Uranyl Nitrate, and Borated Uranyl Nitrate
HEU-MET-THERM-014-001	2 x 2 x 23 Array of Highly Enriched Uranium with Silicon Dioxide, Moderated and Reflected by Polyethylene
HEU-MET-THERM-018-001	Polyethylene Reflected and Moderated Highly Enriched Uranium System with Concrete
HEU-MET-THERM-027-001 HEU-MET-THERM-027-002 HEU-MET-THERM-027-003 HEU-MET-THERM-027-004 HEU-MET-THERM-027-005 HEU-MET-THERM-027-006 HEU-MET-THERM-027-007 HEU-MET-THERM-027-008 HEU-MET-THERM-027-009 HEU-MET-THERM-027-010 HEU-MET-THERM-027-011 HEU-MET-THERM-027-012 HEU-MET-THERM-027-013 HEU-MET-THERM-027-014 HEU-MET-THERM-027-015	Highly Enriched Uranium Metal Moderated by Beryllium Oxide
HEU-SOL-THERM-001-001 HEU-SOL-THERM-001-002 HEU-SOL-THERM-001-003 HEU-SOL-THERM-001-004 HEU-SOL-THERM-001-005 HEU-SOL-THERM-001-006 HEU-SOL-THERM-001-007 HEU-SOL-THERM-001-008 HEU-SOL-THERM-001-009 HEU-SOL-THERM-001-010	Minimally Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate

Case Name	Benchmark Description
HEU-SOL-THERM-002-001 HEU-SOL-THERM-002-002 HEU-SOL-THERM-002-003 HEU-SOL-THERM-002-004 HEU-SOL-THERM-002-005 HEU-SOL-THERM-002-006 HEU-SOL-THERM-002-007 HEU-SOL-THERM-002-008 HEU-SOL-THERM-002-009 HEU-SOL-THERM-002-010 HEU-SOL-THERM-002-011 HEU-SOL-THERM-002-012 HEU-SOL-THERM-002-013 HEU-SOL-THERM-002-014	Concrete Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate
HEU-SOL-THERM-003-001 HEU-SOL-THERM-003-002 HEU-SOL-THERM-003-003 HEU-SOL-THERM-003-004 HEU-SOL-THERM-003-005 HEU-SOL-THERM-003-006 HEU-SOL-THERM-003-007 HEU-SOL-THERM-003-008 HEU-SOL-THERM-003-009 HEU-SOL-THERM-003-010 HEU-SOL-THERM-003-011 HEU-SOL-THERM-003-012 HEU-SOL-THERM-003-013 HEU-SOL-THERM-003-014 HEU-SOL-THERM-003-015 HEU-SOL-THERM-003-016 HEU-SOL-THERM-003-017 HEU-SOL-THERM-003-018 HEU-SOL-THERM-003-019	Plexiglas Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate
HEU-SOL-THERM-008-001 HEU-SOL-THERM-008-002 HEU-SOL-THERM-008-003 HEU-SOL-THERM-008-004 HEU-SOL-THERM-008-005 HEU-SOL-THERM-008-006 HEU-SOL-THERM-008-007 HEU-SOL-THERM-008-008 HEU-SOL-THERM-008-009 HEU-SOL-THERM-008-010 HEU-SOL-THERM-008-011 HEU-SOL-THERM-008-012 HEU-SOL-THERM-008-013 HEU-SOL-THERM-008-014	Plexiglas Reflected Arrays of Highly Enriched Solutions of Uranyl Nitrate
HEU-SOL-THERM-009-001 HEU-SOL-THERM-009-002 HEU-SOL-THERM-009-003 HEU-SOL-THERM-009-004	Water-Reflected 6.4 Liter Spheres of Enriched Uranium Oxyfluoride Solutions

Case Name	Benchmark Description
HEU-SOL-THERM-010-001 HEU-SOL-THERM-010-002 HEU-SOL-THERM-010-003 HEU-SOL-THERM-010-004	Water-Reflected 9.7 Liter Spheres of Enriched Uranium Oxyfluoride Solutions
HEU-SOL-THERM-011-001 HEU-SOL-THERM-011-002	Water-Reflected 17 Liter Spheres of Enriched Uranium Oxyfluoride Solutions
HEU-SOL-THERM-012-001	Water-Reflected 91 Liter Sphere of Enriched Uranium Oxyfluoride Solutions
HEU-SOL-THERM-014-001 HEU-SOL-THERM-014-002 HEU-SOL-THERM-014-003	Uranium Nitrate Solution (70 gU/l) with Gadolinium
HEU-SOL-THERM-015-001 HEU-SOL-THERM-015-002 HEU-SOL-THERM-015-003 HEU-SOL-THERM-015-004 HEU-SOL-THERM-015-005	Uranium Nitrate Solution (100 gU/l) with Gadolinium
HEU-SOL-THERM-016-001 HEU-SOL-THERM-016-002 HEU-SOL-THERM-016-003	Uranium Nitrate Solution (150 gU/l) with Gadolinium
HEU-SOL-THERM-017-001 HEU-SOL-THERM-017-002 HEU-SOL-THERM-017-003 HEU-SOL-THERM-017-004 HEU-SOL-THERM-017-005 HEU-SOL-THERM-017-006 HEU-SOL-THERM-017-007 HEU-SOL-THERM-017-008	Uranium Nitrate Solution (200 gU/l) with Gadolinium
HEU-SOL-THERM-018-001 HEU-SOL-THERM-018-002 HEU-SOL-THERM-018-003 HEU-SOL-THERM-018-004 HEU-SOL-THERM-018-005 HEU-SOL-THERM-018-006 HEU-SOL-THERM-018-007 HEU-SOL-THERM-018-008 HEU-SOL-THERM-018-009 HEU-SOL-THERM-018-010 HEU-SOL-THERM-018-011 HEU-SOL-THERM-018-012	Uranium Nitrate Solution (300 gU/l) with Gadolinium
HEU-SOL-THERM-019-001 HEU-SOL-THERM-019-002 HEU-SOL-THERM-019-003	Uranium Nitrate Solution (400 gU/l) with Gadolinium

Case Name	Benchmark Description
HEU-SOL-THERM-025-003 HEU-SOL-THERM-025-006 HEU-SOL-THERM-025-007 HEU-SOL-THERM-025-008 HEU-SOL-THERM-025-009 HEU-SOL-THERM-025-010 HEU-SOL-THERM-025-011 HEU-SOL-THERM-025-012 HEU-SOL-THERM-025-013 HEU-SOL-THERM-025-014 HEU-SOL-THERM-025-015 HEU-SOL-THERM-025-016 HEU-SOL-THERM-025-017 HEU-SOL-THERM-025-018	Uranium Nitrate Solutions with Gadolinium
HEU-SOL-THERM-033-001 HEU-SOL-THERM-033-002 HEU-SOL-THERM-033-003 HEU-SOL-THERM-033-004 HEU-SOL-THERM-033-005 HEU-SOL-THERM-033-006 HEU-SOL-THERM-033-007 HEU-SOL-THERM-033-008 HEU-SOL-THERM-033-009 HEU-SOL-THERM-033-010 HEU-SOL-THERM-033-011 HEU-SOL-THERM-033-012 HEU-SOL-THERM-033-013 HEU-SOL-THERM-033-014 HEU-SOL-THERM-033-015 HEU-SOL-THERM-033-016 HEU-SOL-THERM-033-017 HEU-SOL-THERM-033-018 HEU-SOL-THERM-033-019 HEU-SOL-THERM-033-020 HEU-SOL-THERM-033-021 HEU-SOL-THERM-033-022 HEU-SOL-THERM-033-023 HEU-SOL-THERM-033-024 HEU-SOL-THERM-033-025 HEU-SOL-THERM-033-026	Highly Enriched Uranyl Nitrate in Annular Tanks with Concrete: Four Nested Tanks
HEU-SOL-THERM-044-030	Concrete Reflected Uranyl Nitrate Solution Cylinder Containing Periodically Distributed Absorber Rods

4.2. Intermediate and Mixed Enrichment Uranium Systems

The benchmark experiments for the intermediate and mixed enrichment uranium (IEU) bridge the gap between the HEU and low enriched uranium (LEU) systems (described in the next section). The originally published SNL NCS benchmark suite had 11 cases from 8 different criticality experiment series. The updated suite includes has cases from 16 ICSBEP Handbook descriptions with a total of 38 benchmark models. The benchmark cases included in the suite are found below in Table 2. The benchmarks are appropriate because the fuel for the Annular Core Research Reactor (ACRR) falls within this enrichment category, and NCS engineers at SNL perform analyses that involve that fuel. The IEU portion of the benchmark suite contains only fast metal experiments and compound experiment systems at this point.

Table 2 – Intermediate Enrichment Uranium Systems in the SNL NCS Benchmark Suite

Case Name	Benchmark Description
IEU-COMP-THERM-001-001 IEU-COMP-THERM-001-003 IEU-COMP-THERM-001-004 IEU-COMP-THERM-001-005 IEU-COMP-THERM-001-008 IEU-COMP-THERM-001-009 IEU-COMP-THERM-001-011 IEU-COMP-THERM-001-012 IEU-COMP-THERM-001-013 IEU-COMP-THERM-001-016 IEU-COMP-THERM-001-019 IEU-COMP-THERM-001-024 IEU-COMP-THERM-001-025 IEU-COMP-THERM-001-026 IEU-COMP-THERM-001-027 IEU-COMP-THERM-001-029	Critical Arrays of Polyethylene-Moderate $U(30)F_4$-Polytetrafluoroethylene One-Inch Cubes
IEU-COMP-THERM-002-001 IEU-COMP-THERM-002-003 IEU-COMP-THERM-002-005	Water-Moderated $U(17)O_2$ Annular Fuel Rods without Absorber and with Gadolinium or Cadmium Absorbers in 6.8-cm Hexagonal Lattices at Different Temperatures
IEU-COMP-THERM-003-001 IEU-COMP-THERM-003-002	TRIGA Mark II Benchmark Critical Experiments
IEU-MET-FAST-001-001 IEU-MET-FAST-001-002 IEU-MET-FAST-001-003 IEU-MET-FAST-001-004	The Early Jemima Experiments: Bare Cylindrical Configurations of Enriched and Natural Uranium
IEU-MET-FAST-002-001	Natural Uranium Reflected Assembly of Enriched and Natural Uranium Plates
IEU-MET-FAST-003-001	Bare Spherical Assembly of $^{235}U(36\%)$
IEU-MET-FAST-004-001	Graphite-Reflected Spherical Assembly of $^{235}U(36\%)$
IEU-MET-FAST-005-001	Steel-Reflected Spherical Assembly of $^{235}U(36\%)$
IEU-MET-FAST-006-001	Duralumin-Reflected Spherical Assembly of $^{235}U(36\%)$
IEU-MET-FAST-007-001	Big Ten: A Large, Mixed-Uranium-Metal Cylindrical Core with 10% Average ^{235}U Enrichment, Surrounded by a Thick ^{238}U Reflector
IEU-MET-FAST-008-001	Depleted-Uranium-Reflected Spherical Assembly of $^{235}U(36\%)$
IEU-MET-FAST-009-001	Spherical Assembly of $^{235}U(36\%)$ with a 5.75-cm Polyethylene Reflector
IEU-MET-FAST-010-001	The U9 Benchmark Assembly: A Cylindrical Assembly of U Metal (9% ^{235}U) with a Thick Depleted Uranium Reflector
IEU-MET-FAST-012-001	ZPR-3 Assembly-41: A Cylindrical Assembly of U Metal (16% ^{235}U), Aluminum, and Steel, Reflected by Depleted Uranium

Case Name	Benchmark Description
IEU-MET-FAST-013-001	ZPR-9 Assembly-1: A Cylindrical Assembly of U Metal (93% ^{235}U) and Depleted Uranium with Aluminum Reflectors
IEU-MET-FAST-014-001 IEU-MET-FAST-014-002	ZPR-9 Assemblies 2 and 3: Cylindrical Assemblies of U Metal and Tungsten with Aluminum Reflectors

4.3. Low Enriched Uranium Systems

The largest expansion of the original SNL NCS benchmark suite occurred for LEU systems. The updated suite has 319 LEU benchmark models from 44 different ICSBEP Handbook descriptions – up from 22 cases produced with just 3 ICSBEP Handbook descriptions. The LEU benchmark cases included in the suite are found below in Table 3. The benchmark suite LEU systems include thermal composite (heterogeneous) systems, a thermal metal experiment, and thermal solution systems. Some of the composite benchmarks included here were developed in the SNL experimental facilities. The LEU systems are appropriate because SNL conducts critical experiments with the fuel described in those benchmarks.

Table 3 – Low Enriched Uranium Systems in the SNL NCS Benchmark Suite

Case Name	Benchmark Description
LEU-COMP-THERM-001-001 LEU-COMP-THERM-001-002 LEU-COMP-THERM-001-003 LEU-COMP-THERM-001-004 LEU-COMP-THERM-001-005 LEU-COMP-THERM-001-006 LEU-COMP-THERM-001-007 LEU-COMP-THERM-001-008	Water-Moderated $U(2.35)O_2$ Fuel Rods in 2.032-cm Square-Pitched Arrays
LEU-COMP-THERM-002-001 LEU-COMP-THERM-002-002 LEU-COMP-THERM-002-003 LEU-COMP-THERM-002-004 LEU-COMP-THERM-002-005	Water-Moderated $U(4.31)O_2$ Fuel Rods in 2.54-cm Square-Pitched Arrays
LEU-COMP-THERM-008-001 LEU-COMP-THERM-008-002 LEU-COMP-THERM-008-003 LEU-COMP-THERM-008-004 LEU-COMP-THERM-008-005 LEU-COMP-THERM-008-006 LEU-COMP-THERM-008-007 LEU-COMP-THERM-008-008 LEU-COMP-THERM-008-009 LEU-COMP-THERM-008-010 LEU-COMP-THERM-008-011 LEU-COMP-THERM-008-012 LEU-COMP-THERM-008-013 LEU-COMP-THERM-008-014 LEU-COMP-THERM-008-015 LEU-COMP-THERM-008-016 LEU-COMP-THERM-008-017	Critical Lattice of UO_2 Fuel Rods and Perturbing Rods in Borated Water

Case Name	Benchmark Description
LEU-COMP-THERM-009-001 LEU-COMP-THERM-009-002 LEU-COMP-THERM-009-003 LEU-COMP-THERM-009-004 LEU-COMP-THERM-009-005 LEU-COMP-THERM-009-006 LEU-COMP-THERM-009-007 LEU-COMP-THERM-009-008 LEU-COMP-THERM-009-009	Water-Moderated Rectangular Clusters of U(4.31)O_2 Fuel Rods (2.54-cm Pitch) Separated by Steel, Boral, Copper, Cadmium, Aluminum, or Zircalloy-4 Plates
LEU-COMP-THERM-010-001 LEU-COMP-THERM-010-004 LEU-COMP-THERM-010-008 LEU-COMP-THERM-010-013 LEU-COMP-THERM-010-017 LEU-COMP-THERM-010-019 LEU-COMP-THERM-010-023 LEU-COMP-THERM-010-030	Critical Arrays of Water-Moderated of U(4.31)O_2 Fuel Rods by Two Lead, Uranium, or Steel Walls
LEU-COMP-THERM-013-001 LEU-COMP-THERM-013-002 LEU-COMP-THERM-013-003 LEU-COMP-THERM-013-004 LEU-COMP-THERM-013-005 LEU-COMP-THERM-013-006 LEU-COMP-THERM-013-007	Water-Moderated Rectangular Clusters of U(4.31)O_2 Fuel Rods (1.892-cm Pitch) Separated by Steel, Boral, Boroflex, Cadmium or Copper Plates, with Steel Reflecting Walls
LEU-COMP-THERM-014-001 LEU-COMP-THERM-014-002 LEU-COMP-THERM-014-005 LEU-COMP-THERM-014-006 LEU-COMP-THERM-014-007	Water-Reflected Arrays of U(4.31)O_2 Fuel Rods (1.890-cm and 1.715-cm Square Pitch) in Borated Water
LEU-COMP-THERM-016-006 LEU-COMP-THERM-016-007 LEU-COMP-THERM-016-008 LEU-COMP-THERM-016-009 LEU-COMP-THERM-016-010 LEU-COMP-THERM-016-011 LEU-COMP-THERM-016-012 LEU-COMP-THERM-016-013	Water-Moderated Rectangular Clusters of U(2.35)O_2 Fuel Rods (2.032-cm Pitch) Separated by Steel, Boral, Copper, Cadmium, Aluminum, or Zircalloy-4 Plates
LEU-COMP-THERM-019-001 LEU-COMP-THERM-019-002 LEU-COMP-THERM-019-003	Water-Moderated Hexagonally Pitched Lattices of U(5%)O_2 Stainless Steel Clad Fuel Rods
LEU-COMP-THERM-020-001 LEU-COMP-THERM-020-002 LEU-COMP-THERM-020-003 LEU-COMP-THERM-020-004 LEU-COMP-THERM-020-005 LEU-COMP-THERM-020-006 LEU-COMP-THERM-020-007	Water-Moderated Hexagonally Pitched Partially Flooded Lattices of U(5%)O_2 Zirconium Clad Fuel Rods

Case Name	Benchmark Description
LEU-COMP-THERM-021-001 LEU-COMP-THERM-021-002 LEU-COMP-THERM-021-003 LEU-COMP-THERM-021-004 LEU-COMP-THERM-021-005 LEU-COMP-THERM-021-006	Hexagonally Pitched Partially Flooded Lattices of $U(5\%)O_2$ Zirconium Clad Fuel Rods Moderated by Water with Boric Acid
LEU-COMP-THERM-022-001 LEU-COMP-THERM-022-002 LEU-COMP-THERM-022-003 LEU-COMP-THERM-022-004 LEU-COMP-THERM-022-005 LEU-COMP-THERM-022-006 LEU-COMP-THERM-022-007	Uniform Water-Moderated Hexagonally Pitched Lattices of Rods with $U(10\%)O_2$ Fuel
LEU-COMP-THERM-023-001 LEU-COMP-THERM-023-002 LEU-COMP-THERM-023-003 LEU-COMP-THERM-023-004 LEU-COMP-THERM-023-005 LEU-COMP-THERM-023-006	Partially Flooded Uniform Lattices of Rods with $U(10\%)O_2$ Fuel
LEU-COMP-THERM-024-001 LEU-COMP-THERM-024-002	Water-Moderated Square-Pitched Uniform Lattices of Rods with $U(10\%)O_2$ Fuel
LEU-COMP-THERM-025-001 LEU-COMP-THERM-025-002 LEU-COMP-THERM-025-003 LEU-COMP-THERM-025-004	Water-Moderated Hexagonally Pitched Uniform Lattices of $U(7.5\%)O_2$ Stainless-Steel-Clad Fuel Rods
LEU-COMP-THERM-026-001 LEU-COMP-THERM-026-003 LEU-COMP-THERM-026-005	Water-Moderated $U(4.92)O_2$ Fuel Rods in 1.29, 1.09, and 1.01 cm Pitch Hexagonal Lattices at Different Temperatures
LEU-COMP-THERM-028-007 LEU-COMP-THERM-028-008 LEU-COMP-THERM-028-009 LEU-COMP-THERM-028-013 LEU-COMP-THERM-028-014 LEU-COMP-THERM-028-019 LEU-COMP-THERM-028-020	Water-Moderated $U(4.31)O_2$ Fuel Rods in Triangular Lattices with Boron, Cadmium and Gadolinium as Soluble Poisons
LEU-COMP-THERM-042-001 LEU-COMP-THERM-042-002 LEU-COMP-THERM-042-003 LEU-COMP-THERM-042-004	Water-Moderated Rectangular Clusters of $U(2.35)O_2$ Fuel Rods (1.684-cm Pitch) Separated by Steel, Boral, Boroflex, Cadmium, or Copper Plates with Steel Reflecting Walls
LEU-COMP-THERM-043-001 LEU-COMP-THERM-043-002 LEU-COMP-THERM-043-003 LEU-COMP-THERM-043-004 LEU-COMP-THERM-043-005 LEU-COMP-THERM-043-006 LEU-COMP-THERM-043-007 LEU-COMP-THERM-043-008 LEU-COMP-THERM-043-009	Critical Loading Configurations of the IPEN/MB-01 Reactor with a Heavy Reflector

Case Name	Benchmark Description
LEU-COMP-THERM-049-001 LEU-COMP-THERM-049-002 LEU-COMP-THERM-049-003 LEU-COMP-THERM-049-004 LEU-COMP-THERM-049-005 LEU-COMP-THERM-049-006 LEU-COMP-THERM-049-007 LEU-COMP-THERM-049-008 LEU-COMP-THERM-049-009 LEU-COMP-THERM-049-010 LEU-COMP-THERM-049-011 LEU-COMP-THERM-049-012 LEU-COMP-THERM-049-013 LEU-COMP-THERM-049-014 LEU-COMP-THERM-049-015 LEU-COMP-THERM-049-016 LEU-COMP-THERM-049-017 LEU-COMP-THERM-049-018	Maracas Program: Polythene Reflected Critical Configurations with Low Enriched and Low Moderated Uranium Dioxide Powder $U(5)O_2$
LEU-COMP-THERM-050-001 LEU-COMP-THERM-050-002 LEU-COMP-THERM-050-003 LEU-COMP-THERM-050-004 LEU-COMP-THERM-050-005 LEU-COMP-THERM-050-006 LEU-COMP-THERM-050-007 LEU-COMP-THERM-050-008 LEU-COMP-THERM-050-009 LEU-COMP-THERM-050-010 LEU-COMP-THERM-050-011 LEU-COMP-THERM-050-012 LEU-COMP-THERM-050-013 LEU-COMP-THERM-050-014 LEU-COMP-THERM-050-015 LEU-COMP-THERM-050-016 LEU-COMP-THERM-050-017 LEU-COMP-THERM-050-018	^{149}Sm Solution Tank in the Middle of Water-Moderated 4.738-Wt.%-Enriched Uranium Dioxide Rod Arrays

Case Name	Benchmark Description
LEU-COMP-THERM-051-001 LEU-COMP-THERM-051-002 LEU-COMP-THERM-051-003 LEU-COMP-THERM-051-004 LEU-COMP-THERM-051-005 LEU-COMP-THERM-051-006 LEU-COMP-THERM-051-007 LEU-COMP-THERM-051-008 LEU-COMP-THERM-051-009 LEU-COMP-THERM-051-010 LEU-COMP-THERM-051-011 LEU-COMP-THERM-051-012 LEU-COMP-THERM-051-013 LEU-COMP-THERM-051-014 LEU-COMP-THERM-051-015 LEU-COMP-THERM-051-016 LEU-COMP-THERM-051-017 LEU-COMP-THERM-051-018 LEU-COMP-THERM-051-019	Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel, Part II – Isolating Plates
LEU-COMP-THERM-052-001 LEU-COMP-THERM-052-002 LEU-COMP-THERM-052-003 LEU-COMP-THERM-052-004 LEU-COMP-THERM-052-005 LEU-COMP-THERM-052-006	Uranium Dioxide (4.738-Wt.%-Enriched) Fuel Rod Arrays Moderated and Reflected by Gadolinium Nitrate Solution
LEU-COMP-THERM-054-001 LEU-COMP-THERM-054-002 LEU-COMP-THERM-054-003 LEU-COMP-THERM-054-004 LEU-COMP-THERM-054-005 LEU-COMP-THERM-054-006 LEU-COMP-THERM-054-007 LEU-COMP-THERM-054-008	Critical Loading Configurations of the IPEN/MB-01 Reactor with UO_2, and UO_2-Gd_2O_3 Rods
LEU-COMP-THERM-058-001 LEU-COMP-THERM-058-002 LEU-COMP-THERM-058-003 LEU-COMP-THERM-058-004 LEU-COMP-THERM-058-005 LEU-COMP-THERM-058-006	Critical Loading Configurations of the IPEN/MB-01 Reactor with a Large Void in the Reflector

Case Name	Benchmark Description
LEU-COMP-THERM-078-001 LEU-COMP-THERM-078-002 LEU-COMP-THERM-078-003 LEU-COMP-THERM-078-004 LEU-COMP-THERM-078-005 LEU-COMP-THERM-078-006 LEU-COMP-THERM-078-007 LEU-COMP-THERM-078-008 LEU-COMP-THERM-078-009 LEU-COMP-THERM-078-010 LEU-COMP-THERM-078-011 LEU-COMP-THERM-078-012 LEU-COMP-THERM-078-013 LEU-COMP-THERM-078-014 LEU-COMP-THERM-078-015	Water-Moderated Square-Pitched U(6.90)O_2 Fuel Rod Lattices with 0.52 Fuel-To-Water Volume Ratio (0.855 cm Pitch)
LEU-COMP-THERM-079-001 LEU-COMP-THERM-079-002 LEU-COMP-THERM-079-003 LEU-COMP-THERM-079-004 LEU-COMP-THERM-079-005 LEU-COMP-THERM-079-006 LEU-COMP-THERM-079-007 LEU-COMP-THERM-079-008 LEU-COMP-THERM-079-009 LEU-COMP-THERM-079-010	Water-Moderated U(4.31)O_2 Fuel Rod Lattices Containing Rhodium Foils
LEU-COMP-THERM-080-001 LEU-COMP-THERM-080-002 LEU-COMP-THERM-080-003 LEU-COMP-THERM-080-004 LEU-COMP-THERM-080-005 LEU-COMP-THERM-080-006 LEU-COMP-THERM-080-007 LEU-COMP-THERM-080-008 LEU-COMP-THERM-080-009 LEU-COMP-THERM-080-010 LEU-COMP-THERM-080-011	Water-Moderated Square-Pitched U(6.90)O_2 Fuel Rod Lattices with 0.67 Fuel-To-Water Volume Ratio
LEU-COMP-THERM-091-001 LEU-COMP-THERM-091-002 LEU-COMP-THERM-091-003 LEU-COMP-THERM-091-004 LEU-COMP-THERM-091-005 LEU-COMP-THERM-091-006 LEU-COMP-THERM-091-007 LEU-COMP-THERM-091-008 LEU-COMP-THERM-091-009	Critical Loading Configurations of the IPEN/MB-01 Reactor with UO_2, Stainless Steel, and Gd_2O_3 Rods
LEU-MET-THERM-001-001	RB Reactor: Natural-Uranium Rods in Heavy Water

Case Name	Benchmark Description
LEU-SOL-THERM-003-001 LEU-SOL-THERM-003-002 LEU-SOL-THERM-003-003 LEU-SOL-THERM-003-004 LEU-SOL-THERM-003-005 LEU-SOL-THERM-003-006 LEU-SOL-THERM-003-007 LEU-SOL-THERM-003-008 LEU-SOL-THERM-003-009	Full and Truncated Bare Spheres of 10% Enriched Uranyl Nitrate Water Solutions
LEU-SOL-THERM-004-001 LEU-SOL-THERM-004-002 LEU-SOL-THERM-004-003 LEU-SOL-THERM-004-004 LEU-SOL-THERM-004-005 LEU-SOL-THERM-004-006 LEU-SOL-THERM-004-007	STACY: Water-Reflected 10% Enriched Uranyl Nitrate Solution in a 60-cm-Diameter Cylindrical Tank
LEU-SOL-THERM-005-001 LEU-SOL-THERM-005-002 LEU-SOL-THERM-005-003	Boron Carbide Absorber Rods in Uranium (5.64% ^{235}U) Nitrate Solution
LEU-SOL-THERM-006-001 LEU-SOL-THERM-006-002 LEU-SOL-THERM-006-003 LEU-SOL-THERM-006-004 LEU-SOL-THERM-006-005	Boron Carbide Absorber Rods in Uranium (10% ^{235}U) Nitrate Solution
LEU-SOL-THERM-007-001 LEU-SOL-THERM-007-002 LEU-SOL-THERM-007-003 LEU-SOL-THERM-007-004 LEU-SOL-THERM-007-005	STACY: Unreflected 10% Enriched Uranyl Nitrate Solution in a 60-cm-Diameter Cylindrical Tank
LEU-SOL-THERM-008-001 LEU-SOL-THERM-008-002 LEU-SOL-THERM-008-003 LEU-SOL-THERM-008-004	STACY: 60-cm Diameter Cylinders of 10%-Enriched Uranyl Nitrate Solutions Reflected with Concrete
LEU-SOL-THERM-009-001 LEU-SOL-THERM-009-002 LEU-SOL-THERM-009-003	STACY: 60-cm Diameter Cylinders of 10%-Enriched Uranyl Nitrate Solutions Reflected with Borated Concrete
LEU-SOL-THERM-010-001 LEU-SOL-THERM-010-002 LEU-SOL-THERM-010-003 LEU-SOL-THERM-010-004	STACY: 60-cm Diameter Cylinders of 10%-Enriched Uranyl Nitrate Solutions Reflected with Polyethylene
LEU-SOL-THERM-016-001 LEU-SOL-THERM-016-002 LEU-SOL-THERM-016-003 LEU-SOL-THERM-016-004 LEU-SOL-THERM-016-005 LEU-SOL-THERM-016-006 LEU-SOL-THERM-016-007	STACY: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions, Water-Reflected

Case Name	Benchmark Description
LEU-SOL-THERM-017-001 LEU-SOL-THERM-017-002 LEU-SOL-THERM-017-003 LEU-SOL-THERM-017-004 LEU-SOL-THERM-017-005 LEU-SOL-THERM-017-006	STACY: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions, Unreflected
LEU-SOL-THERM-018-001 LEU-SOL-THERM-018-002 LEU-SOL-THERM-018-003 LEU-SOL-THERM-018-004 LEU-SOL-THERM-018-005 LEU-SOL-THERM-018-006	STACY: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions Reflected with Concrete
LEU-SOL-THERM-019-001 LEU-SOL-THERM-019-002 LEU-SOL-THERM-019-003 LEU-SOL-THERM-019-004 LEU-SOL-THERM-019-005 LEU-SOL-THERM-019-006	STACY: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions Reflected with Polyethylene
LEU-SOL-THERM-020-001 LEU-SOL-THERM-020-002 LEU-SOL-THERM-020-003 LEU-SOL-THERM-020-004	STACY: 80-cm-Diameter Cylindrical Tank of 10%-Enriched Uranyl Nitrate Solutions, Water-Reflected
LEU-SOL-THERM-021-001 LEU-SOL-THERM-021-002 LEU-SOL-THERM-021-003 LEU-SOL-THERM-021-004	STACY: 80-cm-Diameter Cylindrical Tank of 10%-Enriched Uranyl Nitrate Solutions, Unreflected

4.4. Mixed Uranium / Plutonium Systems

The SNL NCS benchmark suite now contains 37 (up from 28) mixed enrichment uranium / plutonium (MIX) benchmark cases that were obtained from 11 (up from 4) ICSBEP Handbook descriptions. The benchmark cases included in the suite are found below in Table 4. The fast metal experiments and composite material experiments in this region of the benchmark suite are intended to demonstrate that mixtures of the fissile materials of interest at SNL are adequately described by the code system and cross sections.

Table 4 – Mixed Uranium / Plutonium Systems in the SNL NCS Benchmark Suite

Case Name	Benchmark Description
MIX-COMP-THERM-002-002	Rectangular Arrays of Water-Moderated UO_2 - 2 Wt.% PuO_2 (8% ^{240}Pu) Fuel Rods
MIX-COMP-THERM-003-006	Rectangular Arrays of Water-Moderated UO_2 - 6.6 Wt.% PuO_2 Fuel Rods
MIX-COMP-THERM-006-001	Water-Moderated Mixed Oxide Hexagonal Lattices - 2.0 Wt.% PuO_2, 8% ^{240}Pu, Natural Uranium
MIX-COMP-THERM-008-001	Hexagonal Lattices of Mixed Oxide Fuel Pins - 2.0 Wt.% PuO_2, 24% ^{240}Pu, Natural Uranium

Case Name	Benchmark Description
MIX-MET-FAST-001-001	Benchmark Critical Experiment of a Plutonium Sphere Surrounded by Highly Enriched Uranium
MIX-MET-FAST-002-001 MIX-MET-FAST-002-002 MIX-MET-FAST-002-003	Spherical Composite Cores Composed of Plutonium and Highly Enriched Uranium Reflected by Normal Uranium
MIX-MET-FAST-003-001	Sphere of Plutonium Surrounded by Highly Enriched Uranium
MIX-MET-FAST-007-001 MIX-MET-FAST-007-002 MIX-MET-FAST-007-003 MIX-MET-FAST-007-004 MIX-MET-FAST-007-005 MIX-MET-FAST-007-006 MIX-MET-FAST-007-007 MIX-MET-FAST-007-008 MIX-MET-FAST-007-009 MIX-MET-FAST-007-010 MIX-MET-FAST-007-011 MIX-MET-FAST-007-012 MIX-MET-FAST-007-013 MIX-MET-FAST-007-014 MIX-MET-FAST-007-015 MIX-MET-FAST-007-016 MIX-MET-FAST-007-017 MIX-MET-FAST-007-018 MIX-MET-FAST-007-019 MIX-MET-FAST-007-020 MIX-MET-FAST-007-021 MIX-MET-FAST-007-022 MIX-MET-FAST-007-023	Critical Experiments Performed Using Spherical Composite Cores Reflected by Beryllium
MIX-MET-MIXED-001-001	Heterogeneous Cylinder of Plutonium, Highly Enriched Uranium, and Polyethylene
MIX-SOL-THERM-001-001 MIX-SOL-THERM-001-011	Critical Experiments with Mixed Plutonium and Uranium Nitrate Solution at a Plutonium Fraction of 0.2 and 1.0 in Annular Geometry
MIX-SOL-THERM-004-001 MIX-SOL-THERM-004-002	Critical Experiments with Mixed Plutonium and Uranium Nitrate Solution at a Plutonium Fraction of 0.4 in Small Cylindrical Geometry

4.5. Plutonium Systems

The updated SNL NCS benchmark suite currently contains 122 plutonium (PU) benchmark cases that were obtained from 33 ICSBEP Handbook descriptions. The benchmark cases included in the suite are found below in Table 5. The plutonium region of the benchmark suite includes fast metal experiments and thermal solution experiments. The plutonium benchmarks are included in the suite are appropriate for current SNL analyses involving plutonium materials.

Table 5 – Plutonium Systems in the SNL NCS Benchmark Suite

Case Name	Benchmark Description
PU-MET-FAST-001-001	Bare Sphere of Plutonium-239 Metal (4.5% at.% ^{240}Pu, 1.02 wt% Ga)
PU-MET-FAST-002-001	Bare Sphere of Plutonium-239 Metal (^{240}Pu Jezebel)
PU-MET-FAST-003-001 PU-MET-FAST-003-002 PU-MET-FAST-003-003 PU-MET-FAST-003-004 PU-MET-FAST-003-005	Unmoderated Plutonium Metal Button Array
PU-MET-FAST-005-001	Benchmark Critical Experiment of a Plutonium Sphere Reflected by Tungsten
PU-MET-FAST-006-001	Plutonium Sphere Reflected by Normal Uranium Using Flattop
PU-MET-FAST-008-001 PU-MET-FAST-008-002	Benchmark Critical Experiment of a Thorium Reflected Plutonium Sphere
PU-MET-FAST-009-001	Benchmark Critical Experiment of a Plutonium Sphere Reflected by Aluminum
PU-MET-FAST-010-001	Benchmark Critical Experiment of a Delta-Phase Plutonium Sphere Reflected by Normal Uranium
PU-MET-FAST-011-001	Benchmark Critical Experiment of a Water Reflected Alpha-Phase Plutonium Sphere
PU-MET-FAST-012-001	Uranium-Reflected Array of Plutonium Fuel Rods
PU-MET-FAST-013-001	Copper-Reflected Array of Plutonium Fuel Rods
PU-MET-FAST-018-001	Benchmark Critical Experiment of a Delta-Phase Plutonium Sphere Reflected by Beryllium
PU-MET-FAST-019-001	Sphere of Plutonium Reflected by Beryllium
PU-MET-FAST-020-001	Sphere of Plutonium Reflected by Depleted Uranium
PU-MET-FAST-024-001	Polyethylene-Reflected Spherical Assembly of ^{239}Pu(δ, 98%)
PU-MET-FAST-025-001	Spherical Assembly of ^{239}Pu(δ, 98%) with 1.55-cm Steel Reflector
PU-MET-FAST-026-001	Spherical Assembly of ^{239}Pu(δ, 98%) with 11.9-cm Steel Reflector
PU-MET-FAST-027-001 PU-MET-FAST-027-002 PU-MET-FAST-027-003 PU-MET-FAST-027-004 PU-MET-FAST-027-005	Polyethylene-Reflected Spherical Assembly of ^{239}Pu(δ, 89%)
PU-MET-FAST-028-001	Steel-Reflected Spherical Assembly of ^{239}Pu(δ, 89%)
PU-MET-FAST-031-001	Polyethylene-Reflected Spherical Assembly of ^{239}Pu(α, 88%)
PU-MET-FAST-035-001	Spherical Assembly of ^{239}Pu(δ, 98%) with 3.15-cm Lead Reflector

Case Name	Benchmark Description
PU-MET-FAST-037-001 PU-MET-FAST-037-005 PU-MET-FAST-037-007 PU-MET-FAST-037-012 PU-MET-FAST-037-015 PU-MET-FAST-037-016	Flooded 2 x 2 x N Arrays of 3-kg Plutonium Metal Cylinders - Phase 2
PU-SOL-THERM-001-001 PU-SOL-THERM-001-002 PU-SOL-THERM-001-003 PU-SOL-THERM-001-004 PU-SOL-THERM-001-005 PU-SOL-THERM-001-006	Water Reflected 11.5” Diameter Spheres of Plutonium Nitrate Solutions
PU-SOL-THERM-002-001 PU-SOL-THERM-002-002 PU-SOL-THERM-002-003 PU-SOL-THERM-002-004 PU-SOL-THERM-002-005 PU-SOL-THERM-002-006 PU-SOL-THERM-002-007	Water Reflected 12” Diameter Spheres of Plutonium Nitrate Solutions
PU-SOL-THERM-003-001 PU-SOL-THERM-003-002 PU-SOL-THERM-003-003 PU-SOL-THERM-003-004 PU-SOL-THERM-003-005 PU-SOL-THERM-003-006 PU-SOL-THERM-003-007 PU-SOL-THERM-003-008	Water Reflected 13” Diameter Spheres of Plutonium Nitrate Solutions
PU-SOL-THERM-004-001 PU-SOL-THERM-004-002 PU-SOL-THERM-004-003 PU-SOL-THERM-004-004 PU-SOL-THERM-004-005 PU-SOL-THERM-004-006 PU-SOL-THERM-004-007 PU-SOL-THERM-004-008 PU-SOL-THERM-004-009 PU-SOL-THERM-004-010 PU-SOL-THERM-004-011 PU-SOL-THERM-004-012 PU-SOL-THERM-004-013	Water Reflected 14” Diameter Spheres of Plutonium Nitrate Solutions, 0.54% to 3.43%
PU-SOL-THERM-005-001 PU-SOL-THERM-005-002 PU-SOL-THERM-005-003 PU-SOL-THERM-005-004 PU-SOL-THERM-005-005 PU-SOL-THERM-005-006 PU-SOL-THERM-005-007 PU-SOL-THERM-005-008 PU-SOL-THERM-005-009	Water Reflected 14” Diameter Spheres of Plutonium Nitrate Solutions, 4.05% and 4.40%

Case Name	Benchmark Description
PU-SOL-THERM-006-001 PU-SOL-THERM-006-002 PU-SOL-THERM-006-003	Water Reflected 15” Diameter Spheres of Plutonium Nitrate Solutions
PU-SOL-THERM-008-016 PU-SOL-THERM-008-020 PU-SOL-THERM-008-021 PU-SOL-THERM-008-025 PU-SOL-THERM-008-027 PU-SOL-THERM-008-029	Concrete-Reflected 14-Inch Diameter Spheres of Plutonium Nitrate Solutions
PU-SOL-THERM-009-001 PU-SOL-THERM-009-002 PU-SOL-THERM-009-003	Unreflected 48” Diameter Sphere of Plutonium Nitrate Solution
PU-SOL-THERM-013-001 PU-SOL-THERM-013-002 PU-SOL-THERM-013-004 PU-SOL-THERM-013-005 PU-SOL-THERM-013-006 PU-SOL-THERM-013-007 PU-SOL-THERM-013-008 PU-SOL-THERM-013-009 PU-SOL-THERM-013-010 PU-SOL-THERM-013-011 PU-SOL-THERM-013-012 PU-SOL-THERM-013-013 PU-SOL-THERM-013-014 PU-SOL-THERM-013-015 PU-SOL-THERM-013-016 PU-SOL-THERM-013-017 PU-SOL-THERM-013-018 PU-SOL-THERM-013-019 PU-SOL-THERM-013-020 PU-SOL-THERM-013-021 PU-SOL-THERM-013-022	Interacting Cylinders of 256-mm Diameter with Plutonium Nitrate Solution (115.1 g/L) in Air
PU-SOL-THERM-014-001 PU-SOL-THERM-014-007 PU-SOL-THERM-014-013 PU-SOL-THERM-014-018 PU-SOL-THERM-014-024 PU-SOL-THERM-014-030	Interacting Cylinders of 300-mm Diameter with Plutonium Nitrate Solution (115.1 gPu/L) in Air
PU-SOL-THERM-015-001 PU-SOL-THERM-015-007 PU-SOL-THERM-015-011 PU-SOL-THERM-015-015	Interacting Cylinders of 300-mm Diameter with Plutonium Nitrate Solution (152.5 gPu/L) in Air

5. ESTABLISHING AN UPPER SUBCRITICAL LIMIT (USL)

The focus of this report is on the description and content of the updated SNL NCS benchmark suite developed for MCNP6. However, the utility of the benchmark suite can be illustrated by developing an upper subcritical limit (USL) using the full benchmark model set. The USL is a limit on the calculated k_{eff} that is established to ensure that conditions calculated to be subcritical will be subcritical in practice. This chapter will derive a USL value using the bias, the bias uncertainty, the margin of subcriticality, and the margin associated with applicability of the benchmarks to the NCS activities under analysis.

The USL is defined in a NCS procedure for creating a software verification and validation report [14] in the following manner:

$$\begin{aligned} USL &= \text{Statistical Method} - MOS \\ USL &= \text{Statistical Method} - (MOS_{Code} + MOS_{Bench} + MOS_{Validation}) \end{aligned} \qquad \text{Eq (6)}$$

The “Statistical Method” of Eq (6) is provided in the appendices to the NCS procedure and depends on statistical characteristics of the NCS benchmark model suite. The NCS Program at SNL has established a minimum MOS_{Code} of 0.02 based on the computer code system [14]. The NCS engineer must determine if additional margin is required based on the benchmark applicability to the conditions under analysis (MOS_{Bench}). Finally, sensitivity and uncertainty analysis may be used to determine if benchmarks in the suite are correlated with the conditions under analysis. In most cases, the margin related to these investigations ($MOS_{Validation}$) “should be small, if not zero” [14].

The MCNP6 Version 2.0 code system was installed according to the installation instructions from Los Alamos National Laboratory on SNL CEE Engineering Workstation EWS00838 running 64-bit Red Hat Enterprise Linux Workstation version 7.7. The installation test suite that accompanies the code distribution finished with no differences. The results displayed in this chapter were generated on EWS00838 using 5 tasks (or threads) using ENDF/B-VII.1 cross sections for the nuclear data. The calculated k_{eff} results from each benchmark model are found in Table 1 in columns 2 and 3.

5.1. Bias & Bias Uncertainty

The establishment of a bias depends on the specifics of the selected benchmarks, the details contained in the benchmark modeling such as the accuracy of the cross sections, the modeling match to experiment, and the computational methodology. The bias uncertainty accounts for the combined effects of uncertainties in the benchmark critical experiments, the models of the benchmarks, and the calculation method.

The bias for each case in the SNL NCS benchmark suite is computed according to Eq (3). As mentioned in Chapter 1, a positive bias means that the analysis method is conservative (calculation is higher than actual k_{eff}), and a negative bias means that the analysis method is non-conservative. As previously mentioned, the results of the MCNP6 Version 2.0 calculations for the benchmark suite are found in Table 6. The table includes the calculated k_{eff} (k_{Calc}), the calculated standard deviation (σ_{Calc}), the experimental or benchmark k_{eff} (k_{Bench}), the benchmark uncertainty (σ_{Bench}), the bias for the benchmark and the standard deviation of the bias (σ_{Bias})for the benchmark. The standard deviation for the bias of a benchmark is computed using the following equation:

$$\sigma_{Bias} = \sqrt{\sigma_{Calc}^2 + \sigma_{Bench}^2} \quad \text{Eq (7)}$$

Table 6 – MCNP6 Results for SNL NCS Benchmark Suite with ENDF/B-VII Cross Sections

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-COMP-INTER-003-001	1.00713	0.00073	1.0000	0.0057	0.0071	0.0057
HEU-COMP-INTER-003-002	1.00581	0.00078	1.0000	0.0061	0.0058	0.0061
HEU-COMP-INTER-003-003	1.00745	0.00081	1.0000	0.0056	0.0074	0.0057
HEU-COMP-INTER-003-004	1.00645	0.00074	1.0000	0.0055	0.0065	0.0055
HEU-COMP-INTER-003-005	1.00763	0.00083	1.0000	0.0047	0.0076	0.0048
HEU-COMP-INTER-003-006	1.00599	0.00079	1.0000	0.0047	0.0060	0.0048
HEU-COMP-INTER-003-007	1.00288	0.00077	1.0000	0.0050	0.0029	0.0051
HEU-COMP-MIXED-001-002	1.00423	0.00075	1.0012	0.0059	0.0030	0.0059
HEU-COMP-MIXED-001-004	0.98982	0.00082	0.9953	0.0056	-0.0055	0.0057
HEU-COMP-MIXED-001-005	0.99423	0.00080	0.9997	0.0038	-0.0055	0.0039
HEU-COMP-MIXED-001-006	0.99308	0.00079	0.9984	0.0052	-0.0053	0.0053
HEU-COMP-MIXED-001-008	0.99158	0.00082	0.9979	0.0052	-0.0063	0.0053
HEU-COMP-MIXED-001-010	0.99363	0.00079	0.9972	0.0052	-0.0036	0.0053
HEU-COMP-MIXED-001-011	0.99900	0.00080	1.0032	0.0053	-0.0042	0.0054
HEU-COMP-MIXED-001-014	0.99330	0.00084	0.9997	0.0046	-0.0064	0.0047
HEU-COMP-MIXED-001-017	1.01082	0.00085	1.0060	0.0065	0.0048	0.0066
HEU-COMP-MIXED-001-018	1.00635	0.00083	1.0026	0.0064	0.0038	0.0065
HEU-COMP-MIXED-001-019	1.00462	0.00078	1.0013	0.0064	0.0033	0.0064
HEU-COMP-MIXED-001-021	1.00731	0.00092	1.0020	0.0053	0.0053	0.0054
HEU-COMP-MIXED-001-022	1.00294	0.00085	0.9983	0.0053	0.0046	0.0054
HEU-COMP-MIXED-001-023	1.00487	0.00097	0.9998	0.0053	0.0051	0.0054
HEU-COMP-MIXED-001-024	1.00305	0.00089	0.9991	0.0053	0.0040	0.0054
HEU-COMP-MIXED-001-025	1.00697	0.00089	1.0037	0.0053	0.0033	0.0054
HEU-MET-FAST-001-001	1.00049	0.00058	1.0000	0.0010	0.0005	0.0012
HEU-MET-FAST-002-001	1.00133	0.00065	1.0000	0.0030	0.0013	0.0031
HEU-MET-FAST-002-002	1.00063	0.00065	1.0000	0.0030	0.0006	0.0031
HEU-MET-FAST-002-003	1.00095	0.00067	1.0000	0.0030	0.0010	0.0031
HEU-MET-FAST-002-004	0.99832	0.00065	1.0000	0.0030	-0.0017	0.0031
HEU-MET-FAST-002-005	0.99885	0.00063	1.0000	0.0030	-0.0011	0.0031
HEU-MET-FAST-002-006	0.99936	0.00066	1.0000	0.0030	-0.0006	0.0031
HEU-MET-FAST-003-001	0.99359	0.00059	1.0000	0.0050	-0.0064	0.0050
HEU-MET-FAST-003-002	0.99457	0.00058	1.0000	0.0050	-0.0054	0.0050
HEU-MET-FAST-003-003	0.99949	0.00061	1.0000	0.0050	-0.0005	0.0050
HEU-MET-FAST-003-004	0.99675	0.00060	1.0000	0.0030	-0.0032	0.0031
HEU-MET-FAST-003-005	1.00123	0.00062	1.0000	0.0030	0.0012	0.0031
HEU-MET-FAST-003-006	1.00133	0.00065	1.0000	0.0030	0.0013	0.0031

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-MET-FAST-003-007	1.00146	0.00062	1.0000	0.0030	0.0015	0.0031
HEU-MET-FAST-003-008	1.00192	0.00065	1.0000	0.0050	0.0019	0.0050
HEU-MET-FAST-003-009	1.00212	0.00068	1.0000	0.0050	0.0021	0.0050
HEU-MET-FAST-003-010	1.00527	0.00057	1.0000	0.0050	0.0053	0.0050
HEU-MET-FAST-003-011	1.00854	0.00067	1.0000	0.0050	0.0085	0.0050
HEU-MET-FAST-003-012	1.00863	0.00068	1.0000	0.0030	0.0086	0.0031
HEU-MET-FAST-004-001	1.00186	0.00086	1.0020	0.0000	-0.0001	0.0009
HEU-MET-FAST-005-001	0.99569	0.00062	1.0000	0.0036	-0.0043	0.0037
HEU-MET-FAST-005-002	0.99802	0.00067	1.0007	0.0036	-0.0027	0.0037
HEU-MET-FAST-005-003	1.00205	0.00073	0.9996	0.0036	0.0025	0.0037
HEU-MET-FAST-005-004	0.99479	0.00078	0.9989	0.0036	-0.0041	0.0037
HEU-MET-FAST-005-005	0.99903	0.00076	0.9980	0.0036	0.0010	0.0037
HEU-MET-FAST-005-006	0.99725	0.00065	0.9987	0.0036	-0.0015	0.0037
HEU-MET-FAST-006-001	1.00575	0.00081	1.0000	0.0010	0.0057	0.0013
HEU-MET-FAST-006-002	0.98773	0.00083	0.9910	0.0030	-0.0033	0.0031
HEU-MET-FAST-007-001	0.99316	0.00057	0.9950	0.0024	-0.0018	0.0025
HEU-MET-FAST-007-002	0.99851	0.00064	0.9964	0.0014	0.0021	0.0015
HEU-MET-FAST-007-003	0.99996	0.00075	0.9990	0.0013	0.0010	0.0015
HEU-MET-FAST-007-004	0.99888	0.00063	0.9948	0.0013	0.0041	0.0014
HEU-MET-FAST-007-005	1.00206	0.00064	0.9978	0.0018	0.0043	0.0019
HEU-MET-FAST-007-006	1.00607	0.00082	1.0006	0.0013	0.0055	0.0015
HEU-MET-FAST-007-007	1.00258	0.00070	0.9974	0.0014	0.0052	0.0016
HEU-MET-FAST-007-008	0.99931	0.00078	0.9973	0.0013	0.0020	0.0015
HEU-MET-FAST-007-009	1.00267	0.00074	0.9995	0.0056	0.0032	0.0056
HEU-MET-FAST-007-010	1.00073	0.00084	0.9981	0.0012	0.0026	0.0015
HEU-MET-FAST-007-011	0.99662	0.00086	0.9958	0.0013	0.0008	0.0016
HEU-MET-FAST-007-012	0.99203	0.00089	0.9932	0.0012	-0.0012	0.0015
HEU-MET-FAST-007-013	1.00018	0.00089	0.9990	0.0012	0.0012	0.0015
HEU-MET-FAST-007-014	0.99531	0.00094	0.9964	0.0012	-0.0011	0.0015
HEU-MET-FAST-007-015	0.99600	0.00082	0.9959	0.0012	0.0001	0.0015
HEU-MET-FAST-007-016	0.99647	0.00081	0.9969	0.0012	-0.0004	0.0014
HEU-MET-FAST-007-017	0.99360	0.00088	0.9953	0.0012	-0.0017	0.0015
HEU-MET-FAST-007-018	0.99875	0.00074	0.9972	0.0012	0.0016	0.0014
HEU-MET-FAST-007-019	0.99669	0.00065	0.9956	0.0015	0.0011	0.0016
HEU-MET-FAST-007-020	0.99884	0.00074	0.9950	0.0017	0.0038	0.0019
HEU-MET-FAST-007-021	0.99975	0.00079	0.9956	0.0018	0.0041	0.0020
HEU-MET-FAST-007-022	1.00088	0.00081	0.9963	0.0019	0.0046	0.0021
HEU-MET-FAST-007-023	1.00018	0.00080	0.9962	0.0017	0.0040	0.0019
HEU-MET-FAST-007-024	1.00046	0.00078	0.9970	0.0018	0.0035	0.0020
HEU-MET-FAST-007-025	0.99788	0.00086	0.9959	0.0018	0.0020	0.0020

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-MET-FAST-007-026	0.99851	0.00093	0.9966	0.0017	0.0019	0.0019
HEU-MET-FAST-007-027	0.99743	0.00075	0.9948	0.0014	0.0026	0.0016
HEU-MET-FAST-007-028	0.99907	0.00073	0.9970	0.0023	0.0021	0.0024
HEU-MET-FAST-007-029	0.99794	0.00071	0.9961	0.0014	0.0018	0.0016
HEU-MET-FAST-007-030	0.99662	0.00077	0.9964	0.0021	0.0002	0.0022
HEU-MET-FAST-007-031	1.00162	0.00101	0.9996	0.0022	0.0020	0.0024
HEU-MET-FAST-007-032	1.00479	0.00061	0.9941	0.0012	0.0107	0.0013
HEU-MET-FAST-007-033	1.01518	0.00077	0.9977	0.0019	0.0175	0.0021
HEU-MET-FAST-007-034	1.01723	0.00065	0.9959	0.0017	0.0213	0.0018
HEU-MET-FAST-007-035	1.00338	0.00075	1.0003	0.0018	0.0031	0.0020
HEU-MET-FAST-007-036	1.00331	0.00083	0.9999	0.0007	0.0034	0.0011
HEU-MET-FAST-007-037	1.00183	0.00093	0.9988	0.0008	0.0030	0.0012
HEU-MET-FAST-007-038	1.00248	0.00091	1.0000	0.0008	0.0025	0.0012
HEU-MET-FAST-007-039	1.00380	0.00090	1.0018	0.0014	0.0020	0.0017
HEU-MET-FAST-007-040	1.00581	0.00078	1.0013	0.0008	0.0045	0.0011
HEU-MET-FAST-007-041	1.00138	0.00078	0.9994	0.0009	0.0020	0.0012
HEU-MET-FAST-007-042	1.00202	0.00096	1.0016	0.0009	0.0004	0.0013
HEU-MET-FAST-007-043	1.00093	0.00087	0.9998	0.0008	0.0011	0.0012
HEU-MET-FAST-008-001	0.99704	0.00069	0.9989	0.0016	-0.0019	0.0017
HEU-MET-FAST-009-001	0.99664	0.00062	0.9992	0.0015	-0.0026	0.0016
HEU-MET-FAST-009-002	0.99648	0.00055	0.9992	0.0015	-0.0027	0.0016
HEU-MET-FAST-010-001	1.00310	0.00061	0.9992	0.0015	0.0039	0.0016
HEU-MET-FAST-010-002	1.00297	0.00064	0.9992	0.0015	0.0038	0.0016
HEU-MET-FAST-011-001	0.99929	0.00082	0.9989	0.0015	0.0004	0.0017
HEU-MET-FAST-012-001	0.99904	0.00061	0.9992	0.0018	-0.0002	0.0019
HEU-MET-FAST-013-001	0.99691	0.00064	0.9990	0.0015	-0.0021	0.0016
HEU-MET-FAST-014-001	0.99769	0.00064	0.9989	0.0017	-0.0012	0.0018
HEU-MET-FAST-015-001	0.99533	0.00059	0.9996	0.0017	-0.0043	0.0018
HEU-MET-FAST-016-001	1.00243	0.00066	0.9996	0.0018	0.0028	0.0019
HEU-MET-FAST-016-002	1.00171	0.00070	0.9996	0.0018	0.0021	0.0019
HEU-MET-FAST-017-001	1.00096	0.00071	0.9993	0.0014	0.0017	0.0016
HEU-MET-FAST-018-001	1.00002	0.00065	1.0000	0.0014	0.0000	0.0015
HEU-MET-FAST-019-001	1.00657	0.00064	1.0000	0.0028	0.0066	0.0029
HEU-MET-FAST-020-001	1.00112	0.00066	1.0000	0.0028	0.0011	0.0029
HEU-MET-FAST-021-001	0.99748	0.00054	1.0000	0.0024	-0.0025	0.0025
HEU-MET-FAST-022-001	0.99857	0.00060	1.0000	0.0019	-0.0014	0.0020
HEU-MET-FAST-023-002	0.99633	0.00071	1.0000	0.0052	-0.0037	0.0052
HEU-MET-FAST-023-003	1.00688	0.00074	1.0000	0.0052	0.0069	0.0053
HEU-MET-FAST-023-004	1.00669	0.00082	1.0000	0.0052	0.0067	0.0053
HEU-MET-FAST-023-005	1.00303	0.00068	1.0000	0.0052	0.0030	0.0052

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-MET-FAST-023-006	0.99325	0.00063	1.0000	0.0052	-0.0068	0.0052
HEU-MET-FAST-023-007	0.99438	0.00068	1.0000	0.0052	-0.0056	0.0052
HEU-MET-FAST-023-008	1.00214	0.00079	1.0000	0.0052	0.0021	0.0053
HEU-MET-FAST-023-009	1.00013	0.00079	1.0000	0.0052	0.0001	0.0053
HEU-MET-FAST-023-010	0.99216	0.00073	1.0000	0.0052	-0.0078	0.0053
HEU-MET-FAST-023-012	0.99880	0.00064	1.0000	0.0052	-0.0012	0.0052
HEU-MET-FAST-023-013	0.99225	0.00081	1.0000	0.0052	-0.0078	0.0053
HEU-MET-FAST-023-014	1.00077	0.00082	1.0000	0.0052	0.0008	0.0053
HEU-MET-FAST-023-015	1.00212	0.00081	1.0000	0.0052	0.0021	0.0053
HEU-MET-FAST-023-016	0.99847	0.00065	1.0000	0.0052	-0.0015	0.0052
HEU-MET-FAST-023-017	0.99785	0.00075	1.0000	0.0052	-0.0021	0.0053
HEU-MET-FAST-023-018	0.98787	0.00081	1.0000	0.0052	-0.0121	0.0053
HEU-MET-FAST-023-019	0.99608	0.00077	1.0000	0.0052	-0.0039	0.0053
HEU-MET-FAST-023-020	0.99625	0.00075	1.0000	0.0052	-0.0038	0.0053
HEU-MET-FAST-023-021	0.99282	0.00064	1.0000	0.0057	-0.0072	0.0057
HEU-MET-FAST-023-022	0.98544	0.00065	1.0000	0.0052	-0.0146	0.0052
HEU-MET-FAST-024-001	0.99813	0.00072	0.9990	0.0015	-0.0009	0.0017
HEU-MET-FAST-027-001	1.00095	0.00066	1.0000	0.0025	0.0010	0.0026
HEU-MET-FAST-029-001	1.00406	0.00061	1.0000	0.0020	0.0041	0.0021
HEU-MET-FAST-030-001	1.00133	0.00072	1.0000	0.0009	0.0013	0.0012
HEU-MET-FAST-031-001	1.00455	0.00086	1.0000	0.0059	0.0046	0.0060
HEU-MET-FAST-038-001	1.00415	0.00076	0.9999	0.0007	0.0043	0.0010
HEU-MET-FAST-038-002	1.00108	0.00070	0.9999	0.0009	0.0012	0.0011
HEU-MET-FAST-041-001	1.00767	0.00064	1.0013	0.0030	0.0064	0.0031
HEU-MET-FAST-041-002	1.00481	0.00078	1.0022	0.0043	0.0026	0.0044
HEU-MET-FAST-041-003	1.00188	0.00065	1.0006	0.0029	0.0013	0.0030
HEU-MET-FAST-041-004	1.00807	0.00066	1.0006	0.0025	0.0075	0.0026
HEU-MET-FAST-041-005	1.00251	0.00066	1.0006	0.0031	0.0019	0.0032
HEU-MET-FAST-041-006	1.00280	0.00071	1.0006	0.0045	0.0022	0.0046
HEU-MET-FAST-048-001	1.00399	0.00069	0.9998	0.0027	0.0042	0.0028
HEU-MET-FAST-048-002	1.00272	0.00080	1.0001	0.0033	0.0026	0.0034
HEU-MET-FAST-048-003	1.00133	0.00088	1.0002	0.0031	0.0011	0.0032
HEU-MET-FAST-048-004	1.00340	0.00089	0.9988	0.0030	0.0046	0.0031
HEU-MET-FAST-048-005	0.99268	0.00085	0.9996	0.0041	-0.0069	0.0042
HEU-MET-FAST-048-006	1.00245	0.00074	1.0012	0.0034	0.0012	0.0035
HEU-MET-FAST-048-007	1.00221	0.00065	0.9998	0.0050	0.0024	0.0050
HEU-MET-FAST-048-008	0.99879	0.00075	0.9981	0.0047	0.0007	0.0048
HEU-MET-FAST-048-009	0.99712	0.00075	0.9983	0.0024	-0.0012	0.0025
HEU-MET-FAST-048-010	0.99680	0.00083	0.9985	0.0046	-0.0017	0.0047
HEU-MET-FAST-048-011	1.00394	0.00079	0.9997	0.0039	0.0042	0.0040

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-MET-FAST-048-012	1.00045	0.00079	1.0005	0.0046	0.0000	0.0047
HEU-MET-FAST-048-013	1.00470	0.00077	0.9989	0.0036	0.0058	0.0037
HEU-MET-FAST-048-014	0.99972	0.00072	1.0011	0.0049	-0.0014	0.0050
HEU-MET-FAST-048-015	0.99886	0.00071	0.9981	0.0062	0.0008	0.0062
HEU-MET-FAST-048-016	0.99339	0.00080	0.9988	0.0040	-0.0054	0.0041
HEU-MET-FAST-048-017	0.99172	0.00078	0.9978	0.0054	-0.0061	0.0055
HEU-MET-FAST-058-001	1.00210	0.00087	1.0000	0.0026	0.0021	0.0027
HEU-MET-FAST-058-002	1.00374	0.00068	1.0000	0.0035	0.0037	0.0036
HEU-MET-FAST-058-003	1.00267	0.00062	1.0000	0.0027	0.0027	0.0028
HEU-MET-FAST-058-004	1.00156	0.00063	1.0000	0.0021	0.0016	0.0022
HEU-MET-FAST-058-005	1.00007	0.00062	1.0000	0.0033	0.0001	0.0034
HEU-MET-FAST-061-001	1.00483	0.00066	0.9998	0.0025	0.0050	0.0026
HEU-MET-FAST-063-001	0.99978	0.00065	0.9993	0.0040	0.0005	0.0041
HEU-MET-FAST-063-002	1.00085	0.00061	0.9988	0.0047	0.0021	0.0047
HEU-MET-FAST-066-001	1.00378	0.00077	1.0030	0.0033	0.0008	0.0034
HEU-MET-FAST-066-002	1.00025	0.00072	1.0023	0.0029	-0.0020	0.0030
HEU-MET-FAST-066-003	1.00350	0.00071	1.0023	0.0026	0.0012	0.0027
HEU-MET-FAST-066-004	1.00586	0.00080	1.0043	0.0043	0.0016	0.0044
HEU-MET-FAST-066-005	1.00397	0.00071	1.0030	0.0033	0.0010	0.0034
HEU-MET-FAST-066-006	1.00287	0.00068	1.0028	0.0030	0.0001	0.0031
HEU-MET-FAST-066-007	1.00595	0.00073	1.0048	0.0039	0.0011	0.0040
HEU-MET-FAST-066-008	1.00463	0.00078	1.0039	0.0040	0.0007	0.0041
HEU-MET-FAST-066-009	1.00270	0.00077	1.0027	0.0036	0.0000	0.0037
HEU-MET-FAST-084-003	0.99938	0.00062	0.9993	0.0021	0.0001	0.0022
HEU-MET-FAST-084-016	0.99878	0.00064	0.9994	0.0020	-0.0006	0.0021
HEU-MET-FAST-084-026	0.99997	0.00061	0.9993	0.0022	0.0007	0.0023
HEU-MET-FAST-084-027	0.99674	0.00069	0.9994	0.0020	-0.0027	0.0021
HEU-MET-INTER-001-001	1.00116	0.00071	0.9966	0.0026	0.0046	0.0027
HEU-MET-INTER-009-001	0.99315	0.00103	0.9975	0.0030	-0.0044	0.0032
HEU-MET-INTER-009-002	0.99582	0.00094	0.9950	0.0048	0.0008	0.0049
HEU-MET-THERM-003-001	1.00450	0.00084	1.0000	0.0010	0.0045	0.0013
HEU-MET-THERM-003-002	0.98710	0.00077	0.9910	0.0030	-0.0039	0.0031
HEU-MET-THERM-003-003	0.97922	0.00089	0.9826	0.0060	-0.0034	0.0061
HEU-MET-THERM-003-004	0.98597	0.00079	0.9876	0.0040	-0.0016	0.0041
HEU-MET-THERM-003-006	0.98179	0.00088	0.9889	0.0030	-0.0071	0.0031
HEU-MET-THERM-003-007	0.98504	0.00088	0.9919	0.0030	-0.0069	0.0031
HEU-MET-THERM-006-001	0.99783	0.00084	1.0000	0.0044	-0.0022	0.0045
HEU-MET-THERM-006-002	0.99663	0.00086	1.0000	0.0040	-0.0034	0.0041
HEU-MET-THERM-006-003	1.00287	0.00088	1.0000	0.0040	0.0029	0.0041
HEU-MET-THERM-006-004	0.99572	0.00084	1.0000	0.0040	-0.0043	0.0041

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-MET-THERM-006-005	0.99671	0.00078	1.0000	0.0040	-0.0033	0.0041
HEU-MET-THERM-006-006	0.99618	0.00077	1.0000	0.0040	-0.0038	0.0041
HEU-MET-THERM-006-007	0.99483	0.00070	1.0000	0.0040	-0.0052	0.0041
HEU-MET-THERM-006-008	0.99121	0.00079	1.0000	0.0040	-0.0088	0.0041
HEU-MET-THERM-006-009	0.99510	0.00066	1.0000	0.0040	-0.0049	0.0041
HEU-MET-THERM-006-010	1.00627	0.00086	1.0000	0.0040	0.0063	0.0041
HEU-MET-THERM-006-011	0.99817	0.00086	1.0000	0.0040	-0.0018	0.0041
HEU-MET-THERM-006-012	0.99952	0.00069	1.0000	0.0040	-0.0005	0.0041
HEU-MET-THERM-006-015	0.99087	0.00082	1.0000	0.0040	-0.0091	0.0041
HEU-MET-THERM-006-023	1.00287	0.00082	1.0000	0.0040	0.0029	0.0041
HEU-MET-THERM-014-001	1.00565	0.00081	0.9931	0.0015	0.0126	0.0017
HEU-MET-THERM-018-001	0.99949	0.00089	1.0038	0.0041	-0.0043	0.0042
HEU-MET-THERM-027-001	0.99486	0.00060	0.9947	0.0028	0.0002	0.0029
HEU-MET-THERM-027-002	0.99820	0.00068	0.9954	0.0027	0.0028	0.0028
HEU-MET-THERM-027-003	0.99680	0.00059	0.9946	0.0026	0.0022	0.0027
HEU-MET-THERM-027-004	1.00010	0.00059	0.9957	0.0023	0.0044	0.0024
HEU-MET-THERM-027-005	0.99748	0.00064	0.9965	0.0022	0.0010	0.0023
HEU-MET-THERM-027-006	1.00080	0.00065	0.9964	0.0021	0.0044	0.0022
HEU-MET-THERM-027-007	0.99763	0.00062	0.9964	0.0035	0.0012	0.0036
HEU-MET-THERM-027-008	0.99444	0.00062	0.9953	0.0034	-0.0009	0.0035
HEU-MET-THERM-027-009	0.99826	0.00065	0.9950	0.0025	0.0033	0.0026
HEU-MET-THERM-027-010	0.99797	0.00057	0.9962	0.0022	0.0018	0.0023
HEU-MET-THERM-027-011	0.98694	0.00060	0.9956	0.0035	-0.0087	0.0036
HEU-MET-THERM-027-012	0.99043	0.00062	0.9971	0.0032	-0.0067	0.0033
HEU-MET-THERM-027-013	0.99710	0.00058	0.9945	0.0036	0.0026	0.0036
HEU-MET-THERM-027-014	0.98518	0.00067	0.9970	0.0032	-0.0118	0.0033
HEU-MET-THERM-027-015	0.98193	0.00056	0.9962	0.0023	-0.0143	0.0024
HEU-SOL-THERM-001-001	1.00023	0.00085	1.0004	0.0060	-0.0002	0.0061
HEU-SOL-THERM-001-002	0.99607	0.00111	1.0021	0.0072	-0.0060	0.0073
HEU-SOL-THERM-001-003	1.00096	0.00115	1.0003	0.0035	0.0007	0.0037
HEU-SOL-THERM-001-004	0.99708	0.00109	1.0008	0.0053	-0.0037	0.0054
HEU-SOL-THERM-001-005	0.99774	0.00085	1.0001	0.0049	-0.0024	0.0050
HEU-SOL-THERM-001-006	1.00108	0.00087	1.0002	0.0046	0.0009	0.0047
HEU-SOL-THERM-001-007	0.99887	0.00116	1.0008	0.0040	-0.0019	0.0042
HEU-SOL-THERM-001-008	0.99750	0.00110	0.9998	0.0038	-0.0023	0.0040
HEU-SOL-THERM-001-009	0.99411	0.00113	1.0008	0.0054	-0.0067	0.0055
HEU-SOL-THERM-001-010	0.99234	0.00100	0.9993	0.0054	-0.0070	0.0055
HEU-SOL-THERM-002-001	1.00112	0.00109	1.0025	0.0058	-0.0014	0.0059
HEU-SOL-THERM-002-002	1.00747	0.00100	1.0028	0.0058	0.0047	0.0059
HEU-SOL-THERM-002-003	0.99832	0.00111	1.0033	0.0068	-0.0050	0.0069

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-SOL-THERM-002-004	1.00140	0.00106	1.0034	0.0069	-0.0020	0.0070
HEU-SOL-THERM-002-005	1.00355	0.00096	1.0018	0.0044	0.0017	0.0045
HEU-SOL-THERM-002-006	1.00876	0.00109	1.0023	0.0041	0.0065	0.0042
HEU-SOL-THERM-002-007	0.99990	0.00120	1.0025	0.0050	-0.0026	0.0051
HEU-SOL-THERM-002-008	1.00361	0.00119	1.0030	0.0055	0.0006	0.0056
HEU-SOL-THERM-002-009	1.00182	0.00088	1.0012	0.0046	0.0006	0.0047
HEU-SOL-THERM-002-010	1.00187	0.00099	1.0024	0.0050	-0.0005	0.0051
HEU-SOL-THERM-002-011	1.00070	0.00098	1.0017	0.0038	-0.0010	0.0039
HEU-SOL-THERM-002-012	1.00570	0.00098	1.0027	0.0050	0.0030	0.0051
HEU-SOL-THERM-002-013	0.99914	0.00118	1.0025	0.0055	-0.0034	0.0056
HEU-SOL-THERM-002-014	1.00569	0.00111	1.0031	0.0066	0.0026	0.0067
HEU-SOL-THERM-003-001	1.00008	0.00091	1.0016	0.0056	-0.0015	0.0057
HEU-SOL-THERM-003-002	1.00178	0.00088	1.0016	0.0057	0.0002	0.0058
HEU-SOL-THERM-003-003	0.99990	0.00104	1.0014	0.0056	-0.0015	0.0057
HEU-SOL-THERM-003-004	1.00057	0.00099	1.0009	0.0057	-0.0003	0.0058
HEU-SOL-THERM-003-005	0.99682	0.00118	1.0021	0.0068	-0.0053	0.0069
HEU-SOL-THERM-003-006	0.99857	0.00106	1.0013	0.0070	-0.0027	0.0071
HEU-SOL-THERM-003-007	0.99914	0.00076	1.0006	0.0046	-0.0015	0.0047
HEU-SOL-THERM-003-008	0.99855	0.00098	1.0003	0.0033	-0.0017	0.0034
HEU-SOL-THERM-003-009	1.00174	0.00098	0.9996	0.0035	0.0021	0.0036
HEU-SOL-THERM-003-010	0.99607	0.00107	1.0011	0.0050	-0.0050	0.0051
HEU-SOL-THERM-003-011	1.00007	0.00110	0.9997	0.0052	0.0004	0.0053
HEU-SOL-THERM-003-012	1.00111	0.00101	1.0006	0.0047	0.0005	0.0048
HEU-SOL-THERM-003-013	0.99820	0.00081	1.0004	0.0059	-0.0022	0.0060
HEU-SOL-THERM-003-014	1.00093	0.00091	1.0005	0.0047	0.0004	0.0048
HEU-SOL-THERM-003-015	0.99233	0.00092	1.0000	0.0045	-0.0077	0.0046
HEU-SOL-THERM-003-016	0.99785	0.00108	1.0002	0.0037	-0.0023	0.0039
HEU-SOL-THERM-003-017	1.00297	0.00094	0.9994	0.0042	0.0036	0.0043
HEU-SOL-THERM-003-018	0.99576	0.00113	1.0009	0.0050	-0.0051	0.0051
HEU-SOL-THERM-003-019	1.00261	0.00112	0.9991	0.0059	0.0035	0.0060
HEU-SOL-THERM-008-001	0.99971	0.00062	1.0000	0.0030	-0.0003	0.0031
HEU-SOL-THERM-008-002	1.00028	0.00080	1.0000	0.0030	0.0003	0.0031
HEU-SOL-THERM-008-003	0.99866	0.00061	1.0000	0.0030	-0.0013	0.0031
HEU-SOL-THERM-008-004	0.99924	0.00068	1.0000	0.0030	-0.0008	0.0031
HEU-SOL-THERM-008-005	1.00052	0.00065	1.0000	0.0030	0.0005	0.0031
HEU-SOL-THERM-008-006	1.00116	0.00071	1.0000	0.0030	0.0012	0.0031
HEU-SOL-THERM-008-007	1.00026	0.00066	1.0000	0.0030	0.0003	0.0031
HEU-SOL-THERM-008-008	0.99941	0.00068	1.0000	0.0030	-0.0006	0.0031
HEU-SOL-THERM-008-009	1.00313	0.00059	1.0000	0.0030	0.0031	0.0031
HEU-SOL-THERM-008-010	0.99812	0.00068	1.0000	0.0030	-0.0019	0.0031

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-SOL-THERM-008-011	1.00170	0.00060	1.0000	0.0030	0.0017	0.0031
HEU-SOL-THERM-008-012	0.99785	0.00077	1.0000	0.0030	-0.0021	0.0031
HEU-SOL-THERM-008-013	0.99799	0.00068	1.0000	0.0030	-0.0020	0.0031
HEU-SOL-THERM-008-014	0.99875	0.00064	1.0000	0.0030	-0.0012	0.0031
HEU-SOL-THERM-009-001	1.00119	0.00099	0.9990	0.0043	0.0022	0.0044
HEU-SOL-THERM-009-002	1.00162	0.00100	1.0000	0.0039	0.0016	0.0040
HEU-SOL-THERM-009-003	1.00011	0.00101	1.0000	0.0036	0.0001	0.0037
HEU-SOL-THERM-009-004	0.99398	0.00104	0.9986	0.0035	-0.0046	0.0037
HEU-SOL-THERM-010-001	1.00157	0.00092	1.0000	0.0029	0.0016	0.0030
HEU-SOL-THERM-010-002	1.00167	0.00089	1.0000	0.0029	0.0017	0.0030
HEU-SOL-THERM-010-003	0.99806	0.00094	1.0000	0.0029	-0.0019	0.0030
HEU-SOL-THERM-010-004	0.99709	0.00089	0.9992	0.0029	-0.0021	0.0030
HEU-SOL-THERM-011-001	1.00555	0.00094	1.0000	0.0023	0.0055	0.0025
HEU-SOL-THERM-011-002	1.00184	0.00086	1.0000	0.0023	0.0018	0.0025
HEU-SOL-THERM-012-001	1.00160	0.00062	0.9999	0.0058	0.0017	0.0058
HEU-SOL-THERM-014-001	0.99318	0.00080	1.0000	0.0028	-0.0068	0.0029
HEU-SOL-THERM-014-002	1.01152	0.00076	1.0000	0.0052	0.0115	0.0053
HEU-SOL-THERM-014-003	1.02052	0.00081	1.0000	0.0087	0.0205	0.0087
HEU-SOL-THERM-015-001	0.99745	0.00097	1.0000	0.0032	-0.0026	0.0033
HEU-SOL-THERM-015-002	0.98896	0.00085	1.0000	0.0034	-0.0110	0.0035
HEU-SOL-THERM-015-003	1.00792	0.00087	1.0000	0.0068	0.0079	0.0069
HEU-SOL-THERM-015-004	1.01236	0.00092	1.0000	0.0069	0.0124	0.0070
HEU-SOL-THERM-015-005	1.01047	0.00083	1.0000	0.0089	0.0105	0.0089
HEU-SOL-THERM-016-001	0.98936	0.00088	1.0000	0.0036	-0.0106	0.0037
HEU-SOL-THERM-016-002	1.00497	0.00090	1.0000	0.0069	0.0050	0.0070
HEU-SOL-THERM-016-003	1.02482	0.00082	1.0000	0.0079	0.0248	0.0079
HEU-SOL-THERM-017-001	0.99302	0.00088	1.0000	0.0028	-0.0070	0.0029
HEU-SOL-THERM-017-002	0.98058	0.00115	1.0000	0.0040	-0.0194	0.0042
HEU-SOL-THERM-017-003	0.97896	0.00104	1.0000	0.0036	-0.0210	0.0037
HEU-SOL-THERM-017-004	0.99767	0.00085	1.0000	0.0047	-0.0023	0.0048
HEU-SOL-THERM-017-005	1.00488	0.00091	1.0000	0.0058	0.0049	0.0059
HEU-SOL-THERM-017-006	1.00048	0.00090	1.0000	0.0055	0.0005	0.0056
HEU-SOL-THERM-017-007	1.00444	0.00091	1.0000	0.0057	0.0044	0.0058
HEU-SOL-THERM-017-008	0.99878	0.00101	1.0000	0.0067	-0.0012	0.0068
HEU-SOL-THERM-018-001	0.98986	0.00095	1.0000	0.0034	-0.0101	0.0035
HEU-SOL-THERM-018-002	0.98580	0.00115	1.0000	0.0046	-0.0142	0.0047
HEU-SOL-THERM-018-003	0.98574	0.00102	1.0000	0.0042	-0.0143	0.0043
HEU-SOL-THERM-018-004	0.99769	0.00108	1.0000	0.0044	-0.0023	0.0045
HEU-SOL-THERM-018-005	0.98914	0.00096	1.0000	0.0046	-0.0109	0.0047
HEU-SOL-THERM-018-006	0.99194	0.00102	1.0000	0.0045	-0.0081	0.0046

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-SOL-THERM-018-007	1.00483	0.00092	1.0000	0.0058	0.0048	0.0059
HEU-SOL-THERM-018-008	1.00619	0.00093	1.0000	0.0056	0.0062	0.0057
HEU-SOL-THERM-018-009	1.00518	0.00091	1.0000	0.0056	0.0052	0.0057
HEU-SOL-THERM-018-010	1.01779	0.00097	1.0000	0.0057	0.0178	0.0058
HEU-SOL-THERM-018-011	1.02057	0.00085	1.0000	0.0059	0.0206	0.0060
HEU-SOL-THERM-018-012	1.01415	0.00076	1.0000	0.0065	0.0142	0.0065
HEU-SOL-THERM-019-001	0.99617	0.00106	1.0000	0.0041	-0.0038	0.0042
HEU-SOL-THERM-019-002	0.99897	0.00093	1.0000	0.0041	-0.0010	0.0042
HEU-SOL-THERM-019-003	0.99428	0.00086	1.0000	0.0067	-0.0057	0.0068
HEU-SOL-THERM-025-003	0.99518	0.00087	1.0002	0.0064	-0.0050	0.0065
HEU-SOL-THERM-025-006	1.00946	0.00071	1.0002	0.0067	0.0093	0.0067
HEU-SOL-THERM-025-007	1.01296	0.00080	1.0009	0.0073	0.0121	0.0073
HEU-SOL-THERM-025-008	1.01001	0.00070	1.0000	0.0067	0.0100	0.0067
HEU-SOL-THERM-025-009	1.00439	0.00087	1.0002	0.0065	0.0042	0.0066
HEU-SOL-THERM-025-010	1.00915	0.00079	1.0003	0.0043	0.0089	0.0044
HEU-SOL-THERM-025-011	1.00769	0.00078	1.0002	0.0045	0.0075	0.0046
HEU-SOL-THERM-025-012	1.00772	0.00079	1.0002	0.0045	0.0075	0.0046
HEU-SOL-THERM-025-013	1.01276	0.00084	1.0009	0.0047	0.0119	0.0048
HEU-SOL-THERM-025-014	1.00537	0.00077	1.0008	0.0053	0.0046	0.0054
HEU-SOL-THERM-025-015	0.99793	0.00066	1.0002	0.0058	-0.0023	0.0058
HEU-SOL-THERM-025-016	1.00846	0.00084	1.0000	0.0049	0.0085	0.0050
HEU-SOL-THERM-025-017	1.00101	0.00076	1.0000	0.0055	0.0010	0.0056
HEU-SOL-THERM-025-018	0.99883	0.00077	1.0000	0.0061	-0.0012	0.0061
HEU-SOL-THERM-033-001	0.99684	0.00106	1.0000	0.0111	-0.0032	0.0112
HEU-SOL-THERM-033-002	0.99525	0.00099	1.0000	0.0108	-0.0048	0.0108
HEU-SOL-THERM-033-003	0.99508	0.00114	1.0000	0.0065	-0.0049	0.0066
HEU-SOL-THERM-033-004	1.00516	0.00094	1.0000	0.0114	0.0052	0.0114
HEU-SOL-THERM-033-005	1.00205	0.00090	1.0000	0.0111	0.0021	0.0111
HEU-SOL-THERM-033-006	1.00834	0.00099	1.0000	0.0070	0.0083	0.0071
HEU-SOL-THERM-033-007	1.00454	0.00098	1.0000	0.0114	0.0045	0.0114
HEU-SOL-THERM-033-008	1.00659	0.00118	1.0000	0.0111	0.0066	0.0112
HEU-SOL-THERM-033-009	1.00964	0.00118	1.0000	0.0111	0.0096	0.0112
HEU-SOL-THERM-033-010	1.00562	0.00104	1.0000	0.0108	0.0056	0.0108
HEU-SOL-THERM-033-011	1.00521	0.00095	1.0000	0.0111	0.0052	0.0111
HEU-SOL-THERM-033-012	1.00581	0.00098	1.0000	0.0108	0.0058	0.0108
HEU-SOL-THERM-033-013	1.00064	0.00099	1.0000	0.0111	0.0006	0.0111
HEU-SOL-THERM-033-014	1.00267	0.00100	1.0000	0.0108	0.0027	0.0108
HEU-SOL-THERM-033-015	1.00160	0.00111	1.0000	0.0111	0.0016	0.0112
HEU-SOL-THERM-033-016	1.00057	0.00124	1.0000	0.0108	0.0006	0.0109
HEU-SOL-THERM-033-017	0.99767	0.00085	1.0000	0.0111	-0.0023	0.0111

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
HEU-SOL-THERM-033-018	0.99225	0.00110	1.0000	0.0108	-0.0078	0.0109
HEU-SOL-THERM-033-019	0.99364	0.00105	1.0000	0.0104	-0.0064	0.0105
HEU-SOL-THERM-033-020	1.00053	0.00128	1.0000	0.0114	0.0005	0.0115
HEU-SOL-THERM-033-021	0.99993	0.00105	1.0000	0.0070	-0.0001	0.0071
HEU-SOL-THERM-033-022	0.99189	0.00108	1.0000	0.0104	-0.0081	0.0105
HEU-SOL-THERM-033-023	1.00078	0.00110	1.0000	0.0111	0.0008	0.0112
HEU-SOL-THERM-033-024	0.99963	0.00101	1.0000	0.0108	-0.0004	0.0108
HEU-SOL-THERM-033-025	1.00051	0.00104	1.0000	0.0111	0.0005	0.0111
HEU-SOL-THERM-033-026	1.00053	0.00093	1.0000	0.0108	0.0005	0.0108
HEU-SOL-THERM-044-030	1.01231	0.00089	0.9984	0.0065	0.0139	0.0066
IEU-COMP-THERM-001-001	1.00004	0.00083	1.0000	0.0040	0.0000	0.0041
IEU-COMP-THERM-001-003	0.99818	0.00094	1.0000	0.0040	-0.0018	0.0041
IEU-COMP-THERM-001-004	1.00133	0.00089	1.0000	0.0040	0.0013	0.0041
IEU-COMP-THERM-001-005	1.00627	0.00079	1.0000	0.0040	0.0063	0.0041
IEU-COMP-THERM-001-008	0.99988	0.00080	1.0000	0.0040	-0.0001	0.0041
IEU-COMP-THERM-001-009	1.00880	0.00089	1.0000	0.0040	0.0088	0.0041
IEU-COMP-THERM-001-011	0.99907	0.00086	1.0000	0.0040	-0.0009	0.0041
IEU-COMP-THERM-001-012	1.00215	0.00083	1.0000	0.0040	0.0022	0.0041
IEU-COMP-THERM-001-013	1.00065	0.00088	1.0000	0.0040	0.0007	0.0041
IEU-COMP-THERM-001-016	1.00262	0.00078	1.0000	0.0040	0.0026	0.0041
IEU-COMP-THERM-001-019	1.00298	0.00084	1.0000	0.0040	0.0030	0.0041
IEU-COMP-THERM-001-024	1.00551	0.00092	1.0000	0.0040	0.0055	0.0041
IEU-COMP-THERM-001-025	1.00221	0.00085	1.0000	0.0040	0.0022	0.0041
IEU-COMP-THERM-001-026	1.00717	0.00084	1.0000	0.0040	0.0072	0.0041
IEU-COMP-THERM-001-027	1.00318	0.00079	1.0000	0.0040	0.0032	0.0041
IEU-COMP-THERM-001-029	1.00703	0.00098	1.0000	0.0040	0.0070	0.0041
IEU-COMP-THERM-002-001	1.00003	0.00073	1.0014	0.0039	-0.0014	0.0040
IEU-COMP-THERM-002-003	1.00365	0.00074	1.0017	0.0044	0.0019	0.0045
IEU-COMP-THERM-002-005	0.99825	0.00082	1.0014	0.0043	-0.0032	0.0044
IEU-COMP-THERM-003-001	1.00326	0.00085	1.0006	0.0056	0.0027	0.0057
IEU-COMP-THERM-003-002	1.00724	0.00078	1.0046	0.0056	0.0026	0.0057
IEU-MET-FAST-001-001	1.00131	0.00063	0.9989	0.0009	0.0024	0.0011
IEU-MET-FAST-001-002	0.99982	0.00057	0.9997	0.0009	0.0001	0.0011
IEU-MET-FAST-001-003	1.00248	0.00059	0.9993	0.0003	0.0032	0.0007
IEU-MET-FAST-001-004	1.00189	0.00062	1.0002	0.0003	0.0017	0.0007
IEU-MET-FAST-002-001	0.99829	0.00060	1.0000	0.0030	-0.0017	0.0031
IEU-MET-FAST-003-001	1.00144	0.00066	1.0000	0.0017	0.0014	0.0018
IEU-MET-FAST-004-001	1.00800	0.00064	1.0000	0.0030	0.0080	0.0031
IEU-MET-FAST-005-001	1.00185	0.00063	1.0000	0.0021	0.0018	0.0022
IEU-MET-FAST-006-001	0.99491	0.00062	1.0000	0.0023	-0.0051	0.0024

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
IEU-MET-FAST-007-001	1.00558	0.00059	1.0046	0.0002	0.0010	0.0006
IEU-MET-FAST-008-001	1.00640	0.00064	1.0000	0.0018	0.0064	0.0019
IEU-MET-FAST-009-001	1.01049	0.00078	1.0000	0.0053	0.0105	0.0054
IEU-MET-FAST-010-001	0.99399	0.00052	0.9954	0.0024	-0.0014	0.0025
IEU-MET-FAST-012-001	1.00307	0.00050	1.0007	0.0027	0.0024	0.0027
IEU-MET-FAST-013-001	0.99798	0.00052	0.9941	0.0023	0.0039	0.0024
IEU-MET-FAST-014-001	0.99665	0.00048	0.9958	0.0022	0.0009	0.0023
IEU-MET-FAST-014-002	0.99307	0.00047	0.9927	0.0022	0.0004	0.0022
LEU-COMP-THERM-001-001	0.99878	0.00062	0.9998	0.0031	-0.0010	0.0032
LEU-COMP-THERM-001-002	1.00061	0.00080	0.9998	0.0031	0.0008	0.0032
LEU-COMP-THERM-001-003	0.99852	0.00063	0.9998	0.0031	-0.0013	0.0032
LEU-COMP-THERM-001-004	0.99909	0.00052	0.9998	0.0031	-0.0007	0.0031
LEU-COMP-THERM-001-005	0.99829	0.00059	0.9998	0.0031	-0.0015	0.0032
LEU-COMP-THERM-001-006	0.99875	0.00070	0.9998	0.0031	-0.0011	0.0032
LEU-COMP-THERM-001-007	0.99884	0.00068	0.9998	0.0031	-0.0010	0.0032
LEU-COMP-THERM-001-008	0.99587	0.00059	0.9998	0.0031	-0.0039	0.0032
LEU-COMP-THERM-002-001	0.99723	0.00073	0.9997	0.0020	-0.0025	0.0021
LEU-COMP-THERM-002-002	0.99914	0.00080	0.9997	0.0020	-0.0006	0.0022
LEU-COMP-THERM-002-003	0.99959	0.00069	0.9997	0.0020	-0.0001	0.0021
LEU-COMP-THERM-002-004	0.99860	0.00073	0.9997	0.0020	-0.0011	0.0021
LEU-COMP-THERM-002-005	0.99801	0.00073	0.9997	0.0020	-0.0017	0.0021
LEU-COMP-THERM-008-001	1.00007	0.00080	1.0007	0.0012	-0.0006	0.0014
LEU-COMP-THERM-008-002	1.00015	0.00063	1.0007	0.0012	-0.0005	0.0014
LEU-COMP-THERM-008-003	1.00001	0.00061	1.0007	0.0012	-0.0007	0.0013
LEU-COMP-THERM-008-004	1.00143	0.00077	1.0007	0.0012	0.0007	0.0014
LEU-COMP-THERM-008-005	1.00057	0.00067	1.0007	0.0012	-0.0001	0.0014
LEU-COMP-THERM-008-006	1.00226	0.00074	1.0007	0.0012	0.0016	0.0014
LEU-COMP-THERM-008-007	0.99990	0.00068	1.0007	0.0012	-0.0008	0.0014
LEU-COMP-THERM-008-008	1.00063	0.00066	1.0007	0.0012	-0.0001	0.0014
LEU-COMP-THERM-008-009	1.00105	0.00067	1.0007	0.0012	0.0004	0.0014
LEU-COMP-THERM-008-010	0.99902	0.00029	1.0007	0.0012	-0.0017	0.0012
LEU-COMP-THERM-008-011	1.00141	0.00060	1.0007	0.0012	0.0007	0.0013
LEU-COMP-THERM-008-012	1.00149	0.00068	1.0007	0.0012	0.0008	0.0014
LEU-COMP-THERM-008-013	1.00064	0.00066	1.0007	0.0012	-0.0001	0.0014
LEU-COMP-THERM-008-014	1.00134	0.00067	1.0007	0.0012	0.0006	0.0014
LEU-COMP-THERM-008-015	0.99944	0.00070	1.0007	0.0012	-0.0013	0.0014
LEU-COMP-THERM-008-016	1.00078	0.00064	1.0007	0.0012	0.0001	0.0014
LEU-COMP-THERM-008-017	0.99976	0.00065	1.0007	0.0012	-0.0009	0.0014
LEU-COMP-THERM-009-001	0.99918	0.00081	1.0000	0.0021	-0.0008	0.0023
LEU-COMP-THERM-009-002	1.00050	0.00079	1.0000	0.0021	0.0005	0.0022

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-COMP-THERM-009-003	0.99773	0.00073	1.0000	0.0021	-0.0023	0.0022
LEU-COMP-THERM-009-004	0.99949	0.00076	1.0000	0.0021	-0.0005	0.0022
LEU-COMP-THERM-009-005	0.99962	0.00072	1.0000	0.0021	-0.0004	0.0022
LEU-COMP-THERM-009-006	0.99912	0.00071	1.0000	0.0021	-0.0009	0.0022
LEU-COMP-THERM-009-007	1.00102	0.00074	1.0000	0.0021	0.0010	0.0022
LEU-COMP-THERM-009-008	0.99924	0.00077	1.0000	0.0021	-0.0008	0.0022
LEU-COMP-THERM-009-009	0.99960	0.00072	1.0000	0.0021	-0.0004	0.0022
LEU-COMP-THERM-010-001	1.00365	0.00070	1.0000	0.0021	0.0036	0.0022
LEU-COMP-THERM-010-004	0.99620	0.00066	1.0000	0.0021	-0.0038	0.0022
LEU-COMP-THERM-010-008	0.99961	0.00059	1.0000	0.0021	-0.0004	0.0022
LEU-COMP-THERM-010-013	0.99647	0.00075	1.0000	0.0021	-0.0035	0.0022
LEU-COMP-THERM-010-017	0.99986	0.00078	1.0000	0.0028	-0.0001	0.0029
LEU-COMP-THERM-010-019	1.00114	0.00081	1.0000	0.0028	0.0011	0.0029
LEU-COMP-THERM-010-023	1.00337	0.00073	1.0000	0.0028	0.0034	0.0029
LEU-COMP-THERM-010-030	1.00093	0.00068	1.0000	0.0028	0.0009	0.0029
LEU-COMP-THERM-013-001	1.00108	0.00067	1.0000	0.0018	0.0011	0.0019
LEU-COMP-THERM-013-002	0.99979	0.00087	1.0000	0.0018	-0.0002	0.0020
LEU-COMP-THERM-013-003	1.00062	0.00069	1.0000	0.0018	0.0006	0.0019
LEU-COMP-THERM-013-004	1.00240	0.00078	1.0000	0.0018	0.0024	0.0020
LEU-COMP-THERM-013-005	0.99993	0.00079	1.0000	0.0032	-0.0001	0.0033
LEU-COMP-THERM-013-006	1.00083	0.00074	1.0000	0.0018	0.0008	0.0019
LEU-COMP-THERM-013-007	1.00180	0.00080	1.0000	0.0018	0.0018	0.0020
LEU-COMP-THERM-014-001	1.00454	0.00082	1.0000	0.0019	0.0045	0.0021
LEU-COMP-THERM-014-002	0.99067	0.00079	1.0000	0.0077	-0.0093	0.0077
LEU-COMP-THERM-014-005	1.00798	0.00068	1.0000	0.0069	0.0080	0.0069
LEU-COMP-THERM-014-006	1.01019	0.00070	1.0000	0.0033	0.0102	0.0034
LEU-COMP-THERM-014-007	1.00659	0.00069	1.0000	0.0051	0.0066	0.0051
LEU-COMP-THERM-016-006	0.99872	0.00069	1.0000	0.0031	-0.0013	0.0032
LEU-COMP-THERM-016-007	0.99972	0.00066	1.0000	0.0031	-0.0003	0.0032
LEU-COMP-THERM-016-008	0.99956	0.00075	1.0000	0.0031	-0.0004	0.0032
LEU-COMP-THERM-016-009	0.99821	0.00072	1.0000	0.0031	-0.0018	0.0032
LEU-COMP-THERM-016-010	0.99712	0.00064	1.0000	0.0031	-0.0029	0.0032
LEU-COMP-THERM-016-011	0.99984	0.00069	1.0000	0.0031	-0.0002	0.0032
LEU-COMP-THERM-016-012	0.99631	0.00069	1.0000	0.0031	-0.0037	0.0032
LEU-COMP-THERM-016-013	0.99813	0.00063	1.0000	0.0031	-0.0019	0.0032
LEU-COMP-THERM-019-001	1.01664	0.00068	1.0000	0.0063	0.0166	0.0063
LEU-COMP-THERM-019-002	1.01121	0.00073	1.0000	0.0058	0.0112	0.0058
LEU-COMP-THERM-019-003	1.00723	0.00061	1.0000	0.0061	0.0072	0.0061
LEU-COMP-THERM-020-001	0.99482	0.00079	1.0000	0.0061	-0.0052	0.0062
LEU-COMP-THERM-020-002	1.00156	0.00079	1.0000	0.0061	0.0016	0.0062

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-COMP-THERM-020-003	1.00271	0.00075	1.0000	0.0061	0.0027	0.0061
LEU-COMP-THERM-020-004	1.00238	0.00076	1.0000	0.0061	0.0024	0.0061
LEU-COMP-THERM-020-005	1.00402	0.00075	1.0000	0.0061	0.0040	0.0061
LEU-COMP-THERM-020-006	1.00271	0.00076	1.0000	0.0061	0.0027	0.0061
LEU-COMP-THERM-020-007	1.00463	0.00071	1.0000	0.0061	0.0046	0.0061
LEU-COMP-THERM-021-001	1.01273	0.00076	1.0000	0.0072	0.0127	0.0072
LEU-COMP-THERM-021-002	1.01387	0.00073	1.0000	0.0072	0.0139	0.0072
LEU-COMP-THERM-021-003	1.01084	0.00079	1.0000	0.0072	0.0108	0.0072
LEU-COMP-THERM-021-004	1.01210	0.00080	1.0000	0.0050	0.0121	0.0051
LEU-COMP-THERM-021-005	1.01146	0.00067	1.0000	0.0050	0.0115	0.0050
LEU-COMP-THERM-021-006	1.01101	0.00070	1.0000	0.0050	0.0110	0.0050
LEU-COMP-THERM-022-001	1.00283	0.00080	1.0000	0.0046	0.0028	0.0047
LEU-COMP-THERM-022-002	1.00691	0.00077	1.0000	0.0046	0.0069	0.0047
LEU-COMP-THERM-022-003	1.00683	0.00080	1.0000	0.0036	0.0068	0.0037
LEU-COMP-THERM-022-004	1.00735	0.00073	1.0000	0.0037	0.0073	0.0038
LEU-COMP-THERM-022-005	1.00031	0.00075	1.0000	0.0038	0.0003	0.0039
LEU-COMP-THERM-022-006	1.00081	0.00072	1.0000	0.0046	0.0008	0.0047
LEU-COMP-THERM-022-007	1.00405	0.00060	1.0000	0.0046	0.0041	0.0046
LEU-COMP-THERM-023-001	0.99525	0.00073	1.0000	0.0044	-0.0048	0.0045
LEU-COMP-THERM-023-002	0.99909	0.00082	1.0000	0.0044	-0.0009	0.0045
LEU-COMP-THERM-023-003	0.99928	0.00073	1.0000	0.0044	-0.0007	0.0045
LEU-COMP-THERM-023-004	1.00144	0.00071	1.0000	0.0044	0.0014	0.0045
LEU-COMP-THERM-023-005	1.00166	0.00072	1.0000	0.0044	0.0017	0.0045
LEU-COMP-THERM-023-006	1.00211	0.00072	1.0000	0.0044	0.0021	0.0045
LEU-COMP-THERM-024-001	1.00175	0.00084	1.0000	0.0054	0.0017	0.0055
LEU-COMP-THERM-024-002	1.00712	0.00069	1.0000	0.0040	0.0071	0.0041
LEU-COMP-THERM-025-001	0.98957	0.00080	1.0000	0.0041	-0.0104	0.0042
LEU-COMP-THERM-025-002	0.99519	0.00080	1.0000	0.0044	-0.0048	0.0045
LEU-COMP-THERM-025-003	1.00063	0.00076	1.0000	0.0047	0.0006	0.0048
LEU-COMP-THERM-025-004	1.00270	0.00069	1.0000	0.0052	0.0027	0.0052
LEU-COMP-THERM-026-001	1.00347	0.00078	1.0000	0.0034	0.0035	0.0035
LEU-COMP-THERM-026-003	1.00359	0.00083	1.0018	0.0062	0.0018	0.0063
LEU-COMP-THERM-026-005	1.00191	0.00086	1.0007	0.0041	0.0012	0.0042
LEU-COMP-THERM-028-007	0.99628	0.00073	0.9998	0.0047	-0.0035	0.0048
LEU-COMP-THERM-028-008	0.99410	0.00074	0.9998	0.0052	-0.0057	0.0053
LEU-COMP-THERM-028-009	0.99510	0.00082	0.9998	0.0047	-0.0047	0.0048
LEU-COMP-THERM-028-013	0.99580	0.00062	0.9998	0.0050	-0.0040	0.0050
LEU-COMP-THERM-028-014	0.99310	0.00069	1.0001	0.0047	-0.0070	0.0048
LEU-COMP-THERM-028-019	0.99798	0.00069	1.0002	0.0046	-0.0022	0.0047
LEU-COMP-THERM-028-020	0.99547	0.00065	1.0001	0.0046	-0.0046	0.0046

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-COMP-THERM-042-001	0.99857	0.00061	1.0000	0.0016	-0.0014	0.0017
LEU-COMP-THERM-042-002	0.99809	0.00068	1.0000	0.0016	-0.0019	0.0017
LEU-COMP-THERM-042-003	0.99792	0.00069	1.0000	0.0016	-0.0021	0.0017
LEU-COMP-THERM-042-004	0.99919	0.00063	1.0000	0.0017	-0.0008	0.0018
LEU-COMP-THERM-043-001	1.00143	0.00058	0.9999	0.0000	0.0015	0.0006
LEU-COMP-THERM-043-002	1.00052	0.00075	1.0000	0.0000	0.0006	0.0008
LEU-COMP-THERM-043-003	1.00212	0.00064	0.9999	0.0001	0.0022	0.0006
LEU-COMP-THERM-043-004	1.00125	0.00065	1.0001	0.0000	0.0011	0.0007
LEU-COMP-THERM-043-005	1.00040	0.00081	0.9999	0.0000	0.0005	0.0008
LEU-COMP-THERM-043-006	1.00189	0.00075	1.0000	0.0000	0.0018	0.0008
LEU-COMP-THERM-043-007	1.00165	0.00064	1.0001	0.0001	0.0015	0.0006
LEU-COMP-THERM-043-008	1.00188	0.00084	1.0000	0.0001	0.0019	0.0008
LEU-COMP-THERM-043-009	1.00060	0.00077	1.0002	0.0001	0.0004	0.0008
LEU-COMP-THERM-049-001	0.99692	0.00076	1.0000	0.0034	-0.0031	0.0035
LEU-COMP-THERM-049-002	0.99727	0.00097	1.0000	0.0034	-0.0027	0.0035
LEU-COMP-THERM-049-003	0.99999	0.00073	1.0000	0.0034	0.0000	0.0035
LEU-COMP-THERM-049-004	0.99859	0.00078	1.0000	0.0034	-0.0014	0.0035
LEU-COMP-THERM-049-005	0.99952	0.00082	1.0000	0.0042	-0.0005	0.0043
LEU-COMP-THERM-049-006	1.00045	0.00073	1.0000	0.0042	0.0005	0.0043
LEU-COMP-THERM-049-007	0.99904	0.00089	1.0000	0.0042	-0.0010	0.0043
LEU-COMP-THERM-049-008	0.99975	0.00083	1.0000	0.0042	-0.0002	0.0043
LEU-COMP-THERM-049-009	0.99851	0.00074	1.0000	0.0037	-0.0015	0.0038
LEU-COMP-THERM-049-010	1.00045	0.00073	1.0000	0.0037	0.0005	0.0038
LEU-COMP-THERM-049-011	0.99964	0.00087	1.0000	0.0037	-0.0004	0.0038
LEU-COMP-THERM-049-012	0.99880	0.00075	1.0000	0.0037	-0.0012	0.0038
LEU-COMP-THERM-049-013	1.00089	0.00089	1.0000	0.0036	0.0009	0.0037
LEU-COMP-THERM-049-014	0.99895	0.00076	1.0000	0.0036	-0.0011	0.0037
LEU-COMP-THERM-049-015	1.00114	0.00087	1.0000	0.0036	0.0011	0.0037
LEU-COMP-THERM-049-016	0.99894	0.00087	1.0000	0.0036	-0.0011	0.0037
LEU-COMP-THERM-049-017	0.99856	0.00085	1.0000	0.0036	-0.0014	0.0037
LEU-COMP-THERM-049-018	1.00223	0.00076	1.0000	0.0030	0.0022	0.0031
LEU-COMP-THERM-050-001	0.99871	0.00075	1.0004	0.0010	-0.0017	0.0013
LEU-COMP-THERM-050-002	0.99843	0.00085	1.0004	0.0010	-0.0020	0.0013
LEU-COMP-THERM-050-003	0.99901	0.00083	1.0004	0.0010	-0.0014	0.0013
LEU-COMP-THERM-050-004	0.99918	0.00076	1.0004	0.0010	-0.0012	0.0013
LEU-COMP-THERM-050-005	1.00041	0.00073	1.0004	0.0010	0.0000	0.0012
LEU-COMP-THERM-050-006	1.00294	0.00086	1.0004	0.0010	0.0025	0.0013
LEU-COMP-THERM-050-007	0.99973	0.00099	1.0004	0.0010	-0.0007	0.0014
LEU-COMP-THERM-050-008	0.99705	0.00072	1.0004	0.0010	-0.0033	0.0012
LEU-COMP-THERM-050-009	0.99800	0.00084	1.0004	0.0010	-0.0024	0.0013

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-COMP-THERM-050-010	0.99734	0.00074	1.0004	0.0010	-0.0031	0.0012
LEU-COMP-THERM-050-011	0.99771	0.00078	1.0004	0.0010	-0.0027	0.0013
LEU-COMP-THERM-050-012	0.99925	0.00081	1.0004	0.0010	-0.0011	0.0013
LEU-COMP-THERM-050-013	0.99916	0.00092	1.0004	0.0010	-0.0012	0.0014
LEU-COMP-THERM-050-014	0.99962	0.00091	1.0004	0.0010	-0.0008	0.0014
LEU-COMP-THERM-050-015	0.99985	0.00084	1.0004	0.0010	-0.0005	0.0013
LEU-COMP-THERM-050-016	1.00071	0.00076	1.0004	0.0010	0.0003	0.0013
LEU-COMP-THERM-050-017	1.00085	0.00087	1.0004	0.0010	0.0005	0.0013
LEU-COMP-THERM-050-018	1.00139	0.00084	1.0004	0.0010	0.0010	0.0013
LEU-COMP-THERM-051-001	0.99821	0.00068	1.0010	0.0020	-0.0028	0.0021
LEU-COMP-THERM-051-002	1.00020	0.00063	1.0010	0.0024	-0.0008	0.0025
LEU-COMP-THERM-051-003	0.99936	0.00073	1.0010	0.0024	-0.0016	0.0025
LEU-COMP-THERM-051-004	1.00026	0.00067	1.0010	0.0024	-0.0007	0.0025
LEU-COMP-THERM-051-005	0.99980	0.00070	1.0010	0.0024	-0.0012	0.0025
LEU-COMP-THERM-051-006	1.00045	0.00066	1.0010	0.0024	-0.0005	0.0025
LEU-COMP-THERM-051-007	0.99975	0.00068	1.0010	0.0024	-0.0012	0.0025
LEU-COMP-THERM-051-008	1.00065	0.00063	1.0010	0.0024	-0.0003	0.0025
LEU-COMP-THERM-051-009	0.99941	0.00073	1.0010	0.0019	-0.0016	0.0020
LEU-COMP-THERM-051-010	0.99952	0.00073	1.0010	0.0019	-0.0015	0.0020
LEU-COMP-THERM-051-011	0.99552	0.00072	1.0010	0.0019	-0.0055	0.0020
LEU-COMP-THERM-051-012	0.99511	0.00070	1.0010	0.0019	-0.0059	0.0020
LEU-COMP-THERM-051-013	0.99243	0.00063	1.0010	0.0022	-0.0086	0.0023
LEU-COMP-THERM-051-014	0.99157	0.00071	1.0010	0.0019	-0.0094	0.0020
LEU-COMP-THERM-051-015	0.99354	0.00073	1.0010	0.0024	-0.0075	0.0025
LEU-COMP-THERM-051-016	0.99500	0.00076	1.0010	0.0020	-0.0060	0.0021
LEU-COMP-THERM-051-017	0.99691	0.00076	1.0010	0.0027	-0.0041	0.0028
LEU-COMP-THERM-051-018	0.99571	0.00068	1.0010	0.0021	-0.0053	0.0022
LEU-COMP-THERM-051-019	0.99670	0.00069	1.0010	0.0019	-0.0043	0.0020
LEU-COMP-THERM-052-001	0.99222	0.00069	1.0003	0.0023	-0.0081	0.0024
LEU-COMP-THERM-052-002	0.99262	0.00074	1.0003	0.0036	-0.0077	0.0037
LEU-COMP-THERM-052-003	1.00186	0.00069	1.0003	0.0034	0.0016	0.0035
LEU-COMP-THERM-052-004	0.99460	0.00082	1.0003	0.0023	-0.0057	0.0024
LEU-COMP-THERM-052-005	0.99131	0.00067	1.0003	0.0036	-0.0090	0.0037
LEU-COMP-THERM-052-006	0.98940	0.00061	1.0003	0.0034	-0.0109	0.0035
LEU-COMP-THERM-054-001	1.00155	0.00066	1.0003	0.0000	0.0012	0.0007
LEU-COMP-THERM-054-002	1.00152	0.00064	1.0001	0.0000	0.0014	0.0006
LEU-COMP-THERM-054-003	1.00169	0.00080	1.0000	0.0000	0.0016	0.0008
LEU-COMP-THERM-054-004	1.00182	0.00080	1.0003	0.0000	0.0016	0.0008
LEU-COMP-THERM-054-005	0.99942	0.00075	1.0001	0.0000	-0.0007	0.0008
LEU-COMP-THERM-054-006	1.00149	0.00072	0.9998	0.0000	0.0017	0.0007

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-COMP-THERM-054-007	0.99986	0.00078	1.0002	0.0000	-0.0003	0.0008
LEU-COMP-THERM-054-008	1.00094	0.00073	0.9999	0.0000	0.0011	0.0007
LEU-COMP-THERM-058-001	1.00154	0.00074	1.0000	0.0000	0.0016	0.0007
LEU-COMP-THERM-058-002	0.99989	0.00069	1.0000	0.0000	-0.0001	0.0007
LEU-COMP-THERM-058-003	1.00036	0.00077	1.0000	0.0000	0.0004	0.0008
LEU-COMP-THERM-058-004	1.00092	0.00078	1.0000	0.0000	0.0009	0.0008
LEU-COMP-THERM-058-005	1.00011	0.00067	1.0000	0.0000	0.0001	0.0007
LEU-COMP-THERM-058-006	1.00115	0.00071	1.0000	0.0000	0.0012	0.0007
LEU-COMP-THERM-078-001	0.99689	0.00083	0.9995	0.0010	-0.0026	0.0013
LEU-COMP-THERM-078-002	0.99822	0.00089	0.9990	0.0010	-0.0008	0.0013
LEU-COMP-THERM-078-003	0.99732	0.00071	0.9990	0.0010	-0.0017	0.0012
LEU-COMP-THERM-078-004	0.99709	0.00089	0.9986	0.0010	-0.0015	0.0013
LEU-COMP-THERM-078-005	0.99609	0.00089	0.9980	0.0010	-0.0019	0.0013
LEU-COMP-THERM-078-006	0.99681	0.00081	0.9974	0.0010	-0.0006	0.0013
LEU-COMP-THERM-078-007	0.99783	0.00092	0.9994	0.0010	-0.0016	0.0014
LEU-COMP-THERM-078-008	0.99744	0.00086	0.9987	0.0010	-0.0013	0.0013
LEU-COMP-THERM-078-009	0.99559	0.00084	0.9978	0.0010	-0.0022	0.0013
LEU-COMP-THERM-078-010	0.99497	0.00070	0.9969	0.0010	-0.0019	0.0012
LEU-COMP-THERM-078-011	0.99822	0.00073	0.9994	0.0010	-0.0012	0.0012
LEU-COMP-THERM-078-012	0.99886	0.00082	0.9993	0.0010	-0.0004	0.0013
LEU-COMP-THERM-078-013	0.99703	0.00078	0.9993	0.0010	-0.0023	0.0013
LEU-COMP-THERM-078-014	0.99676	0.00074	0.9991	0.0010	-0.0023	0.0012
LEU-COMP-THERM-078-015	0.99721	0.00078	0.9996	0.0010	-0.0024	0.0013
LEU-COMP-THERM-079-001	0.99787	0.00078	0.9999	0.0016	-0.0020	0.0018
LEU-COMP-THERM-079-002	1.00043	0.00084	1.0002	0.0016	0.0002	0.0018
LEU-COMP-THERM-079-003	0.99985	0.00089	1.0005	0.0016	-0.0006	0.0018
LEU-COMP-THERM-079-004	1.00059	0.00095	1.0004	0.0016	0.0002	0.0019
LEU-COMP-THERM-079-005	1.00013	0.00075	1.0004	0.0016	-0.0003	0.0018
LEU-COMP-THERM-079-006	0.99821	0.00067	0.9994	0.0008	-0.0012	0.0010
LEU-COMP-THERM-079-007	0.99916	0.00079	1.0003	0.0008	-0.0011	0.0011
LEU-COMP-THERM-079-008	0.99990	0.00066	1.0008	0.0008	-0.0009	0.0010
LEU-COMP-THERM-079-009	0.99973	0.00079	1.0003	0.0008	-0.0006	0.0011
LEU-COMP-THERM-079-010	1.00073	0.00067	1.0009	0.0008	-0.0002	0.0010
LEU-COMP-THERM-080-001	0.99584	0.00085	0.9976	0.0010	-0.0018	0.0013
LEU-COMP-THERM-080-002	0.99819	0.00074	0.9982	0.0010	0.0000	0.0012
LEU-COMP-THERM-080-003	0.99820	0.00072	0.9984	0.0010	-0.0002	0.0012
LEU-COMP-THERM-080-004	0.99826	0.00081	0.9981	0.0010	0.0002	0.0013
LEU-COMP-THERM-080-005	0.99695	0.00084	0.9979	0.0010	-0.0010	0.0013
LEU-COMP-THERM-080-006	0.99600	0.00081	0.9975	0.0010	-0.0015	0.0013
LEU-COMP-THERM-080-007	0.99889	0.00091	0.9993	0.0010	-0.0004	0.0014

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-COMP-THERM-080-008	0.99746	0.00078	0.9987	0.0010	-0.0012	0.0013
LEU-COMP-THERM-080-009	0.99648	0.00080	0.9982	0.0010	-0.0017	0.0013
LEU-COMP-THERM-080-010	0.99658	0.00082	0.9972	0.0010	-0.0006	0.0013
LEU-COMP-THERM-080-011	0.99606	0.00087	0.9984	0.0010	-0.0023	0.0013
LEU-COMP-THERM-091-001	1.00212	0.00077	1.0005	0.0010	0.0016	0.0013
LEU-COMP-THERM-091-002	1.00111	0.00073	1.0006	0.0010	0.0005	0.0012
LEU-COMP-THERM-091-003	1.00108	0.00072	1.0004	0.0010	0.0007	0.0012
LEU-COMP-THERM-091-004	1.00081	0.00070	1.0006	0.0010	0.0002	0.0012
LEU-COMP-THERM-091-005	1.00096	0.00069	1.0006	0.0010	0.0004	0.0012
LEU-COMP-THERM-091-006	1.00040	0.00066	1.0006	0.0010	-0.0002	0.0012
LEU-COMP-THERM-091-007	0.99843	0.00067	1.0004	0.0010	-0.0020	0.0012
LEU-COMP-THERM-091-008	0.99789	0.00061	1.0004	0.0010	-0.0025	0.0012
LEU-COMP-THERM-091-009	0.99694	0.00067	1.0004	0.0010	-0.0035	0.0012
LEU-MET-THERM-001-001	0.99816	0.00066	0.9990	0.0057	-0.0008	0.0057
LEU-SOL-THERM-003-001	0.99503	0.00069	0.9997	0.0039	-0.0047	0.0040
LEU-SOL-THERM-003-002	0.99709	0.00059	0.9993	0.0042	-0.0022	0.0042
LEU-SOL-THERM-003-003	1.00171	0.00063	0.9995	0.0042	0.0022	0.0042
LEU-SOL-THERM-003-004	0.99229	0.00069	0.9995	0.0042	-0.0072	0.0043
LEU-SOL-THERM-003-005	0.99754	0.00053	0.9997	0.0048	-0.0022	0.0048
LEU-SOL-THERM-003-006	0.99830	0.00053	0.9999	0.0049	-0.0016	0.0049
LEU-SOL-THERM-003-007	0.99507	0.00052	0.9994	0.0049	-0.0043	0.0049
LEU-SOL-THERM-003-008	1.00065	0.00040	0.9993	0.0052	0.0014	0.0052
LEU-SOL-THERM-003-009	0.99886	0.00043	0.9996	0.0052	-0.0007	0.0052
LEU-SOL-THERM-004-001	1.00063	0.00062	0.9994	0.0008	0.0012	0.0010
LEU-SOL-THERM-004-002	1.00215	0.00063	0.9999	0.0009	0.0023	0.0011
LEU-SOL-THERM-004-003	0.99861	0.00059	0.9999	0.0009	-0.0013	0.0011
LEU-SOL-THERM-004-004	1.00187	0.00052	0.9999	0.0010	0.0020	0.0011
LEU-SOL-THERM-004-005	1.00155	0.00058	0.9999	0.0010	0.0016	0.0012
LEU-SOL-THERM-004-006	1.00213	0.00050	0.9994	0.0011	0.0027	0.0012
LEU-SOL-THERM-004-007	1.00149	0.00054	0.9996	0.0011	0.0019	0.0012
LEU-SOL-THERM-005-001	0.99901	0.00052	1.0000	0.0042	-0.0010	0.0042
LEU-SOL-THERM-005-002	0.99999	0.00056	1.0000	0.0051	0.0000	0.0051
LEU-SOL-THERM-005-003	1.00012	0.00050	1.0000	0.0064	0.0001	0.0064
LEU-SOL-THERM-006-001	0.99915	0.00075	1.0000	0.0037	-0.0009	0.0038
LEU-SOL-THERM-006-002	1.00447	0.00079	1.0000	0.0038	0.0045	0.0039
LEU-SOL-THERM-006-003	0.99784	0.00072	1.0000	0.0041	-0.0022	0.0042
LEU-SOL-THERM-006-004	1.00029	0.00072	1.0000	0.0041	0.0003	0.0042
LEU-SOL-THERM-006-005	1.00246	0.00085	1.0000	0.0047	0.0025	0.0048
LEU-SOL-THERM-007-001	0.99475	0.00073	0.9961	0.0009	-0.0013	0.0012
LEU-SOL-THERM-007-002	0.99637	0.00068	0.9973	0.0009	-0.0009	0.0011

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-SOL-THERM-007-003	0.99712	0.00068	0.9985	0.0010	-0.0014	0.0012
LEU-SOL-THERM-007-004	1.00054	0.00062	0.9988	0.0011	0.0017	0.0013
LEU-SOL-THERM-007-005	0.99779	0.00058	0.9983	0.0011	-0.0005	0.0012
LEU-SOL-THERM-008-001	1.00162	0.00055	1.0002	0.0015	0.0014	0.0016
LEU-SOL-THERM-008-002	1.00082	0.00057	0.9999	0.0014	0.0009	0.0015
LEU-SOL-THERM-008-003	1.00216	0.00051	0.9999	0.0014	0.0023	0.0015
LEU-SOL-THERM-008-004	1.00380	0.00057	0.9999	0.0014	0.0039	0.0015
LEU-SOL-THERM-009-001	1.00067	0.00066	0.9998	0.0014	0.0009	0.0015
LEU-SOL-THERM-009-002	1.00053	0.00056	0.9999	0.0014	0.0006	0.0015
LEU-SOL-THERM-009-003	1.00004	0.00055	0.9999	0.0014	0.0001	0.0015
LEU-SOL-THERM-010-001	1.00087	0.00054	0.9999	0.0015	0.0010	0.0016
LEU-SOL-THERM-010-002	0.99985	0.00063	0.9999	0.0014	0.0000	0.0015
LEU-SOL-THERM-010-003	0.99984	0.00056	1.0000	0.0014	-0.0002	0.0015
LEU-SOL-THERM-010-004	1.00182	0.00052	1.0001	0.0014	0.0017	0.0015
LEU-SOL-THERM-016-001	1.00458	0.00076	0.9996	0.0013	0.0050	0.0015
LEU-SOL-THERM-016-002	1.00346	0.00077	0.9999	0.0013	0.0036	0.0015
LEU-SOL-THERM-016-003	1.00449	0.00070	0.9994	0.0014	0.0051	0.0016
LEU-SOL-THERM-016-004	1.00258	0.00072	0.9996	0.0014	0.0030	0.0016
LEU-SOL-THERM-016-005	1.00311	0.00069	0.9995	0.0014	0.0036	0.0016
LEU-SOL-THERM-016-006	1.00182	0.00074	0.9992	0.0015	0.0026	0.0017
LEU-SOL-THERM-016-007	1.00185	0.00081	0.9994	0.0015	0.0024	0.0017
LEU-SOL-THERM-017-001	1.00151	0.00072	0.9981	0.0013	0.0034	0.0015
LEU-SOL-THERM-017-002	1.00175	0.00079	0.9986	0.0013	0.0031	0.0015
LEU-SOL-THERM-017-003	1.00063	0.00072	0.9989	0.0014	0.0017	0.0016
LEU-SOL-THERM-017-004	1.00088	0.00079	0.9992	0.0014	0.0017	0.0016
LEU-SOL-THERM-017-005	1.00140	0.00071	0.9987	0.0015	0.0027	0.0017
LEU-SOL-THERM-017-006	1.00067	0.00067	0.9996	0.0015	0.0011	0.0016
LEU-SOL-THERM-018-001	1.00172	0.00062	0.9992	0.0010	0.0025	0.0012
LEU-SOL-THERM-018-002	1.00181	0.00065	0.9996	0.0010	0.0022	0.0012
LEU-SOL-THERM-018-003	1.00220	0.00068	0.9996	0.0010	0.0026	0.0012
LEU-SOL-THERM-018-004	1.00126	0.00068	0.9997	0.0010	0.0016	0.0012
LEU-SOL-THERM-018-005	1.00124	0.00065	0.9992	0.0010	0.0020	0.0012
LEU-SOL-THERM-018-006	1.00206	0.00072	0.9996	0.0010	0.0025	0.0012
LEU-SOL-THERM-019-001	1.00137	0.00067	0.9997	0.0009	0.0017	0.0011
LEU-SOL-THERM-019-002	1.00263	0.00066	0.9995	0.0009	0.0031	0.0011
LEU-SOL-THERM-019-003	1.00284	0.00065	0.9999	0.0009	0.0029	0.0011
LEU-SOL-THERM-019-004	1.00120	0.00072	0.9996	0.0009	0.0016	0.0012
LEU-SOL-THERM-019-005	1.00314	0.00062	0.9998	0.0009	0.0033	0.0011
LEU-SOL-THERM-019-006	1.00048	0.00062	0.9994	0.0009	0.0011	0.0011
LEU-SOL-THERM-020-001	1.00049	0.00066	0.9995	0.0010	0.0010	0.0012

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
LEU-SOL-THERM-020-002	1.00033	0.00043	0.9996	0.0010	0.0007	0.0011
LEU-SOL-THERM-020-003	0.99948	0.00049	0.9997	0.0012	-0.0002	0.0013
LEU-SOL-THERM-020-004	1.00027	0.00055	0.9998	0.0012	0.0005	0.0013
LEU-SOL-THERM-021-001	0.99838	0.00056	0.9983	0.0009	0.0001	0.0011
LEU-SOL-THERM-021-002	0.99705	0.00061	0.9985	0.0010	-0.0015	0.0012
LEU-SOL-THERM-021-003	0.99484	0.00059	0.9989	0.0011	-0.0041	0.0012
LEU-SOL-THERM-021-004	0.99913	0.00053	0.9993	0.0012	-0.0002	0.0013
MIX-COMP-THERM-002-002	1.00217	0.00077	1.0009	0.0045	0.0013	0.0046
MIX-COMP-THERM-003-006	1.00258	0.00072	1.0000	0.0020	0.0026	0.0021
MIX-COMP-THERM-006-001	0.99745	0.00084	1.0016	0.0051	-0.0042	0.0052
MIX-COMP-THERM-008-001	0.99892	0.00073	0.9997	0.0032	-0.0008	0.0033
MIX-MET-FAST-001-001	0.99966	0.00055	1.0000	0.0016	-0.0003	0.0017
MIX-MET-FAST-002-001	1.00449	0.00070	1.0000	0.0042	0.0045	0.0043
MIX-MET-FAST-002-002	1.00527	0.00077	1.0000	0.0044	0.0053	0.0045
MIX-MET-FAST-002-003	1.00434	0.00058	1.0000	0.0048	0.0043	0.0048
MIX-MET-FAST-003-001	1.00177	0.00054	0.9993	0.0016	0.0025	0.0017
MIX-MET-FAST-007-001	1.00337	0.00084	1.0000	0.0045	0.0034	0.0046
MIX-MET-FAST-007-002	1.00769	0.00075	1.0000	0.0023	0.0077	0.0024
MIX-MET-FAST-007-003	1.00617	0.00070	1.0000	0.0028	0.0062	0.0029
MIX-MET-FAST-007-004	1.00527	0.00071	1.0000	0.0028	0.0053	0.0029
MIX-MET-FAST-007-005	1.00279	0.00064	1.0000	0.0032	0.0028	0.0033
MIX-MET-FAST-007-006	0.99880	0.00061	1.0000	0.0035	-0.0012	0.0036
MIX-MET-FAST-007-007	1.00616	0.00064	1.0000	0.0032	0.0062	0.0033
MIX-MET-FAST-007-008	1.00522	0.00075	1.0000	0.0030	0.0052	0.0031
MIX-MET-FAST-007-009	1.00577	0.00076	1.0000	0.0028	0.0058	0.0029
MIX-MET-FAST-007-010	1.00488	0.00063	1.0000	0.0027	0.0049	0.0028
MIX-MET-FAST-007-011	1.00374	0.00062	1.0000	0.0026	0.0037	0.0027
MIX-MET-FAST-007-012	1.00301	0.00053	1.0000	0.0030	0.0030	0.0030
MIX-MET-FAST-007-013	1.00055	0.00075	1.0000	0.0033	0.0006	0.0034
MIX-MET-FAST-007-014	1.00849	0.00066	1.0000	0.0032	0.0085	0.0033
MIX-MET-FAST-007-015	1.00719	0.00067	1.0000	0.0032	0.0072	0.0033
MIX-MET-FAST-007-016	1.00512	0.00066	1.0000	0.0028	0.0051	0.0029
MIX-MET-FAST-007-017	1.00586	0.00076	1.0000	0.0028	0.0059	0.0029
MIX-MET-FAST-007-018	1.00860	0.00067	1.0000	0.0030	0.0086	0.0031
MIX-MET-FAST-007-019	1.00728	0.00064	1.0000	0.0034	0.0073	0.0035
MIX-MET-FAST-007-020	1.00487	0.00067	1.0000	0.0030	0.0049	0.0031
MIX-MET-FAST-007-021	1.00477	0.00063	1.0000	0.0031	0.0048	0.0032
MIX-MET-FAST-007-022	1.00375	0.00068	1.0000	0.0030	0.0037	0.0031
MIX-MET-FAST-007-023	1.00382	0.00066	1.0000	0.0028	0.0038	0.0029
MIX-MET-MIXED-001-001	0.99905	0.00094	0.9991	0.0013	0.0000	0.0016

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
MIX-SOL-THERM-001-001	0.99461	0.00078	1.0000	0.0016	-0.0054	0.0018
MIX-SOL-THERM-001-011	1.00450	0.00082	1.0000	0.0052	0.0045	0.0053
MIX-SOL-THERM-004-001	0.99471	0.00101	1.0000	0.0033	-0.0053	0.0035
MIX-SOL-THERM-004-002	0.99685	0.00084	1.0000	0.0033	-0.0031	0.0034
PU-MET-FAST-001-001	1.00089	0.00059	1.0000	0.0020	0.0009	0.0021
PU-MET-FAST-002-001	0.99979	0.00057	1.0000	0.0020	-0.0002	0.0021
PU-MET-FAST-003-001	1.00239	0.00067	1.0000	0.0030	0.0024	0.0031
PU-MET-FAST-003-002	0.99430	0.00063	1.0000	0.0030	-0.0057	0.0031
PU-MET-FAST-003-003	0.99397	0.00079	1.0000	0.0030	-0.0060	0.0031
PU-MET-FAST-003-004	0.99801	0.00067	1.0000	0.0030	-0.0020	0.0031
PU-MET-FAST-003-005	0.99920	0.00063	1.0000	0.0030	-0.0008	0.0031
PU-MET-FAST-005-001	1.00166	0.00063	1.0000	0.0013	0.0017	0.0014
PU-MET-FAST-006-001	1.00010	0.00070	1.0000	0.0030	0.0001	0.0031
PU-MET-FAST-008-001	0.99848	0.00058	1.0000	0.0006	-0.0015	0.0008
PU-MET-FAST-008-002	0.99702	0.00059	1.0000	0.0006	-0.0030	0.0008
PU-MET-FAST-009-001	1.00466	0.00069	1.0000	0.0027	0.0047	0.0028
PU-MET-FAST-010-001	0.99905	0.00065	1.0000	0.0018	-0.0010	0.0019
PU-MET-FAST-011-001	0.99991	0.00072	1.0000	0.0010	-0.0001	0.0012
PU-MET-FAST-012-001	1.00157	0.00071	1.0009	0.0021	0.0007	0.0022
PU-MET-FAST-013-001	1.00756	0.00070	1.0034	0.0023	0.0042	0.0024
PU-MET-FAST-018-001	0.99916	0.00079	1.0000	0.0030	-0.0008	0.0031
PU-MET-FAST-019-001	1.00018	0.00067	0.9992	0.0015	0.0010	0.0016
PU-MET-FAST-020-001	0.99955	0.00062	0.9993	0.0017	0.0003	0.0018
PU-MET-FAST-024-001	1.00235	0.00066	1.0000	0.0020	0.0024	0.0021
PU-MET-FAST-025-001	0.99913	0.00064	1.0000	0.0020	-0.0009	0.0021
PU-MET-FAST-026-001	0.99780	0.00054	1.0000	0.0024	-0.0022	0.0025
PU-MET-FAST-027-001	1.00229	0.00069	0.9977	0.0021	0.0046	0.0022
PU-MET-FAST-027-002	0.99862	0.00075	0.9980	0.0022	0.0006	0.0023
PU-MET-FAST-027-003	0.99950	0.00062	0.9977	0.0021	0.0018	0.0022
PU-MET-FAST-027-004	0.99144	0.00075	0.9978	0.0026	-0.0064	0.0027
PU-MET-FAST-027-005	0.99811	0.00079	0.9977	0.0024	0.0004	0.0025
PU-MET-FAST-028-001	1.00094	0.00059	1.0000	0.0022	0.0009	0.0023
PU-MET-FAST-031-001	1.00375	0.00072	1.0000	0.0021	0.0037	0.0022
PU-MET-FAST-035-001	0.99727	0.00064	1.0000	0.0016	-0.0027	0.0017
PU-MET-FAST-037-001	1.00374	0.00071	1.0000	0.0044	0.0037	0.0045
PU-MET-FAST-037-005	1.00077	0.00076	1.0000	0.0037	0.0008	0.0038
PU-MET-FAST-037-007	1.00223	0.00074	1.0000	0.0037	0.0022	0.0038
PU-MET-FAST-037-012	0.99879	0.00065	1.0000	0.0037	-0.0012	0.0038
PU-MET-FAST-037-015	1.00288	0.00076	1.0000	0.0037	0.0029	0.0038
PU-MET-FAST-037-016	1.00481	0.00080	1.0000	0.0037	0.0048	0.0038

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
PU-SOL-THERM-001-001	1.00323	0.00091	1.0000	0.0050	0.0032	0.0051
PU-SOL-THERM-001-002	1.00633	0.00092	1.0000	0.0050	0.0063	0.0051
PU-SOL-THERM-001-003	1.00803	0.00086	1.0000	0.0050	0.0080	0.0051
PU-SOL-THERM-001-004	1.00375	0.00097	1.0000	0.0050	0.0037	0.0051
PU-SOL-THERM-001-005	1.00603	0.00106	1.0000	0.0050	0.0060	0.0051
PU-SOL-THERM-001-006	1.00874	0.00094	1.0000	0.0050	0.0087	0.0051
PU-SOL-THERM-002-001	1.00244	0.00096	1.0000	0.0047	0.0024	0.0048
PU-SOL-THERM-002-002	1.00412	0.00099	1.0000	0.0047	0.0041	0.0048
PU-SOL-THERM-002-003	1.00139	0.00097	1.0000	0.0047	0.0014	0.0048
PU-SOL-THERM-002-004	1.00725	0.00103	1.0000	0.0047	0.0072	0.0048
PU-SOL-THERM-002-005	1.00666	0.00081	1.0000	0.0047	0.0067	0.0048
PU-SOL-THERM-002-006	1.00523	0.00088	1.0000	0.0047	0.0052	0.0048
PU-SOL-THERM-002-007	1.00765	0.00089	1.0000	0.0047	0.0076	0.0048
PU-SOL-THERM-003-001	1.00120	0.00076	1.0000	0.0047	0.0012	0.0048
PU-SOL-THERM-003-002	1.00220	0.00078	1.0000	0.0047	0.0022	0.0048
PU-SOL-THERM-003-003	1.00419	0.00090	1.0000	0.0047	0.0042	0.0048
PU-SOL-THERM-003-004	1.00466	0.00070	1.0000	0.0047	0.0047	0.0048
PU-SOL-THERM-003-005	1.00533	0.00085	1.0000	0.0047	0.0053	0.0048
PU-SOL-THERM-003-006	1.00481	0.00092	1.0000	0.0047	0.0048	0.0048
PU-SOL-THERM-003-007	1.00624	0.00086	1.0000	0.0047	0.0062	0.0048
PU-SOL-THERM-003-008	1.00652	0.00079	1.0000	0.0047	0.0065	0.0048
PU-SOL-THERM-004-001	1.00262	0.00079	1.0000	0.0047	0.0026	0.0048
PU-SOL-THERM-004-002	0.99825	0.00077	1.0000	0.0047	-0.0018	0.0048
PU-SOL-THERM-004-003	1.00032	0.00067	1.0000	0.0047	0.0003	0.0047
PU-SOL-THERM-004-004	0.99782	0.00079	1.0000	0.0047	-0.0022	0.0048
PU-SOL-THERM-004-005	0.99809	0.00077	1.0000	0.0047	-0.0019	0.0048
PU-SOL-THERM-004-006	1.00100	0.00078	1.0000	0.0047	0.0010	0.0048
PU-SOL-THERM-004-007	1.00325	0.00075	1.0000	0.0047	0.0032	0.0048
PU-SOL-THERM-004-008	0.99880	0.00082	1.0000	0.0047	-0.0012	0.0048
PU-SOL-THERM-004-009	0.99934	0.00084	1.0000	0.0047	-0.0007	0.0048
PU-SOL-THERM-004-010	1.00020	0.00070	1.0000	0.0047	0.0002	0.0048
PU-SOL-THERM-004-011	0.99977	0.00096	1.0000	0.0047	-0.0002	0.0048
PU-SOL-THERM-004-012	1.00255	0.00076	1.0000	0.0047	0.0026	0.0048
PU-SOL-THERM-004-013	1.00052	0.00086	1.0000	0.0047	0.0005	0.0048
PU-SOL-THERM-005-001	1.00131	0.00065	1.0000	0.0047	0.0013	0.0047
PU-SOL-THERM-005-002	1.00353	0.00081	1.0000	0.0047	0.0035	0.0048
PU-SOL-THERM-005-003	1.00232	0.00084	1.0000	0.0047	0.0023	0.0048
PU-SOL-THERM-005-004	1.00528	0.00080	1.0000	0.0047	0.0053	0.0048
PU-SOL-THERM-005-005	1.00669	0.00066	1.0000	0.0047	0.0067	0.0047
PU-SOL-THERM-005-006	1.00494	0.00075	1.0000	0.0047	0.0049	0.0048

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
PU-SOL-THERM-005-007	1.00338	0.00081	1.0000	0.0047	0.0034	0.0048
PU-SOL-THERM-005-008	0.99919	0.00074	1.0000	0.0047	-0.0008	0.0048
PU-SOL-THERM-005-009	1.00068	0.00074	1.0000	0.0047	0.0007	0.0048
PU-SOL-THERM-006-001	1.00025	0.00072	1.0000	0.0035	0.0003	0.0036
PU-SOL-THERM-006-002	1.00121	0.00067	1.0000	0.0035	0.0012	0.0036
PU-SOL-THERM-006-003	1.00127	0.00077	1.0000	0.0035	0.0013	0.0036
PU-SOL-THERM-008-016	1.00679	0.00088	1.0000	0.0033	0.0068	0.0034
PU-SOL-THERM-008-020	1.00939	0.00078	1.0000	0.0028	0.0094	0.0029
PU-SOL-THERM-008-021	0.99648	0.00086	1.0000	0.0040	-0.0035	0.0041
PU-SOL-THERM-008-025	1.01440	0.00091	1.0000	0.0042	0.0144	0.0043
PU-SOL-THERM-008-027	1.01031	0.00103	1.0000	0.0042	0.0103	0.0043
PU-SOL-THERM-008-029	1.01445	0.00082	1.0000	0.0041	0.0145	0.0042
PU-SOL-THERM-009-001	1.01388	0.00044	1.0000	0.0033	0.0139	0.0033
PU-SOL-THERM-009-002	1.01980	0.00044	1.0000	0.0033	0.0198	0.0033
PU-SOL-THERM-009-003	1.01877	0.00036	1.0000	0.0033	0.0188	0.0033
PU-SOL-THERM-013-001	1.00492	0.00097	0.9980	0.0040	0.0069	0.0041
PU-SOL-THERM-013-002	1.00440	0.00093	0.9980	0.0040	0.0064	0.0041
PU-SOL-THERM-013-004	1.00436	0.00105	0.9965	0.0052	0.0079	0.0053
PU-SOL-THERM-013-005	1.00345	0.00086	0.9965	0.0052	0.0069	0.0053
PU-SOL-THERM-013-006	1.00232	0.00084	0.9965	0.0052	0.0058	0.0053
PU-SOL-THERM-013-007	1.00670	0.00095	0.9965	0.0052	0.0102	0.0053
PU-SOL-THERM-013-008	1.00260	0.00115	0.9965	0.0052	0.0061	0.0053
PU-SOL-THERM-013-009	1.00296	0.00099	0.9965	0.0052	0.0065	0.0053
PU-SOL-THERM-013-010	1.00376	0.00097	0.9965	0.0052	0.0073	0.0053
PU-SOL-THERM-013-011	1.00638	0.00087	0.9965	0.0062	0.0099	0.0063
PU-SOL-THERM-013-012	1.00467	0.00096	0.9965	0.0062	0.0082	0.0063
PU-SOL-THERM-013-013	0.99885	0.00099	0.9965	0.0062	0.0023	0.0063
PU-SOL-THERM-013-014	1.00226	0.00107	0.9965	0.0062	0.0058	0.0063
PU-SOL-THERM-013-015	1.00903	0.00106	0.9959	0.0062	0.0131	0.0063
PU-SOL-THERM-013-016	1.00351	0.00104	0.9959	0.0062	0.0076	0.0063
PU-SOL-THERM-013-017	1.00252	0.00092	0.9959	0.0062	0.0066	0.0063
PU-SOL-THERM-013-018	1.00075	0.00099	0.9959	0.0062	0.0049	0.0063
PU-SOL-THERM-013-019	1.00132	0.00095	0.9959	0.0062	0.0054	0.0063
PU-SOL-THERM-013-020	1.00312	0.00101	0.9959	0.0062	0.0072	0.0063
PU-SOL-THERM-013-021	1.00794	0.00097	0.9966	0.0043	0.0113	0.0044
PU-SOL-THERM-013-022	1.00310	0.00111	0.9966	0.0043	0.0065	0.0044
PU-SOL-THERM-014-001	1.00622	0.00108	0.9980	0.0032	0.0082	0.0034
PU-SOL-THERM-014-007	1.00455	0.00112	0.9980	0.0032	0.0066	0.0034
PU-SOL-THERM-014-013	1.00589	0.00104	0.9980	0.0043	0.0079	0.0044
PU-SOL-THERM-014-018	1.00860	0.00100	0.9980	0.0043	0.0106	0.0044

Benchmark	k_{Calc}	σ_{Calc}	k_{Bench}	σ_{Bench}	$Bias$	σ_{Bias}
PU-SOL-THERM-014-024	1.00903	0.00094	0.9980	0.0043	0.0110	0.0044
PU-SOL-THERM-014-030	1.00315	0.00099	0.9980	0.0043	0.0051	0.0044
PU-SOL-THERM-015-001	1.00509	0.00104	0.9980	0.0038	0.0071	0.0039
PU-SOL-THERM-015-007	1.00819	0.00099	0.9971	0.0047	0.0111	0.0048
PU-SOL-THERM-015-011	1.00152	0.00095	0.9971	0.0047	0.0044	0.0048
PU-SOL-THERM-015-015	1.00728	0.00109	0.9971	0.0047	0.0102	0.0048
Using Eq (3), the average bias ($\overline{Bias}$) is computed to be 0.00068. Using Eq (4), the variance of the average bias (s^2) is computed to be 0.0000089. Using Eq (5), the average total uncertainty ($\overline{\sigma}_t^2$) is computed to be 0.0000040.						

The error bars in the figures below are the 1σ values computed using Eq (7). The biases from different regions of the benchmark suite are shown below in Figure 3 where Region I is HEU, Region II is IEU, Region III is LEU, Region IV is PU, and Region VI is MIX.

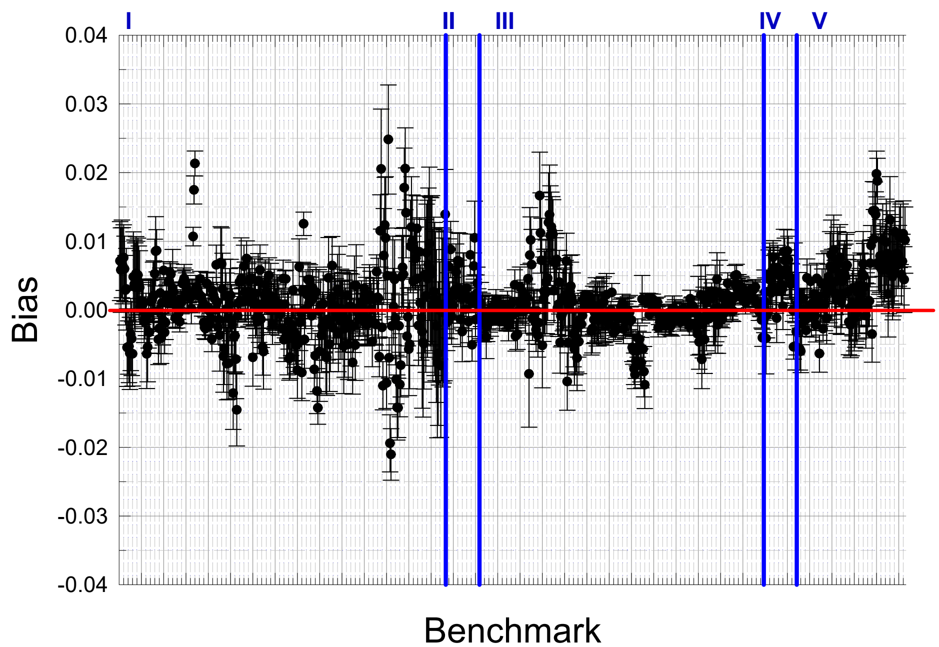

Figure 3 – Regions of SNL NCS Benchmark Suite with Biases

The summary (or final) row of Table 6 provides the average bias, the variance in the average bias, and the average total uncertainty for the cases in the benchmark suite.

5.2. Trend Analysis

5.2.1. Average Neutron Lethargy Causing Fission (EALF)

We start our trend analysis by examining the bias as a function of the average neutron lethargy causing fission (EALF). A plot of the bias as a function of EALF is found in Figure 4. As previously noted with the original release of the benchmark suite, there is a sparsity of benchmarks in the intermediate lethargy range between the EALF values for fast and thermal systems. However, the ICSBEP Handbook document is also sparse with respect to benchmarks in the intermediate energy range and the SNL NCS benchmark suite has added additional cases in this range since its first release. Fortunately, most of the systems analyzed for criticality safety purposes will fall in either the fast or thermal energy regions, so the sparsity of coverage does not present a significant issue.

As noted in previous work [1], regression analysis and fits for the data using statistical software and tools are certainly possible. However, the observation that there are biases above and below 0.0 for the entire eight-decade span in lethargy found in the benchmark suite is still accurate. Therefore, we will not attempt to modify our bias and bias uncertainty as a function of the average neutron lethargy causing fission. That is, trends in the EALF will not be utilized to modify the MOS determined from the benchmark suite.

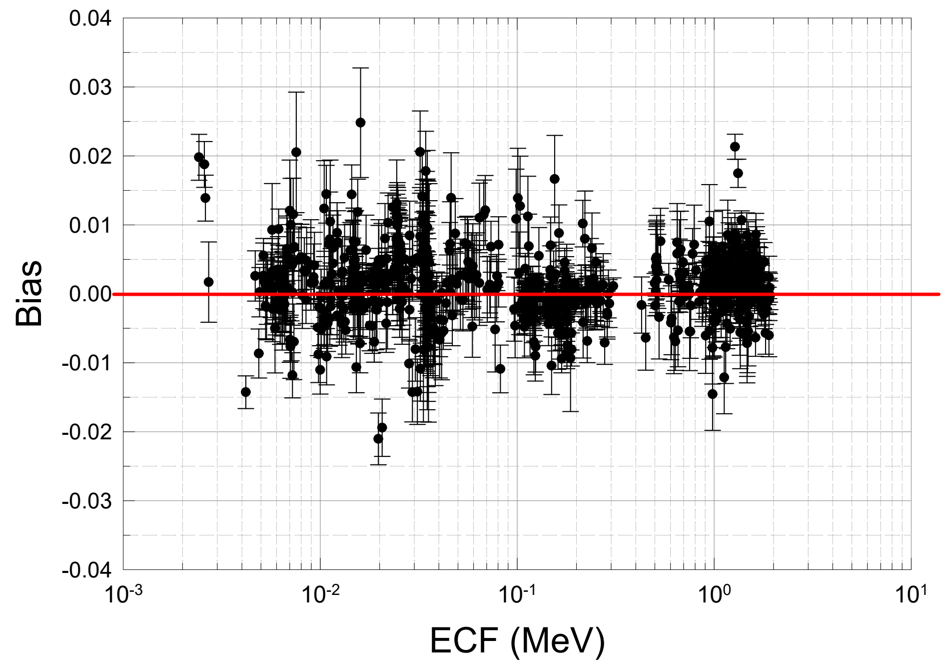

Figure 4 – Bias as a Function of EALF

5.2.2. Average Neutron Energy Causing Fission (ECF)

Another parameter extracted from the criticality calculations is the average neutron energy causing fission (ECF). The information provided by this parameter is somewhat like the EALF parameter, and it is preferred to EALF by some NCS engineers. The plot of benchmark bias as a function of ECF is found in Figure 5. As we noted with the EALF parameter, a regression fit to any function could be performed, but that would imply meaning or significance to the form selected for the fit. To the authors' knowledge, there is no physical or mathematical reason for selecting a regression fit for the bias as function the average neutron energy causing fission (e.g., there is no physical process or algorithm in the Monte Carlo process that would lead us to choose a quadratic fit over a linear + exponential fit). Therefore, we will not attempt to modify our bias and bias uncertainty as a function of the average neutron energy causing fission. Thus, trends in the ECF will not be utilized to modify the MOS determined from the benchmark suite.

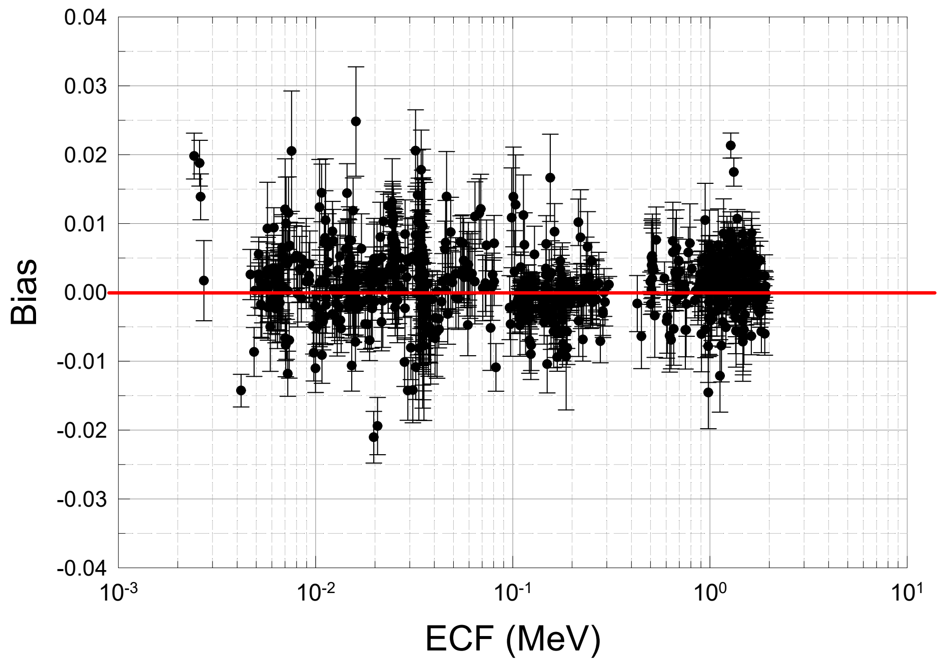

Figure 5 – Bias as a Function of ECF

5.3. Statistical Analysis of Benchmark k_{eff} Results

The establishment of the proper value for USL depends upon choosing the appropriate statistical treatment of the results from the MCNP6 k_{eff} calculations. The first step in the process for the statistical treatment is to compute a normalized k_{eff} value for each of the benchmarks in the suite using the following equation:

$$\text{Normalized } k_{eff} = \frac{k_{Calc}}{k_{Bench}} \qquad \text{Eq (8)}$$

The SNL procedure specifies that the Anderson-Darling Goodness of Fit test is applied to the normalized k_{eff} values using a Gaussian distribution. Performing the test in this way is an assessment of whether the benchmark k_{eff} values are normally distributed. The results of the Anderson-Darling test for normality indicate that the null hypothesis (that is, the data is normally distributed) should be rejected.

In addition to performing the Anderson-Darling test, a couple of additional figures were produced to visually depict how the data departs from a Gaussian distribution. A histogram of the normalized k_{eff} values of SNL NCS benchmark suite is found in Figure 6. Comparison of this histogram to a histogram for a Gaussian distribution will show a significant deviation. In addition, a normal probability plot was produced for the normalized k_{eff} values, and the plot is found in Figure 7. For normally distributed data, observations should lie approximately on a straight line. The figure shows significant deviation from the straight line that is expected from a normal distribution.

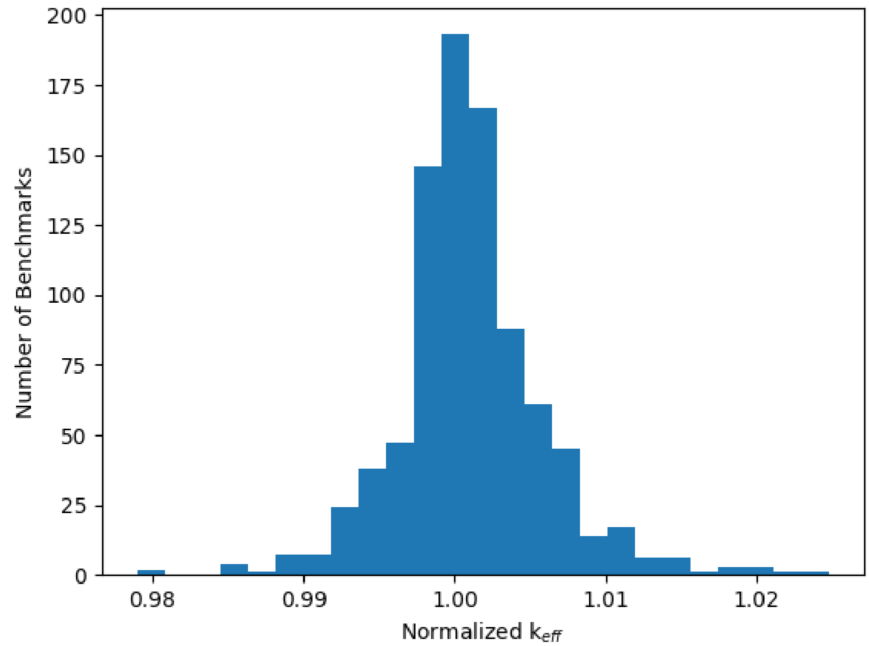

Figure 6 – Histogram for Normalized k_{eff} Values of SNL NCS Benchmark Suite

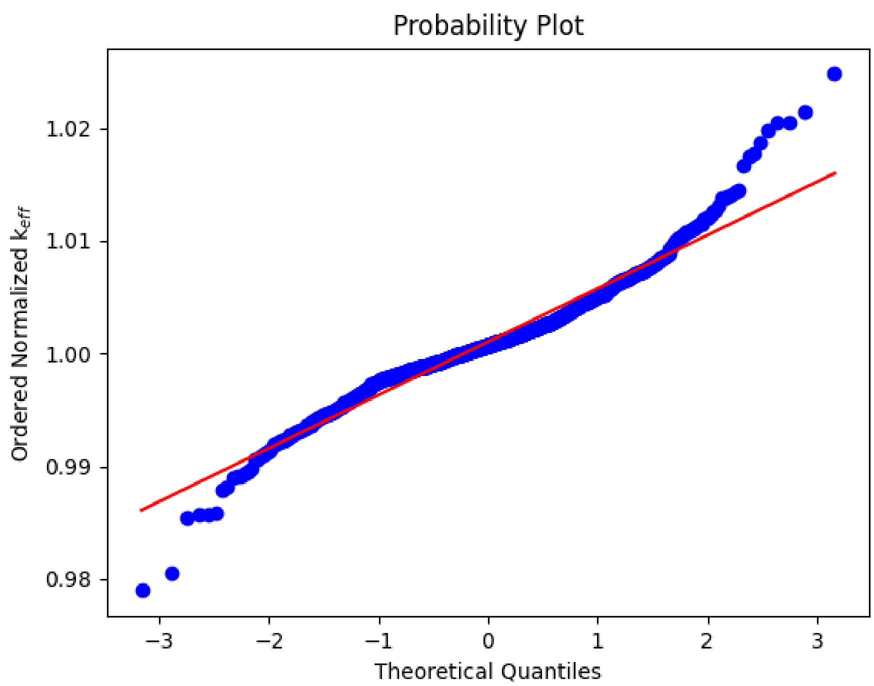

Figure 7 – Normal Probability Plot for Normalized k_{eff} Values of SNL NCS Benchmark Suite

Now that it has been determined that the data associated with the SNL NCS benchmark suite is not normally distributed, a non-parametric analysis of the results must be performed. That is, a single-side lower tolerance limit ***CANNOT*** be applied because it relies on the underlying data to being drawn from a Gaussian (or at least near Gaussian) distribution. The non-parametric approach used in this report is drawn from NUREG/CR-6698 [15]. The approach selected is more conservative from other non-parametric techniques for determining a distribution-free confidence interval.

As the non-parametric technique is applied, a determination must be made as to whether the smallest bias in the data set is less than or equal to zero. For the SNL NCS benchmark suite, the smallest bias is less than zero, so the "Statistical Method" in Eq (6) for the non-parametric technique is given by the following:

$$\text{Statistical Method} = [smallest(k_{eff} - \sigma_t)] - NPM \qquad \text{Eq (9)}$$

where the NPM is the non-parametric margin is obtained from a table in the NUREG/CR-6698 document. In the case of the SNL NCS benchmark suite, the NPM is 0.0. With Eq (9), the following is the method for determination of the USL:

$$USL = [smallest(k_{eff} - \sigma_t)] - (MOS_{Code} + MOS_{Bench} + MOS_{Validation}) \qquad \text{Eq (10)}$$

Analysis of the MCNP6 calculated k_{eff} values reveals that $[smallest(k_{eff} - \sigma_t)]$ is 0.973 for the SNL NCS benchmark suite. As previously mentioned, the minimum MOS_{Code} within the NCS Program at SNL is 0.02. If the entire benchmark suite is used for a CSA, the USL for that analysis is determined by this equation:

$$USL = 0.953 - MOS_{Bench} - MOS_{Validation} \qquad \text{Eq (11)}$$

6. SUMMARY

In this report, we have described the update to the SNL NCS benchmark suite. The benchmark suite was developed to be used for validation of the MCNP6 Version 2.0 computer code for NCS purposes with the ENDF/B-VII.1 cross sections. The updated benchmark models were selected from the benchmark suite found in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments (ICSBEP Handbook)*. The benchmark suite covers a broad range of fissile material types, material forms, moderators, reflectors, and neutron energy spectra.

The SNL NCS benchmark suite handles configuration management and change control by utilizing an SNL corporate instance of GitLab. In addition to the benchmark models, the NCS engineers at SNL have developed a utility for reducing the burden created when producing a SVVR. The SVVR utility is also hosted on the SNL corporate instance of GitLab.

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