Summary Report for Special Service Agreement TAL-NAPC20191003-003

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April 2020

Introduction

The aim of this work was to review the ICSBEP and IRPhEP Handbooks in order to develop a candidate list of benchmark evaluations that provide data other than simple k_{eff} and, if feasible, develop MCNP input decks for those benchmarks. A combination of (i) the ICSBEP's "DICE" search tool, (ii) the IRPhEP's "IDAT" tool, and (iii) personal experience, have been utilized to support this effort. There are undoubtedly many additional resources that can be studied in the longer term (a notable example being the IAEA's own Technical Report Series #480, "Research Reactor Benchmarking Database: Facility Specification and Experimental Data") to supplement this list, but the following provides a starting point for potential benchmark testing of evaluated nuclear data files beyond that traditionally done via criticality eigenvalue only calculations.

Potential Benchmarks for Further Study

Based upon the stated review, the following benchmarks seem promising. In many cases a complete geometry model in MCNP form has been developed although the appropriate tally cards may not yet be finalized. A summary of the data available from these benchmarks, including, when available, an MCNP geometry plot, is presented below.

LEU-COMP-THERM-005 (LCT5)

The ICSBEP LCT5 evaluation describes a series of UO_2 (either 4.3% or 2.35% enriched ^{235}U) reactor lattice experiments performed at Pacific Northwest Laboratory in the early 1980s. These experiments were sponsored by British Nuclear Fuels Limited and include critical (and subcritical) configurations with differing enrichments, lattice spacing and dissolved gadolinium concentration in the light water moderator and reflector. The ICSBEP evaluation focusses on criticality, but the primary reference (PNL-4976, "Criticality Experiments with Low Enriched UO_2 Fuel Rods in Water Containing Dissolved Gadolinium" which is available in electronic form from https://www.osti.gov) also describes measurements of "fast fission rate", i.e., ($^{238}U(n,f)/^{235}U(n,f)$) and "relative conversion rate", i.e., ($^{238}U(n,\gamma)/^{235}U(n,f)$) for selected configurations. Previously developed LCT5 MCNP input decks can be modified to calculate these additional experimental data.

LEU-COMP-THERM-008 (LCT8)

The ICSBEP LCT8 evaluation describes a series of UO_2 (2.46% enriched ^{235}U) reactor lattice experiments performed at Babcock and Wilcox's Lynchburg Research Center in the early 1970s. This suite of experiments is also known as the B&W Core XI experiments. It consists of a square 45 x 45 central array of water moderated UO_2 fuel rods with various combinations of poison pins and water holes. This central array is surrounded by additional "driver" fuel rods that form a somewhat cylindrical shape. Although the ICSBEP evaluation focusses on criticality, an Appendix is included that provides pin power data, usually over a symmetric octant of the central 15x15 rod array, for 11 different fuel/poison/water hole configurations. Further information is available in the various Babcock and Wilcox reports referenced by the evaluator and which are available in electronic form from https://www.osti.gov. A quarter-core MCNP model with the appropriate fuel rod tallies is available. Figures 1 and 2 illustrate the core geometry for LCT8 case 2; first for one of the central region's 15x15 arrays and second for the top, right quadrant quarter core model.

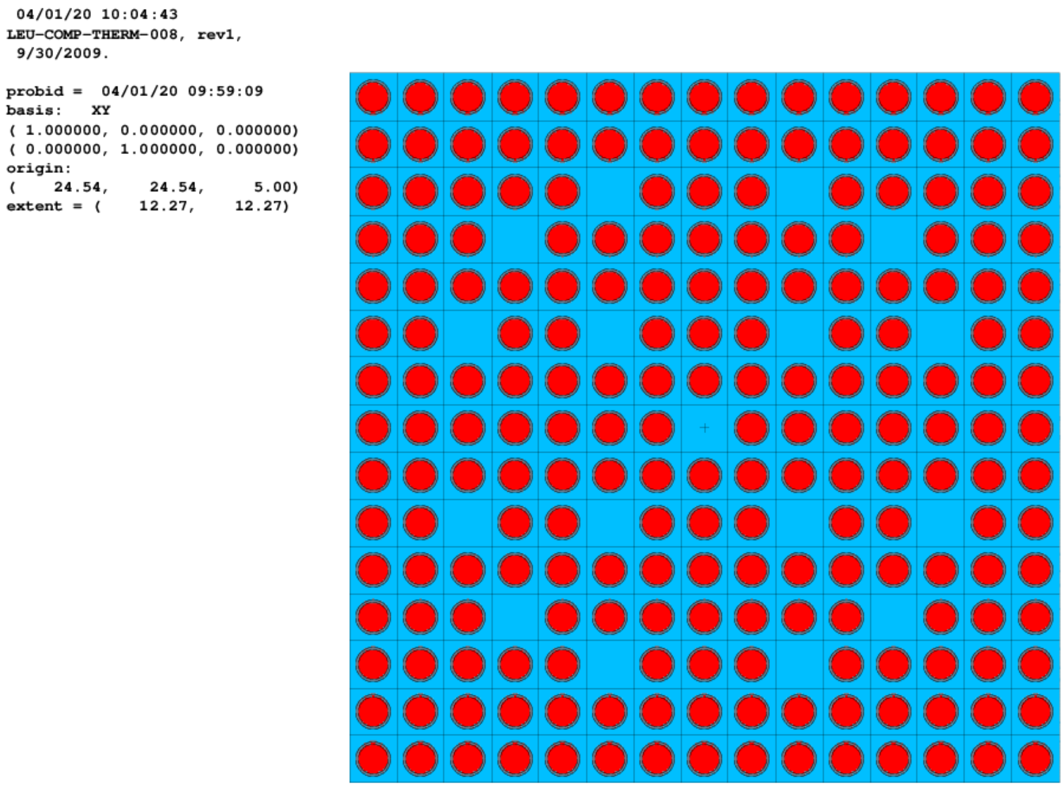

Figure 1. Radial slice plot for the LCT8.2 central region 15x15 cluster where pin power data were obtained.

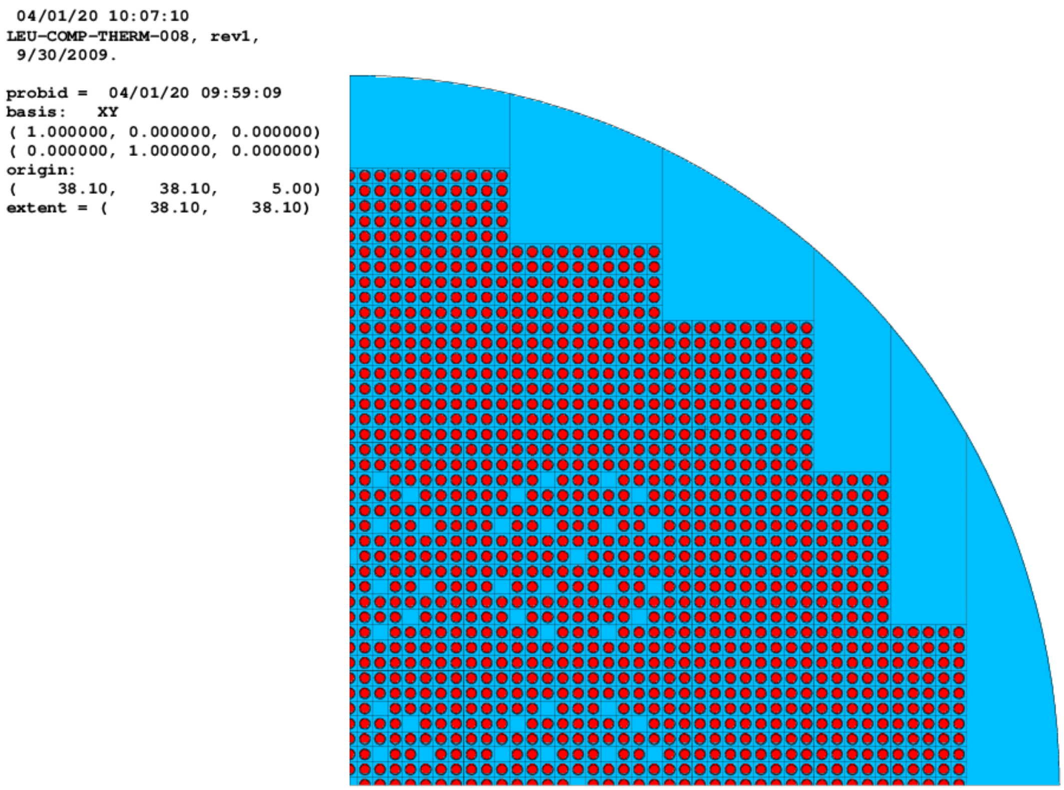

Figure 2. Radial slice plot for the LCT8.2 quarter-core model.

LEU-COMP-THERM-026 (LCT26)

The ICSBEP LCT26 evaluation describes a series of UO_2 (5% enriched ^{235}U) reactor lattice experiments performed at the MATR facility at the Institute of Physics and Power Engineering in the early 1990s. Three critical lattice arrangements with differing hexagonal pitch are defined at for "cold" (near 20°C) and "hot" (near 200°C) conditions. Sample room temperature MCNP input decks are provided in the evaluation's Appendix but they have not been independently verified at this time.

LEU-COMP-THERM-032 (LCT32)

The ICSBEP LCT32 evaluation describes a series of UO_2 (10% enriched ^{235}U) water-moderated lattice configurations of varying lattice spacings in the temperature range from 20°C to 274°C. These experiments were performed in the mid-1960s at the Kurchatov Institute in Russia. MCNP input decks are provided in the evaluation's Appendix but have not been independently verified.

LEU-COMP-THERM-056 (LCT56)

The ICSBEP LCT56 evaluation describes a water-moderated, water reflected Boiling Water Reactor type fuel assembly configuration (5% enriched ^{235}U in UO_2). The experiments were performed at the BORAX-V facility at Idaho National Laboratory in the early 1960s. The evaluation focusses on criticality but the evaluator notes that Reference 1 ("Design and Hazards Summary Report Boiling Reactor Experiment V (BORAX V)", ANL-6302) includes "… core characteristics such as control rod calibrations, excess reactivity, shutdown reactivity margin, reactivity effects of various core components, reactivity effects of temperature and voids, neutron flux and power distributions, and cadmium ratios were measured …". This document is available in electronic form from https://www.osti.gov. A sample MCNP input deck is provided in the evaluation's Appendix but has not been independently verified at this time.

HEU-COMP-THERM-022 (HCT22)

The ICSBEP HCT22 evaluation describes a series of 11 critical experiments involving lattices of SPERT III water moderated and water reflected highly-enriched UO_2 plate fuel. The ICSBEP evaluation focusses on developing a criticality model, but the "Supplemental Information" section notes that vertical and radial flux distributions were measured by activation of bare and cadmium-covered gold foils. Additional data may be found in the references cited by the evaluator. Those documents may be obtained in electronic form from https://www.osti.gov. MCNP geometry models for the 11 cases are available. The following slice plots, Figures 3 and 4, illustrate the central poison rod and adjacent fuel plates for the configuration used for radial and axial flux measurements and their overall position within the full core model.

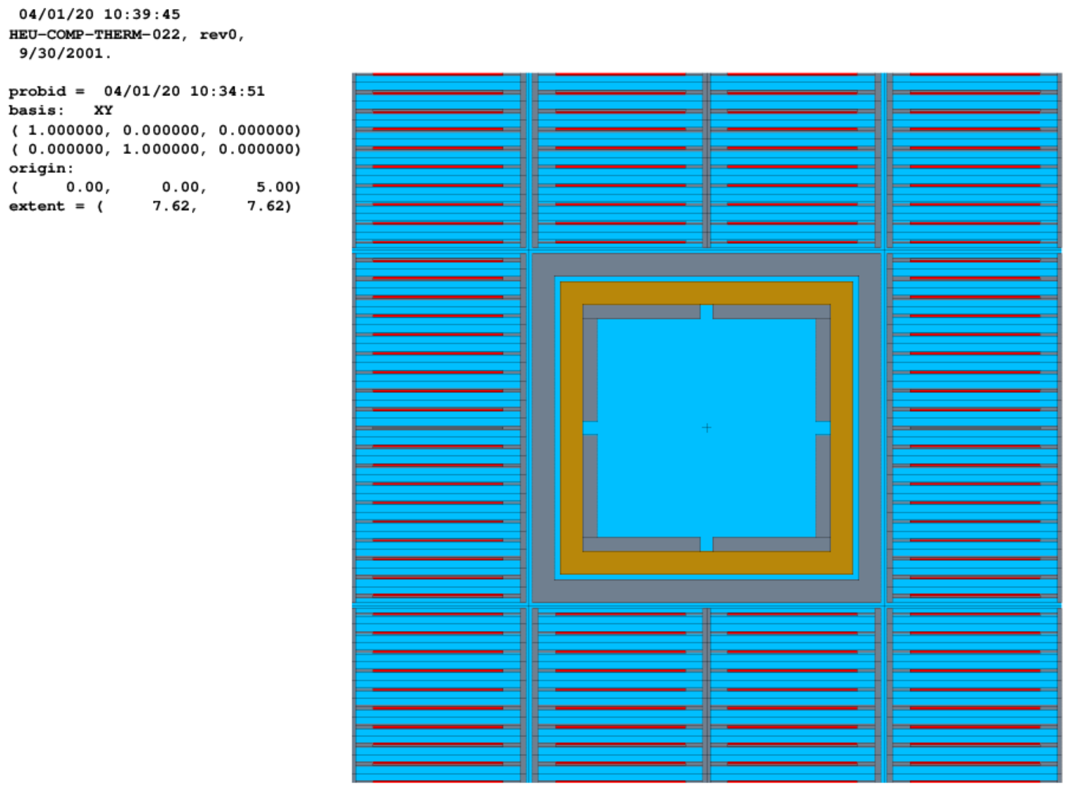

Figure 3. HCT22.11. A radial slice plot illustrating the poison control box and part of the adjacent fuel assemblies.

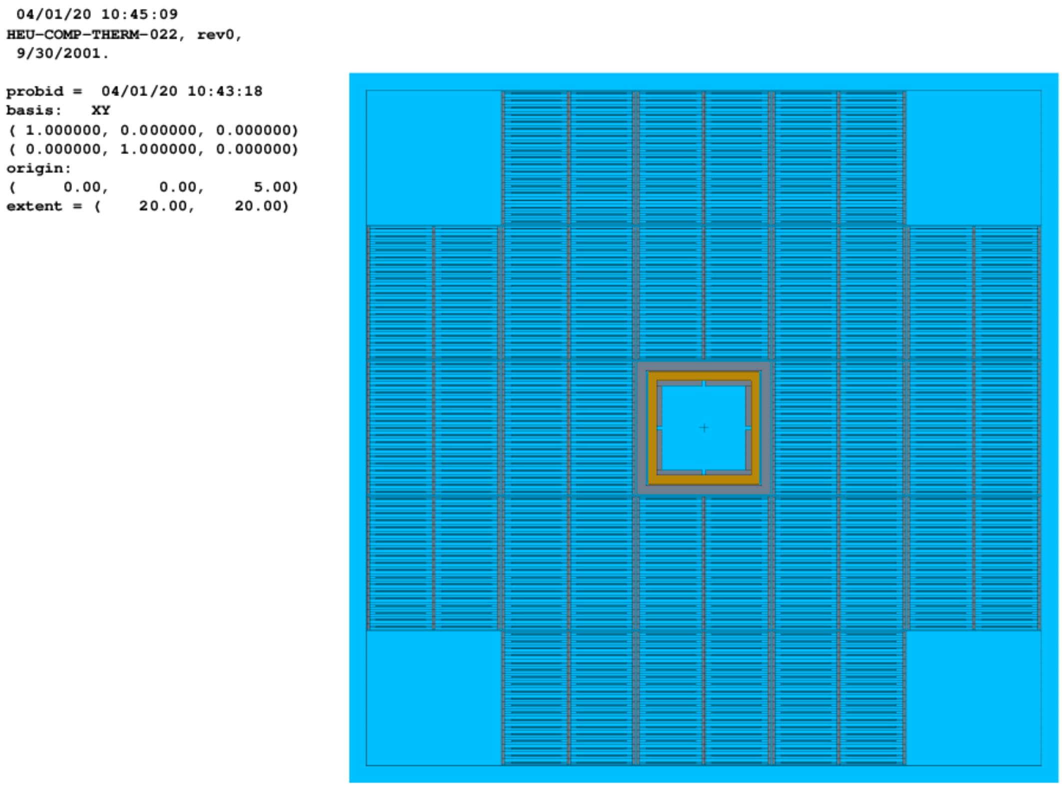

Figure 4. A radial slice plot for HCT22, case 11. The full extent of the water reflector is not shown.

DIMPLE-LWR-EXP-001 (DIMPLE1)/LEU-COMP-THERM-048 (LCT48)

The DIMPLE S01 experimental program occurred at the UKAEA's Winfrith site in the early 1980s. It included critical experiments with low enriched UO_2 rods (~3.0 wt.% ^{235}U) with light water moderation and reflection. The ICSBEP LCT48 evaluation, used for criticality calculations, defines a 3D model consisting of 1565 fuel rods positioned in a near cylindrical arrangement. The IRPhEP model is a 2D radial slice used to calculate reaction rate ratios for $^{235,238}U$ and ^{239}Pu fission as well as ^{238}U capture for a subset of the fuel rods. As shown in Figure 5, the MCNP 2D model takes advantage of the core's quarter-core symmetry.

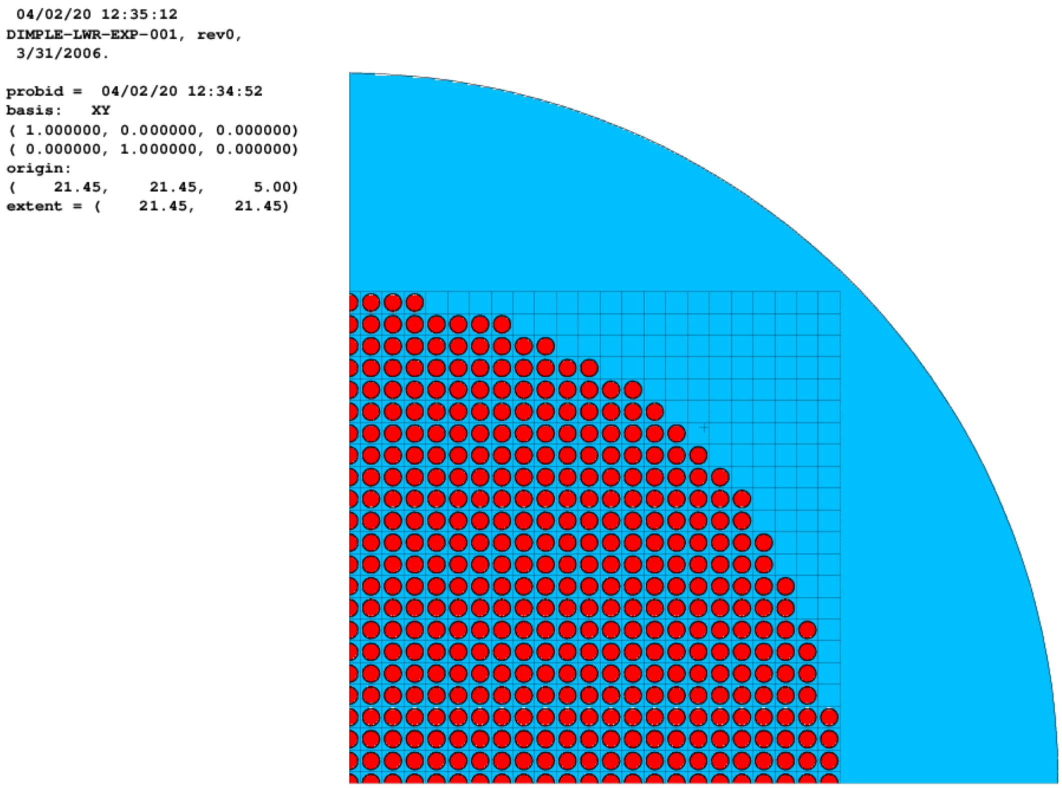

Figure 5. A quarter-core radial slice plot of the Dimple S01A core.

DIMPLE-LWR-EXP-002(DIMPLE2)/LEU-COMP-THERM-055 (LCT55)

The DIMPLE S06 experimental program occurred at the UKAEA's Winfrith site in the late 1980s and early 1990s. It included critical experiments with low enriched UO_2 rods (~3.0 wt.% ^{235}U) in a cruciform array. The experimental program is known as the "S06" series and two core configurations, designated S06A and S06B are described in these evaluations. The S06A core was light water moderated and reflected, similar to the S01 series previously described. The S06B core included a tight-fitting stainless steel region that simulates a PWR core baffle. The ICSBEP LCT55 evaluation, used for criticality calculations, defines a 3D model consisting of 3072 fuel rods. The IRPhEP model is a 2D radial slice used to calculate reaction rate ratios for $^{235,238}U$ and ^{239}Pu fission as well as ^{238}U capture. As shown in Figure 6, the MCNP 2D model takes advantage of the core's 1/8 (octant)-core symmetry.

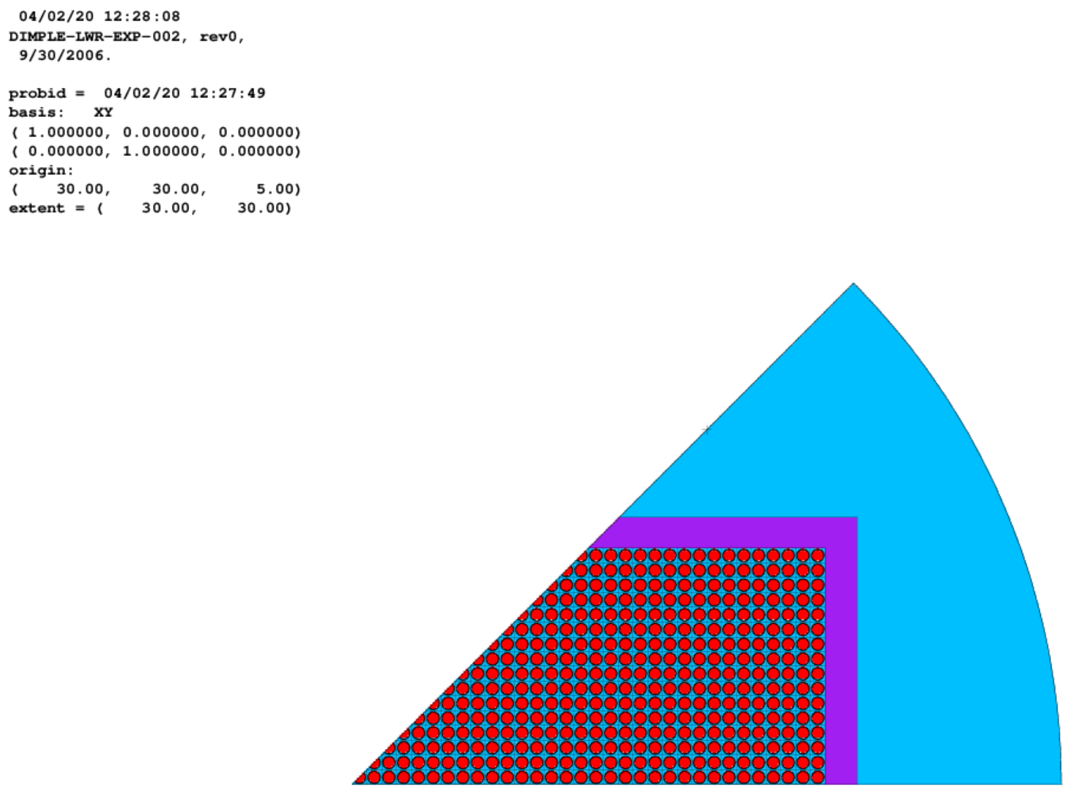

Figure 6. A radial slice (octant symmetric) of the Dimple S06 core plan. Core S06B (shown here) includes a tight-fitting stainless steel baffle followed by a water reflector. Core S06A omits the baffle and only contains a water reflector.

KRITZ-LWR-RESR-003

The KRITZ reactor operated in Studsvik, Sweden during the first half of the 1970s, and included several experimental programs, known as KRITZ-2:1, KRITZ-2:13 and KRITZ-2:19. The first two utilized UO_2 fuel rods, the latter mixed-oxide fuel rods. Criticality for KRITZ-2:13 was attained at isothermal conditions at room temperature (22.1°C) and at elevated temperature (243.0°C), using boron concentration and water level. Relative rod fission rates were measured for selected fuel rods at both temperatures. The core is a 40x40 square pitch lattice positioned asymmetrically within the pressure vessel, as shown in the MCNP generated figure below. The MCNP model is for room temperature. Dimensional information is provided in the evaluation to extend this model to the elevated temperature condition, but that MCNP input file has not yet been created. Thermal expansion causes the rods and lattice to expand, with a corresponding decrease in material number density. This offers the potential to create multiple computer models with and without various thermal expansion to assess what geometry features are most important to precisely model at higher temperatures. Analysis of the KRITZ-2:1 (KRITZ-LWR-RESR-002) data may be a future activity. That core consisted of a 44x44 rod array on a slightly tighter pitch. For that core the rod fission rate data are only available at elevated temperature.

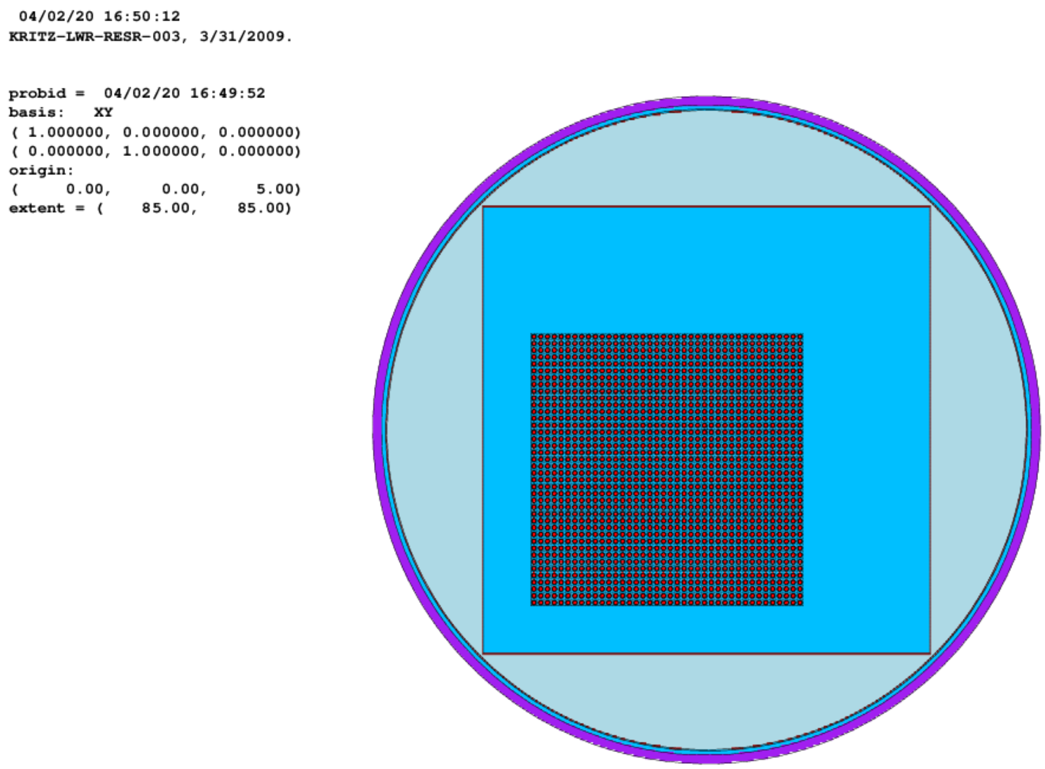

Figure 7. A slice plot of the KRITZ-2:13 core. A 40x40 rod lattice asymmetrically located within the pressure vessel. The borated light water reflector is shown in blue, a saturated steam region is shown in pale green.

TCA-LWR-EXP-001/LEU-COMP-THERM-006 (LCT6) and -035 (LCT35)

Tank-type Critical Assembly (TCA) experiments designed to yield temperature coefficient of reactivity data near and slightly above room temperature were performed at JAERI in the late 1980s. The experiments described here consisted of UO_2 (2.6 wt% ^{235}U) fuel rods in a square-pitched array. Moderation and reflection occurred with light water (“A” cores), borated light water (“B” cores) or soluble gadolinium in light water (“C”) cores. Three different array configurations, from as small as 17x18 rods to as large as 26x26 rods were defined for each core type and criticality was attained at a range of temperatures from ~15°C to ~62°C. Nine MCNP models at room temperature are available presently. It is not clear at this time what (if any) thermal expansion effects need to be modelled for these relatively modest temperature increases. The evaluation only provides room temperature dimensions and material number densities. All cores exhibit quarter-core symmetry and one configuration (Core A-1a) consisting of a 21x21 rod array and reflector is shown in Figure 8.

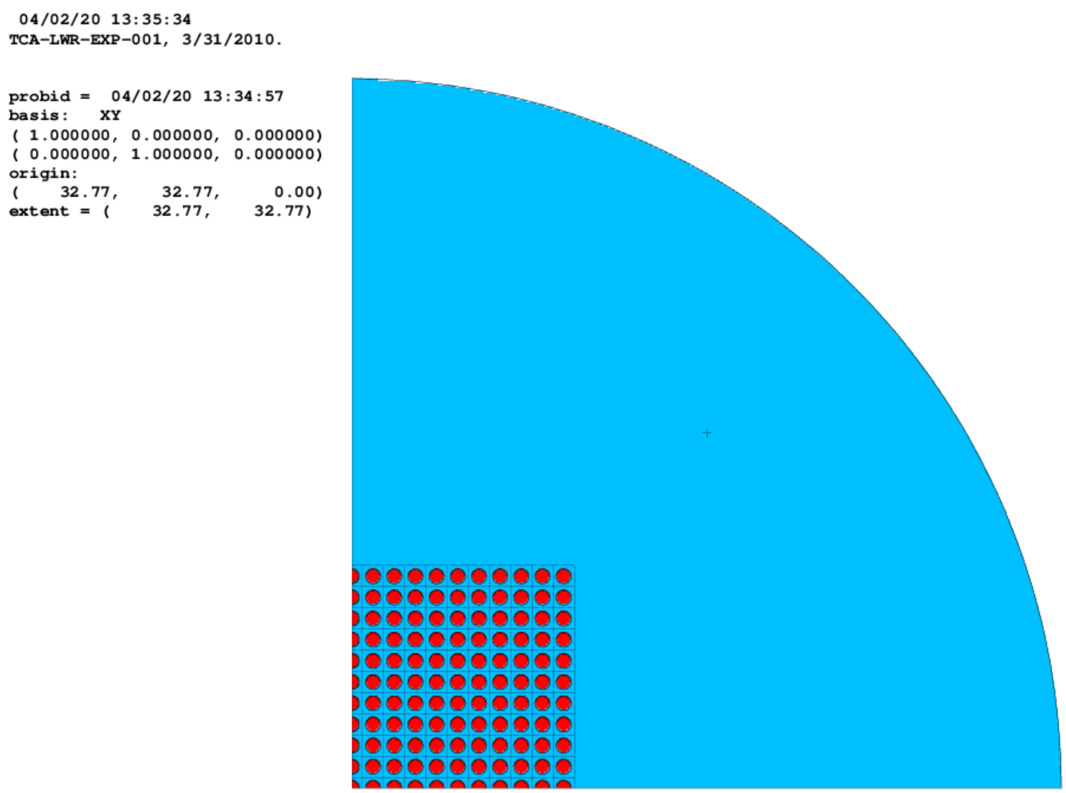

Figure 8. A quarter core slice plot of the TCA, Core A1a model. The full core would be represented by a 21 x 21 rod lattice.

CREOLE-PWR-EXP-001

The CREOLE (Coefficient of Reactivity in EOLE) was an experimental program to obtain reactivity temperature coefficient data over a temperature range from room temperature to ~300°C. This measurement program was performed at CEA-Cadarache's EOLE facility in the late 1970s. Data were obtained for UO_2 and mixed-oxide (UO_2-PuO_2) lattices. Radial fission rate data were also obtained. An MCNP input deck describing the UO_2 "clean" lattice configuration is provided in the Appendix, but has not been independently verified.

FCA-FUND-EXP-001

Fission rate ratio measurements, including for minor actinides, were performed by JAEA in the Fast Critical Assembly at Tokai-mura in the early 1980s. This measurement program is designated FCA IX and includes seven configurations, IX-1 to IX-7. Sample MCNP input files describing both heterogeneous and homogeneous models for FCA IX-7 are provided in the Appendix but have not been verified.

MINERVE-FUND-RESR-001

MINERVE is an experimental pool reactor consisting of a 90% ^{235}U-enriched driver zone surrounding a square central cavity where a test lattice can be inserted. The core is surrounded by a thick graphite reflector. The measurements described in the evaluation were part of the "CERES Phase II" program. That program provided fission product worth data meant to mimic fission product poisoning found in light-water-reactor spent fuels. The measurements used separated fission product isotopes that were introduced into UO_2 pellets. The isotopes considered in the MINERVE-I program include ^{147,149,152,nat}Sm, ^{143,145,nat}Nd, ^{153}Eu, ^{155}Gd and ^{103}Rh. A second program, MINERVE-II included ^{95}Mo, ^{99}Tc and ^{133}Cs. MCNP models were not included in this evaluation report.

TENDL-2019 Photonuclear ACE file testing

Prior to its release near the end of 2019, a testing effort was undertaken for the next generation suite of Talys Evaluated Nuclear Data Library photonuclear files g-TENDL-2019 https://tendl.web.psi.ch/tendl_2019/tar.html. This was not an effort to validate the physics accuracy of these files, rather to simply verify that the ACE files produced by NJOY from the underlying TENDL-2019 evaluations were structurally correct and that physically sounds MCNP jobs utilizing these files would run to completion. A “mode e p n” MCNP input deck and ACE files generated at the Agency were utilized for this work. This input, as employed for iron, is shown in the following Table.

Table 1. MCNP Input File to Test TENDL-2019 Isotopic Iron Photonuclear ACE Files

```
Example photonuclear simulation: find the n spectrum from a
disc
c
c Fe
    1   11   -7.86    -11 21 -22
    2    0           ( 11 :-21: 22 ) -91
    9    0                             91

   11    cz      5.0
   21    pz      0.0
   22    pz      2.5
   91    so    150.0

 mode e p n
 sdef pos=0 0 0 sur=21 vec=0 0 1 dir=1 par=3 erg=20
c
c
   m11 plib=14p elib=01e nlib=00c pnlib=19u
       26054 0.05845
       26056 0.91754
       26057 0.02119
       26058 0.00282
 mpn11
       26054
       26056
       26057
       26058
c
 fcl:p  1 0 0
 phys:p 3j 1
 cut:p j   7.320
 cut:e j   7.320
c
 wwp:e,p,n 5 3 5 0 0
 wwe:e,p,n 20
 wwn1:e,p  0.2    0.2     -1
```

```
 wwn1:n    0.0001 0.0001  -1
c
  e15     0.01 0.05 0.1 0.4 0.6 0.8 1
          1.25 1.5 1.75 2 2.5 3 3.5 4 5 6 7 8 9 10 12.3858
  f15:n   0.0 100.0 1.25 0.0
c
  e22     0.01 0.05 0.1 0.4 0.6 0.8 1
          1.25 1.5 1.75 2 2.5 3 3.5 4 5 6 7 8 9 10 12.3858
  f22:n   11 21 22 (11 21 22)
c
  nps 250000000
c nps 2500000
c
  print
```

This input file was suitably modified to test the ACE photonuclear nuclear data files for all stable elements/isotopes from Z=3 through Z=83 as well as ^{232}Th and ^{234,235,238}U. Values on the "cut:p" and "cut:e" were varied by element as appropriate, or set to minimum of 100 keV. The "nps" card value was set to 250 million or 50 million histories. All jobs ran to completion and in all cases the respective MCNP decks .inp and .outp files were made available to the Agency under the auspice of the CoNDERC project.

MCNP k_{eff} Reproducibility and Uncertainty Assessment

Section 3.3.4.9 of the MCNP® User's Manual (LA-UR-17-29981) recommends a minimum of 10,000 neutron histories per cycle when executing kcode jobs in order to avoid a potential bias in the calculation of k_{eff}. This is relatively new guidance and might exceed the typical histories per cycle specified in many user's legacy input decks. A suite of six benchmark input decks have been re-run for a fixed number (50 million) of active histories for a variety of neutron histories per cycle in order to assess the magnitude of this potential k_{eff} bias. The benchmarks are identified in Table 2. This particular selection allows the potential bias to be assessed for a variety of problem spectra, such as unmoderated FAST and INTERmediate assemblies as well as reflected and unreflected THERMal assemblies.

Table 2. Legacy Benchmarks Tested for Potential k_{eff} Calculation Bias

Benchmark Identifier	Comment

HEU-MET-FAST-001 (HMF1)	Godiva. Single homogeneous sphere model.
IEU-MET-FAST-007 (IMF7)	Big-10. Detailed, heterogeneous discs and annular plates, model.
HEU-SOL-THERM-050.3 (HST50.3)	A small, unreflected cylinder containing an HEU solution with small H/U ratio. This is a high leakage thermal assembly
HEU-SOL-THERM-042.8 (HST42.8)	A large, unreflected cylinder containing an HEU solution with a large H/U ratio. This is a low leakage thermal assembly.
LEU-COMP-THERM-005.1 & -005.12 (LCT5.1 and LCT5.12)	UO_2 lattice with varying rod pitch, producing a water-to-fuel volume ratio of 0.5 (case 1) or 2.7 (case 12).
LEU-COMP-THERM-007.1 & -007.4 (LCT7.1 and LCT7.4)	UO_2 lattice with varying rod pitch, producing a moderator-to-fuel ratio of 1.8 (case 1) or 11.5 (case 4).

The number of histories/cycle was one of (i) 1000, (ii) 5000, (iii) 10,000, (iv) 20,000, (v) 50,000 or (vi) 100,000. In all instances 50 warmup cycles were run followed by enough active cycles to total 50 million active histories. MCNP's rand card "hist" parameter was initially set to 1 and then advanced by 50 million per job for a total of 20 independent jobs for each of the histories/cycle values noted above, producing six sets of 20 independent jobs.

The individual calculated values are tabulated in Appendix B for each benchmark noted above. While the subsequent discussion focusses in the HMF1 (Godiva) results, the general conclusions are mostly applicable to all of these assemblies.

An analysis of variance was performed on these 120 k_{calc} values. Three possible averages were calculated. First is an average and standard deviation based upon the 120 individual k_{calc} values. Second, for a given history/cycle value the 20 k_{calc} values were averaged. In addition, those 20 k_{calc} samples were used to estimate the standard deviation of those respective populations for comparison with MCNP's estimated k_{eff} uncertainty. A third grouping of these data was to average the six k_{calc} values for the same starting "hist" value. This yielded 20 additional k_{calc} averages.

As the primary concern to be addressed was the potential for a calculated k_{eff} bias, we review the HMF1 average calculated eigenvalue as a function of histories/cycle. From 100,000 histories/cycle to 1,000 histories/cycle those average results are 1.00006±0.00002, 1.00008±0.00003, 1.00007±0.00002, 1.00002±0.00002 and 1.00003±0.00003 and 0.99995±0.00003, respectively. The results for 20,000 histories/cycle and above are tightly clustered at about 1.00007±0.00002 and then decrease for the 10,000 histories/cycle and 5,000 history/cycle jobs, bottoming out at an average of 0.99995±0.00003 for the 1,000 histories/cycle. As determined by an ANOVA (Analysis of Variance) F-Test, performed at the 95% confidence level, this is a statistically significant difference and supports the assertion that calculated k_{eff} is biased when running with too small a particle history/cycle value. However, it should be noted that this potential bias is small, amounting to about 10 pcm, a value not that different from the calculated k_{eff} uncertainty for a 50 million history job.

Applying the same analysis to the other benchmarks yields mixed results. In all cases it is always the 1,000 histories/cycle average that deviates from the remaining history/cycle average. For the intermediate spectrum IMF7 (Big-10) assembly there is also evidence for a small, again about 10 pcm, calculated k_{eff} bias. The ANOVA 95% F-Test also supports a difference in calculated k_{eff} among the difference particle histories/cycles. But for the six thermal spectrum assemblies, the F-Test only suggests a difference for the HST42.8, LCT7.1 and LCT5.12 benchmarks, while there is no statistically significant difference in the HST50.3, LCT7.4 or LCT5.1 benchmark k_{eff} calculations. There does not appear to be a pattern among these six cases. For example, between the two solution benchmarks the HST42.8 assembly is more "thermal" than HST50.3 while for the LCTs the 7.4 and 5.1 configurations are more "thermal" than 7.1 and 5.12, respectively. For those cases where a statistically significant difference was seen, that difference was about 12 pcm and so is similar in magnitude to that for the intermediate spectrum (IMF7, Big-10) and fast spectrum (HMF1, Godiva) assemblies. When not deemed statistically significant the difference was as small as 2 pcm.

Hence from this limited study we conclude there is marginal evidence for a small, on the order of 10 pcm, bias in calculated k_{eff} when running MCNP criticality problems if the history/cycle value is on the order of 1,000. For 5,000 or more (once again, the MCNP manual recommends a minimum of 10,000) histories/cycle there is likely no bias in calculated k_{eff}, at least for a sensitivity level of around 10 pcm.

Another feature of these calculations is the ability to assess the validity of MCNP's k_{eff} uncertainty. Returning to the HMF1 (Godiva) results we see that the typical uncertainty is about 8 pcm. For each of the twenty sets of kcode jobs we may also calculate an estimated standard deviation which is found to be 8.3 pcm, 12.7 pcm, 8.2 pcm, 9.7 pcm, 11.3 pcm and 11.0 pcm for the 100,000 histories/cycle to 1,000 histories/cycle, respectively. These results suggest that the MCNP k_{eff} uncertainty may be slightly underestimated. The same is true for the other assemblies.

A final observation of interest. The range of calculated k_{eff} values seen (see the "pop. min" and "pop. max" rows) often spans a range of 4 or more times the estimated population standard deviation. This is an entirely reasonable result for a 20-sample population, and serves as a stark reminder to all that when a Monte Carlo result is obtained with a plus or minus standard deviation band that the true result will actually be outside of that band about 1/3 of the time. Quoting a result with a corresponding 95% confidence interval provides a much more realistic assessment of the bounding interval where the true answer resides.

Conclusions, Observations and Recommendations

A primary goal of this work was to identify potential critical benchmarks from the ICSBEP and IRPhEP Handbooks that could be used to supplement nuclear data testing. Past data testing efforts have focused almost exclusively on assessing the accuracy of nuclear data for predicting k_{eff} at room temperature. The proposed list of benchmarks provided above has the potential to allow data testing to expand beyond that, to include temperature coefficient of reactivity, reactor pin power and spectral index calculations that are then compared to measured data.

In some instances, MCNP models have already been developed and require minimal or no modification to use. A list of the input files that were provided to the Agency in electronic form is provided in Appendix A.

The benchmarks identified here are by no means an exclusive list. Much further research is warranted in order to extend this initial benchmark suite. In addition, users are cautioned that the benchmark specifications may sometimes need to be enhanced. As these evaluations age, some of which are up to 20 years old, the approximations and simplifications made at that time and judged to be insignificant (by the standards of the day) might no longer be insignificant. The precision (and hopefully the accuracy) of modern and future calculations will only increase as the capability and availability of computers increases, and so it is only natural that the sophistication of the underlying computer models should also increase.

In that regard, as future calculations shift from just k_{eff} to include additional types of data there will likely be renewed questions about the minimum acceptable running strategy. For example, a typical k_{eff} calculation might use 50 million or so active neutron histories to yield an acceptable uncertainty on calculated k_{eff}. The studies documented above suggest that the current MCNP user guidance of a minimum of 10,000 histories/cycle is sufficiently large so that there is no history/cycle bias in that calculation. But as user's progress to calculate other quantities such as spectral indices, pin power distributions, temperature coefficients, etc. does the same guidance hold? Those jobs will almost certainly be much larger. Past, albeit limited, experience suggests that jobs of 1 billion active histories or more will be necessary to achieve the required statistical uncertainty for meaningful C/E comparisons. What should the running strategy be for those jobs? Will 2.5 million active histories/cycle for 400 cycles work, or will a future MCNP user guidance recommend not only a minimum history/cycle value but include a minimum number of cycles (hundreds, thousands, …)? It would seem that sensitivity studies, perhaps covering a range of 2.5 million histories/cycle for 400 cycles down to 100,000 histories/cycle for 5,000 cycles, to determine the reproducibility of various calculated parameters would be useful. And even the one billion active history number is somewhat arbitrary. Will replicate jobs of 250 million histories suffice? Or are 5 billion histories needed? Again, a range of sensitivity studies is recommended to provide guidance to users.

Appendix A

Presented here is a listing of all electronic files shared with the Agency as part of this contract.

MCNP Input File Summary

Filename(s)	Description
lct008xx_3Dqc.e80_00c_250M.inp	Quarter-core MCNP input for LCT8, case xx (xx ranges from 02 to 09 plus 11, 16 and 17). Fission rate tallies for $^{234,235,238}U$ as well as the fuel material are accrued over a 16 cm region centered at the axial midplane for each rod in the central 15x15 rod region (cases 02-09 and 11).
hct022xx.e80_00c_250M.inp	Full-core MCNP input for HCT22, case xx (xx ranges from 01 to 11). Further research is needed to determine what experimental data are available and what tally definitions are appropriate.
dimple1_S01A_2Dqc.e80_00c_250M.inp	Quarter-core 2D MCNP input for DIMPLE-LWR-EXP-001. Reaction rate tally definitions ($^{235,238}U$ and ^{239}Pu fission, ^{238}U capture and individual fuel rod fission) are specified for each rod in the model.
dimple2_S06A_2Doc.e80_00c.250M.inp dimple2_S06B_2Doc.e80_00c.250M.inp	2D MCNP input for DIMPLE-LWR-EXP-002's S06A and S06B with octant symmetry. Reaction rate tally definitions ($^{235,238}U$ and ^{239}Pu fission, ^{238}U capture and individual fuel rod fission) are specified for each rod in the model.
kritz213_22C.e80_00c_250M.inp	MCNP input for KRITZ-LWR-RESR-003 at 22°C. This is a full-core model for a 40x40 rod array asymmetrically positioned within its pressure vessel. Reaction rate tally definitions ($^{235,238}U$ and ^{239}Pu fission, ^{238}U capture and individual fuel rod fission) over an 11 cm axial region are specified for each rod in the model.

<table>
<tr><td>tca.a?_qc.e80_00c_250M.inp
tca.b?_qc.e80_00c_250M.inp
tca.c?_qc.e80_00c_250M.inp</td><td>MCNP input for TCA-LWR-EXP-001, core types “a”, “b” and “c”. There are three slightly different lattice configurations for each core type; designated “1a”, “2a” and “3” for type “a” and designated as “1”, “2” and “3” for core types “b” and “c”. Critical configurations are defined at a range of temperatures from ~15°C to ~62°C. Nine room temperature input files are available at present.</td></tr>
<tr><td colspan="2">Note: All input decks currently use LANL produced ENDF/B-VIII.0 room temperature (.00c or .80t) cross section data. The current kcode card calls for 100 warmup cycles followed by 5000 active cycles with 50,000 histories/cycle. This will yield 250 million active histories. A variety of other commented kcode cards are also included in each input file. Sensitivity calculations are recommended to determine the optimum job size for each problem.</td></tr>
</table>

Appendix B

Independent MCNP k_{calc} values, uncertainties and selected average and population standard deviation calculations for the Godiva (HEU-MET-FAST-001), Big-10 (IEU-MET-FAST-007), HEU-SOL-THERM-042.8, HEU-SOL-THERM-050.3, LEU-COMP-THERM-005.1 & 005.12 and LEU-COMP-THERM-007.1 & -007.4 critical assemblies are tabulated on the following pages.

MCNP k_{calc} values and uncertainties for Godiva (HEU-MET-FAST-001). Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

			k_{calc} and unc		k_{calc} and unc		k_{calc} and unc		k_{calc} and unc		k_{calc} and unc		k_{calc} and unc	
Job	Average	Pop. SD	100K		50K		20K		10K		5K		1K	
1	1.00009	10.6	**0.99992**	9	**1.00024**	8	1.00014	8	1.00007	8	1.00009	8	1.00005	8
2	1.00004	7.7	1.00012	8	1.00012	9	1.00000	8	1.00007	8	0.99996	8	0.99995	8
3	1.00002	13.6	0.99997	9	1.00022	9	1.00007	8	1.00009	9	0.99987	8	0.99988	8
4	0.99990	7.2	**0.99992**	8	0.99994	8	1.00001	9	**0.99980**	8	**0.99986**	8	0.99988	8
5	0.99999	7.5	0.99998	9	0.99998	9	1.00008	8	1.00004	8	1.00000	8	0.99986	8
6	1.00006	6.9	1.00002	8	1.00011	9	1.00015	8	1.00001	8	0.99997	8	1.00009	8
7	1.00000	6.1	0.99999	8	1.00004	8	1.00009	9	0.99998	8	0.99991	8	0.99999	8
8	1.00006	6.2	1.00004	8	1.00017	8	1.00001	8	1.00000	8	1.00006	8	1.00008	8
9	1.00007	14.1	1.00014	8	1.00016	8	1.00018	8	1.00001	9	1.00013	8	0.99981	8
10	1.00007	5.8	1.00004	9	1.00016	8	1.00002	8	1.00006	8	1.00001	8	**1.00011**	8
11	1.00000	3.9	1.00005	8	1.00001	8	1.00003	9	0.99997	9	0.99996	8	0.99996	8
12	1.00005	11.7	**1.00024**	9	1.00010	9	**0.99991**	8	1.00008	8	0.99998	8	0.99998	8
13	1.00000	14.8	1.00016	9	1.00015	9	0.99996	8	0.99988	8	1.00004	8	0.99979	8
14	1.00010	8.7	1.00008	8	1.00020	8	1.00003	8	**1.00019**	8	1.00009	8	0.99998	8
15	1.00012	7.2	1.00007	8	1.00010	8	**1.00023**	8	1.00013	8	1.00017	8	1.00003	8
16	1.00009	16.1	1.00017	9	1.00008	9	1.00000	8	1.00009	8	**1.00034**	8	0.99986	8
17	1.00008	7.2	1.00009	9	1.00021	8	1.00004	8	1.00002	8	1.00010	8	1.00002	8
18	0.99994	9.9	1.00005	9	0.99993	9	1.00006	8	0.99990	8	0.99991	8	0.99980	8
19	1.00002	9.3	1.00007	8	0.99987	8	1.00009	8	0.99993	8	1.00009	8	1.00004	8
20	0.99999	19.1	1.00001	8	**0.99977**	8	1.00020	9	1.00017	8	1.00001	8	**0.99975**	8
Average	1.00003	11.0	1.00006	8.3	1.00008	12.7	1.00007	8.2	1.00002	9.7	1.00003	11.3	0.99995	11.0
pop. min	**0.99975**	**min**	**0.99992**		**0.99977**		**0.99991**		**0.99980**		**0.99986**		**0.99975**	
pop. max	**1.00034**	**max**	**1.00024**		**1.00024**		**1.00023**		**1.00019**		**1.00034**		**1.00011**	
max-min, pcm:	59		32		47		32		39		48		36	

MCNP k_{calc} values and uncertainties for Big-10 (IEU-MET-FAST-007). Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

Job	Average	Pop. SD	k_{calc} and unc 100K		k_{calc} and unc 50K		k_{calc} and unc 20K		k_{calc} and unc 10K		k_{calc} and unc 5K		k_{calc} and unc 1K	
1	1.00420	8.0	1.00417	8	1.00424	7	1.00424	7	1.00422	7	1.00429	7	1.00406	7
2	1.00424	12.6	1.00415	7	1.00435	7	1.00433	7	1.00412	7	**1.00437**	8	1.00410	7
3	1.00425	14.3	1.00416	7	1.00422	8	1.00451	7	1.00429	7	1.00422	8	1.00410	7
4	1.00416	9.0	1.00407	8	1.00432	7	**1.00410**	8	**1.00411**	7	1.00414	7	1.00419	7
5	1.00421	12.8	1.00430	7	**1.00408**	7	1.00424	8	1.00436	7	1.00425	7	**1.00403**	7
6	1.00429	2.7	1.00429	7	1.00432	7	1.00429	7	1.00430	7	1.00427	7	1.00424	7
7	1.00425	12.8	1.00425	7	1.00437	8	1.00438	7	1.00431	7	1.00413	8	1.00407	7
8	1.00427	15.4	1.00406	7	1.00432	7	**1.00453**	7	1.00428	8	1.00422	8	1.00423	7
9	1.00426	11.7	1.00428	8	**1.00439**	8	1.00428	7	1.00428	7	1.00431	8	1.00404	7
10	1.00429	8.3	**1.00434**	7	1.00424	8	1.00443	8	1.00425	7	1.00429	7	1.00420	7
11	1.00421	5.5	1.00425	8	1.00425	8	1.00421	8	1.00419	7	1.00425	7	1.00411	7
12	1.00434	7.0	1.00428	7	1.00428	8	1.00436	7	**1.00444**	7	1.00428	7	**1.00440**	7
13	1.00421	13.3	**1.00404**	7	1.00432	7	1.00433	8	1.00433	7	1.00414	7	1.00409	7
14	1.00418	8.3	1.00425	7	1.00425	8	1.00418	7	1.00416	8	**1.00403**	7	1.00422	7
15	1.00429	6.3	1.00421	8	1.00437	7	1.00431	7	1.00433	7	1.00422	7	1.00428	7
16	1.00423	9.6	1.00429	8	1.00422	7	1.00431	8	1.00412	7	1.00434	7	1.00412	7
17	1.00428	6.4	1.00429	7	1.00420	7	1.00439	7	1.00428	7	1.00424	8	1.00428	7
18	1.00424	13.3	1.00405	7	1.00416	7	1.00430	7	1.00443	7	1.00431	8	1.00420	7
19	1.00423	7.4	1.00433	8	1.00420	7	1.00421	7	1.00412	7	1.00420	7	1.00429	7
20	1.00427	3.9	1.00430	7	1.00430	8	1.00420	7	1.00428	8	1.00427	7	1.00424	7
Average	1.00424	10.2	1.00422	9.8	1.00427	7.9	1.00431	10.8	1.00426	9.9	1.00424	8.1	1.00417	10.0
pop. min	**1.00403**	**min**	**1.00404**		**1.00408**		**1.00410**		**1.00411**		**1.00403**		**1.00403**	
pop. max	**1.00453**	**max**	**1.00434**		**1.00439**		**1.00453**		**1.00444**		**1.00437**		**1.00440**	
max-min, pcm:	50		30		31		43		33		34		37	

MCNP k_{calc} values and uncertainties for HEU-SOL-THERM-050.3). Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

Job	Average	Pop. SD	k_{calc} and unc 100K		k_{calc} and unc 50K		k_{calc} and unc 20K		k_{calc} and unc 10K		k_{calc} and unc 5K		k_{calc} and unc 1K	
1	1.00239	13.8	1.00237	14	1.00247	14	1.00255	15	1.00236	14	1.00246	15	1.00215	15
2	1.00235	6.6	1.00232	15	1.00225	14	1.00234	14	1.00238	15	1.00235	15	1.00245	15
3	1.00235	13.0	1.00259	15	1.00233	15	1.00231	14	1.00239	14	1.00221	14	1.00229	15
4	1.00235	10.5	1.00236	16	1.00231	14	1.00232	15	1.00251	14	1.00242	15	1.00220	15
5	1.00235	13.9	1.00221	15	1.00253	15	1.00231	15	1.00230	15	1.00224	15	**1.00252**	15
6	1.00247	23.4	1.00260	14	**1.00265**	15	**1.00272**	14	**1.00217**	15	1.00248	15	1.00220	15
7	1.00242	6.0	1.00237	14	1.00241	14	1.00243	15	1.00245	15	1.00251	15	1.00234	15
8	1.00232	11.2	1.00215	15	1.00247	15	1.00228	15	1.00228	15	1.00241	15	1.00232	15
9	1.00240	13.1	1.00256	15	1.00242	15	1.00217	15	1.00235	15	1.00245	15	1.00245	15
10	1.00237	12.2	1.00235	15	1.00241	15	1.00253	15	1.00241	14	1.00234	15	1.00216	15
11	1.00248	14.1	1.00249	15	1.00242	14	1.00234	14	**1.00275**	14	1.00243	15	1.00247	15
12	1.00242	11.1	1.00235	14	1.00231	14	1.00237	14	1.00245	15	**1.00262**	15	1.00239	15
13	1.00248	9.2	1.00249	14	1.00258	15	1.00242	15	1.00245	14	1.00257	15	1.00234	15
14	1.00239	10.6	1.00244	15	1.00250	15	1.00237	15	1.00231	15	1.00250	15	1.00224	15
15	1.00223	19.1	1.00211	15	**1.00212**	14	1.00235	14	1.00251	14	**1.00199**	15	1.00231	15
16	1.00236	31.9	**1.00278**	15	1.00215	14	**1.00210**	15	**1.00275**	14	1.00222	15	1.00214	15
17	1.00231	11.0	1.00213	15	1.00222	15	1.00242	14	1.00237	15	1.00235	15	1.00236	15
18	1.00231	17.3	1.00228	14	1.00223	15	1.00257	15	1.00243	15	1.00225	14	**1.00207**	15
19	1.00242	12.2	1.00218	14	1.00239	15	1.00247	15	1.00245	15	1.00250	15	1.00250	15
20	1.00224	15.8	**1.00201**	14	1.00245	15	1.00228	15	1.00236	14	1.00219	14	1.00214	15
Average	1.00237	15.3	1.00236	19.4	1.00238	14.0	1.00238	14.1	1.00242	13.8	1.00237	15.4	1.00230	13.5
pop. min	**1.00199**	**min**	**1.00201**		**1.00212**		**1.00210**		**1.00217**		**1.00199**		**1.00207**	
pop. max	**1.00278**	**max**	**1.00278**		**1.00265**		**1.00272**		**1.00275**		**1.00262**		**1.00252**	
max-min, pcm:	79		77		53		62		58		63		45	

MCNP k_{calc} values and uncertainties for HEU-SOL-THERM-042.8. Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

Job	Average	Pop. SD	k_{calc} and unc 100K		k_{calc} and unc 50K		k_{calc} and unc 20K		k_{calc} and unc 10K		k_{calc} and unc 5K		k_{calc} and unc 1K	
1	1.00074	6.0	1.00070	4	1.00071	3	1.00080	3	1.00083	3	1.00074	3	1.00068	3
2	1.00078	12.4	1.00076	4	1.00079	3	**1.00093**	3	1.00085	3	1.00081	3	1.00056	3
3	1.00072	6.9	1.00071	4	1.00075	3	1.00069	3	1.00083	3	1.00073	3	1.00062	3
4	1.00079	9.3	1.00074	3	1.00083	3	1.00088	3	1.00082	3	1.00083	3	1.00062	3
5	1.00080	11.8	1.00075	3	1.00082	4	1.00069	3	**1.00098**	3	1.00087	3	1.00067	3
6	1.00077	7.0	1.00074	4	1.00077	3	1.00082	3	1.00074	3	1.00086	3	1.00066	3
7	1.00070	10.5	1.00068	3	1.00082	3	**1.00063**	3	1.00079	3	**1.00054**	3	1.00074	3
8	1.00079	12.0	1.00069	4	1.00085	4	1.00092	3	1.00093	3	1.00070	3	1.00067	3
9	1.00077	13.0	1.00082	4	1.00072	3	1.00085	3	1.00082	3	1.00088	3	1.00053	3
10	1.00076	9.0	1.00074	4	1.00070	3	1.00081	3	1.00076	3	1.00089	3	1.00063	3
11	1.00076	9.7	1.00061	4	1.00081	3	1.00088	3	1.00079	3	1.00078	3	1.00068	3
12	1.00076	10.8	1.00067	3	1.00078	3	1.00086	3	1.00088	3	1.00060	3	1.00075	3
13	1.00067	7.1	1.00063	3	**1.00059**	4	1.00066	3	1.00079	3	1.00071	3	1.00064	3
14	1.00075	14.0	1.00068	4	1.00084	4	1.00072	3	1.00096	3	1.00074	3	1.00055	3
15	1.00072	7.3	**1.00060**	4	1.00072	3	1.00078	3	1.00070	3	1.00081	3	1.00071	3
16	1.00072	9.5	1.00067	4	1.00074	3	1.00069	3	1.00070	3	**1.00090**	3	1.00063	3
17	1.00065	13.7	1.00065	4	1.00074	3	1.00073	3	1.00073	3	1.00065	3	**1.00038**	3
18	1.00065	6.7	1.00061	4	1.00069	3	1.00066	3	**1.00057**	3	1.00062	3	1.00076	3
19	1.00079	6.3	1.00076	4	**1.00086**	3	1.00083	3	1.00078	3	1.00084	3	1.00069	3
20	1.00081	7.0	**1.00085**	4	1.00083	3	1.00083	3	1.00069	3	1.00089	3	**1.00077**	3
Average	1.00074	10.2	1.00070	6.8	1.00077	6.8	1.00078	9.3	1.00080	9.8	1.00077	10.8	1.00065	9.2
pop. min	**1.00038**	**min**	**1.00060**		**1.00059**		**1.00063**		**1.00057**		**1.00054**		**1.00038**	
pop. max	**1.00098**	**max**	**1.00085**		**1.00086**		**1.00093**		**1.00098**		**1.00090**		**1.00077**	
max-min, pcm:	60		25		27		30		41		36		39	

MCNP k_{calc} values and uncertainties for LEU-COMP-THERM-005.1. Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

			k_{calc} and unc		k_{calc} and unc		k_{calc} and unc		k_{calc} and unc		k_{calc} and unc		k_{calc} and unc	
Job	Average	Pop. SD	100K		50K		20K		10K		5K		1K	
1	1.00210	10.6	1.00202	11	1.00227	11	1.00202	11	1.00220	11	**1.00205**	11	1.00205	11
2	1.00224	13.8	1.00222	11	1.00224	11	1.00228	11	1.00218	11	1.00206	11	**1.00248**	11
3	1.00221	13.2	1.00238	11	1.00228	11	1.00219	11	**1.00198**	11	1.00219	11	1.00222	11
4	1.00218	10.8	1.00201	10	1.00220	11	1.00230	11	1.00220	11	1.00227	11	1.00210	11
5	1.00215	13.6	1.00202	11	1.00219	11	**1.00240**	11	1.00211	11	**1.00205**	11	1.00214	11
6	1.00223	8.9	1.00226	11	1.00233	11	1.00217	11	1.00232	11	1.00218	11	1.00211	11
7	1.00215	9.2	1.00225	11	1.00220	11	1.00219	11	1.00199	11	1.00215	11	1.00210	11
8	1.00225	11.8	1.00227	10	**1.00239**	11	1.00234	11	1.00206	11	1.00223	11	1.00218	11
9	1.00219	11.6	1.00229	11	**1.00207**	11	1.00219	11	1.00234	11	1.00221	11	1.00205	11
10	1.00220	6.8	1.00222	11	1.00220	11	1.00221	11	1.00214	11	1.00232	11	1.00213	11
11	1.00218	18.4	1.00200	11	1.00219	11	1.00228	11	1.00248	11	1.00214	11	1.00199	11
12	1.00214	11.2	1.00224	11	1.00222	11	1.00213	11	1.00218	11	1.00214	11	**1.00193**	11
13	1.00229	16.8	**1.00246**	11	1.00234	10	**1.00201**	11	1.00228	11	**1.00245**	11	1.00221	11
14	1.00230	15.1	1.00212	11	1.00236	11	1.00225	11	**1.00249**	11	1.00215	11	1.00243	11
15	1.00218	14.9	1.00227	11	1.00237	11	1.00209	11	1.00225	11	1.00215	11	1.00195	11
16	1.00215	12.8	**1.00197**	11	1.00229	11	1.00207	11	1.00229	11	1.00216	11	1.00209	11
17	1.00219	8.4	1.00231	11	1.00227	11	1.00211	11	1.00211	11	1.00215	11	1.00218	11
18	1.00219	9.8	1.00229	11	1.00224	11	1.00212	11	1.00228	11	1.00217	11	1.00204	11
19	1.00218	5.7	1.00222	11	1.00214	11	1.00210	11	1.00218	11	1.00226	11	1.00218	11
20	1.00215	10.2	1.00211	11	1.00223	11	**1.00201**	11	1.00218	11	1.00209	11	1.00229	11
Average	1.00219	12.1	1.00220	13.7	1.00225	8.1	1.00217	11.1	1.00221	13.6	1.00218	9.6	1.00214	14.0
pop. min	**1.00193**	**min**	**1.00197**		**1.00207**		**1.00201**		**1.00198**		**1.00205**		**1.00193**	
pop. max	**1.00249**	**max**	**1.00246**		**1.00239**		**1.00240**		**1.00249**		**1.00245**		**1.00248**	
max-min, pcm:	56		49		32		39		51		40		55	

MCNP k_{calc} values and uncertainties for LEU-COMP-THERM-005.12. Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

Job	Average	Pop. SD	k_{calc} and unc 100K		k_{calc} and unc 50K		k_{calc} and unc 20K		k_{calc} and unc 10K		k_{calc} and unc 5K		k_{calc} and unc 1K	
1	1.00482	14.7	**1.00504**	10	1.00475	10	1.00475	10	1.00475	10	1.00495	10	1.00465	10
2	1.00474	7.8	**1.00473**	10	1.00477	10	1.00482	10	1.00481	10	**1.00466**	10	1.00463	10
3	1.00477	10.7	1.00475	10	1.00461	10	1.00475	10	1.00491	10	1.00486	10	1.00471	10
4	1.00481	9.5	1.00488	9	1.00488	11	1.00473	10	1.00473	10	1.00493	10	1.00472	10
5	1.00480	8.7	1.00493	10	1.00486	10	1.00473	10	1.00469	10	1.00478	10	1.00480	10
6	1.00474	16.5	1.00497	10	1.00485	10	1.00478	10	**1.00451**	10	1.00470	10	1.00462	10
7	1.00475	16.7	1.00474	11	1.00472	10	1.00469	10	1.00498	10	1.00487	10	1.00449	10
8	1.00485	8.8	1.00487	11	1.00490	10	1.00479	10	1.00499	10	1.00477	10	1.00477	10
9	1.00483	11.4	1.00478	10	1.00488	10	1.00476	10	1.00489	10	**1.00498**	10	1.00466	10
10	1.00468	14.6	1.00477	10	1.00463	10	1.00462	10	1.00469	10	1.00489	10	**1.00446**	10
11	1.00482	15.1	1.00475	11	1.00479	10	1.00483	10	**1.00507**	10	1.00485	10	1.00461	10
12	1.00484	15.8	1.00479	10	1.00465	10	1.00508	10	1.00471	10	1.00484	10	**1.00495**	10
13	1.00485	18.0	1.00478	10	1.00492	10	**1.00515**	10	1.00461	10	1.00478	10	1.00486	10
14	1.00483	11.9	1.00480	10	1.00491	10	1.00481	10	1.00502	10	1.00473	10	1.00470	10
15	1.00480	19.1	**1.00473**	10	**1.00495**	10	1.00492	10	1.00479	10	1.00496	10	**1.00446**	10
16	1.00479	6.2	1.00481	10	1.00470	10	1.00473	10	1.00487	10	1.00482	10	1.00479	10
17	1.00487	7.8	1.00481	10	1.00483	10	1.00491	10	1.00493	10	1.00497	10	1.00477	10
18	1.00476	15.8	1.00492	10	**1.00456**	10	**1.00458**	10	1.00490	10	1.00484	10	1.00478	10
19	1.00479	9.3	1.00474	10	1.00478	10	1.00492	11	1.00485	10	1.00481	10	1.00465	10
20	1.00479	8.7	1.00482	10	1.00470	10	1.00489	10	1.00487	10	1.00478	10	1.00468	10
Average	1.00479	12.7	1.00482	8.7	1.00478	11.4	1.00481	13.8	1.00483	14.4	1.00484	9.1	1.00469	12.7
pop. min	**1.00446**	**min**	**1.00473**		**1.00456**		**1.00458**		**1.00451**		**1.00466**		**1.00446**	
pop. max	**1.00515**	**max**	**1.00504**		**1.00495**		**1.00515**		**1.00507**		**1.00498**		**1.00495**	
max-min, pcm:	69		31		39		57		56		32		49	

MCNP k_{calc} values and uncertainties for LEU-COMP-THERM-007.1. Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

Job	Average	Pop. SD	k_{calc} and unc 100K		k_{calc} and unc 50K		k_{calc} and unc 20K		k_{calc} and unc 10K		k_{calc} and unc 5K		k_{calc} and unc 1K	
1	0.99664	11.4	0.99652	11	0.99654	11	0.99672	11	0.99665	11	0.99682	11	0.99660	11
2	0.99662	14.2	0.99661	12	0.99673	11	**0.99653**	11	0.99660	11	0.99681	11	0.99641	11
3	0.99664	21.5	0.99675	11	0.99680	11	0.99670	11	**0.99636**	11	0.99685	11	0.99638	11
4	0.99671	16.8	0.99668	12	**0.99693**	11	0.99661	11	0.99685	11	0.99672	11	0.99646	11
5	0.99663	13.0	0.99673	12	**0.99644**	11	0.99659	11	0.99670	11	0.99653	11	0.99678	11
6	0.99661	15.4	**0.99650**	11	0.99659	12	0.99662	11	0.99681	11	0.99676	11	0.99640	11
7	0.99658	11.4	0.99658	12	0.99672	12	0.99659	11	0.99654	11	0.99667	11	0.99639	11
8	0.99659	4.2	0.99659	12	0.99662	11	0.99662	11	0.99661	11	0.99658	11	0.99651	11
9	0.99672	6.2	0.99681	11	0.99676	11	0.99667	12	0.99674	11	0.99668	11	0.99665	11
10	0.99662	10.7	0.99662	11	0.99652	12	0.99665	11	0.99661	11	**0.99650**	11	**0.99680**	11
11	0.99668	11.7	0.99664	12	0.99657	11	0.99666	11	0.99676	11	**0.99688**	11	0.99659	11
12	0.99669	14.4	0.99672	11	0.99682	11	**0.99683**	11	0.99652	11	**0.99650**	11	0.99673	11
13	0.99674	20.0	**0.99694**	12	0.99664	12	0.99662	12	**0.99704**	11	0.99654	11	0.99666	11
14	0.99668	8.9	0.99680	11	0.99674	11	0.99669	11	0.99669	11	0.99661	11	0.99655	11
15	0.99670	20.5	0.99693	12	0.99673	11	0.99662	11	0.99678	11	0.99682	11	**0.99634**	11
16	0.99668	12.7	0.99673	12	0.99681	12	0.99656	11	0.99654	11	0.99682	11	0.99659	11
17	0.99674	8.3	0.99682	12	0.99682	12	0.99680	11	0.99666	11	0.99667	11	0.99666	11
18	0.99662	12.2	0.99667	11	0.99681	12	0.99665	11	0.99647	11	0.99651	11	0.99659	11
19	0.99663	16.4	0.99682	11	0.99646	11	0.99673	11	0.99670	11	0.99666	11	0.99640	11
20	0.99664	11.3	0.99671	11	0.99653	11	0.99655	11	0.99656	11	0.99682	11	0.99664	11
Average	0.99666	13.5	0.99671	12.2	0.99668	13.9	0.99665	7.8	0.99666	15.1	0.99669	13.0	0.99656	13.9
pop. min	**0.99634**	**min**	**0.99650**		**0.99644**		**0.99653**		**0.99636**		**0.99650**		**0.99634**	
pop. max	**0.99704**	**max**	**0.99694**		**0.99693**		**0.99683**		**0.99704**		**0.99688**		**0.99680**	
max-min, pcm:	70		44		49		30		68		38		46	

MCNP k_{calc} values and uncertainties for LEU-COMP-THERM-007.4. Results are for 20 independent jobs using one of the six kcode parameter strategies (100,000 histories/cycle, 50,000 histories/cycle, … , 1000 histories/cycle) identified previously. Minimum and maximum k_{calc} values for each kcode parameter strategy a noted in **red** and **green**, respectively.

Job	Average	Pop. SD	k_{calc} and unc 100K		k_{calc} and unc 50K		k_{calc} and unc 20K		k_{calc} and unc 10K		k_{calc} and unc 5K		k_{calc} and unc 1K	
1	0.99857	8.8	0.99867	9	0.99866	9	0.99850	9	0.99846	9	0.99862	9	0.99853	9
2	0.99856	20.8	**0.99885**	9	**0.99840**	9	**0.99834**	9	0.99862	9	**0.99873**	9	0.99840	9
3	0.99856	15.1	0.99867	8	0.99864	9	**0.99876**	9	0.99843	9	0.99837	9	0.99851	9
4	0.99855	11.9	0.99837	9	0.99861	9	0.99847	9	0.99850	9	0.99867	9	0.99866	9
5	0.99854	5.2	0.99859	9	0.99848	9	0.99851	9	0.99852	9	0.99861	9	0.99850	9
6	0.99860	5.6	0.99853	8	0.99866	9	0.99863	9	0.99857	9	0.99856	9	0.99866	9
7	0.99848	12.5	0.99850	9	0.99852	9	0.99840	9	0.99865	9	0.99851	9	**0.99828**	9
8	0.99847	6.2	0.99845	9	0.99851	9	0.99856	9	0.99841	9	0.99840	9	0.99849	9
9	0.99858	10.1	0.99854	9	0.99851	9	0.99853	9	0.99849	9	0.99870	9	**0.99872**	9
10	0.99855	11.5	0.99875	9	0.99847	9	0.99861	9	0.99856	9	0.99847	9	0.99845	9
11	0.99849	17.2	**0.99827**	9	0.99854	9	0.99859	9	0.99863	9	**0.99828**	9	0.99864	9
12	0.99861	10.2	0.99861	9	0.99877	9	0.99862	9	0.99848	9	0.99864	9	0.99852	9
13	0.99858	5.8	0.99867	9	0.99854	9	0.99858	9	0.99856	9	0.99850	9	0.99860	9
14	0.99855	11.4	0.99852	9	0.99845	9	0.99859	9	**0.99875**	9	0.99844	9	0.99857	9
15	0.99855	10.4	0.99858	9	0.99857	9	0.99852	9	**0.99837**	9	0.99860	9	0.99868	9
16	0.99853	9.5	0.99857	9	0.99864	9	0.99857	9	0.99850	9	0.99855	9	0.99836	9
17	0.99857	12.4	0.99869	9	0.99865	9	0.99851	9	0.99838	9	0.99850	9	0.99868	9
18	0.99861	11.6	0.99855	9	**0.99883**	9	0.99852	9	0.99862	9	0.99853	9	0.99858	9
19	0.99853	9.2	0.99846	9	0.99864	9	0.99860	9	0.99845	9	0.99861	9	0.99844	9
20	0.99861	5.6	0.99867	9	0.99858	9	0.99864	9	0.99853	9	0.99866	9	0.99857	9
Average	0.99855	11.0	0.99858	13.2	0.99858	10.7	0.99855	9.0	0.99852	9.8	0.99855	11.6	0.99854	11.7
pop. min	**0.99827**	**min**	**0.99827**		**0.99840**		**0.99834**		**0.99837**		**0.99828**		**0.99828**	
pop. max	**0.99885**	**max**	**0.99885**		**0.99883**		**0.99876**		**0.99875**		**0.99873**		**0.99872**	
max-min, pcm:	58		58		43		42		38		45		44	