EVALUATION AND EXTENSION OF THE EXPERIMENTAL BASIS FOR LICENSING 5-10% ENRICHED NUCLEAR REACTOR FUEL

Final Report for Contract NRC-02-06-015

Ronald E. Pevey, Principal Investigator

Lukus Barnes

Susan King

Nuclear Engineering Department

The University of Tennessee, Knoxville

November 2008

ABSTRACT

The objective of this two-year project was to examine the need for critical experiments in the 5%-10% ^{235}U enrichment range in support of the licensing of nuclear reactor uranium fuel production. The results of this project will directly benefit the Nuclear Regulatory Commission (NRC) Nuclear Criticality Safety (NCS) staff as well as the NCS community worldwide by examining the need for additional experimental benchmarks for new, higher enriched reactor fuel designs.

The need for this project has risen as nuclear fuel cycle facilities are potentially considering future extension of the licensing bases for the 5-10% enrichment range. Therefore, the database of critical experiments in this range needed to be examined to determine if it is sufficient for NRC to extend the licensing basis.

Points along the fuel production cycle deemed important for analysis included uranium hexafluoride gas container shipping, uranium dioxide powder production, uranium dioxide finished fuel pellet storage, and fueled reactor assembly cask shipping. These configurations were modeled for both normal and contingency cases with varying fuel enrichments of 5%, 6%, 8% and 10%. In addition, late in the project a "damp powder" base case was identified and a preliminary analysis of this case was added to the scope.

The International Handbook of Evaluated Criticality Safety Benchmark Experiments (ICSBEP Handbook) was used to identify potentially applicable evaluated benchmark experiments that were of interest in this task, sorted using two search criteria: 4%-11% ^{235}U enrichment and 0-10 eV energy of average lethargy of fission (EALF). For the actual analysis, however, the base cases were compared with all of the available experiments for which TSUNAMI-produced SDF files could be located. The applicability of each of the experiments to each of the base cases was evaluated based on the TSUNAMI-produced c_k parameter, following previously published ORNL guidance on recommended values of this parameter for acceptance of an experiment.

This evaluation indicates that existing experiments generally provide adequate coverage of the base cases examined, including the bulk powder cases added late in the study. The principal exceptions to this conclusion were the UF_6 cylinder cases, which shows a relatively poor coverage (with only a handful of cases meeting the c_k criteria used in the project), and the higher enrichment bulk damp powder case. Because of the relatively low numbers (~40%) of SDF files available for identified critical experiments, validation of this type of situation may require either a more stringent set of controls to avoid the problematic configurations, performance of TSUNAMI studies of additional exising experiments, or an extension of the experimental database.

TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

I.A. Background

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Materials Safety and Safeguards (NMSS) is responsible for the licensing and regulation of nuclear fuel cycle facilities that process and handle fissile material. These facilities are potentially considering future extension of the licensing basis to the 5-10 wt% range of ^{235}U enrichment. This project was undertaken to assess the availability of experiments in this range sufficient to allow the NRC to be able to extend this licensing basis.

The "International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95) 2007 edition (ICSBEP Handbook[1]) documents numerous critical experiments with enrichments less than 20 wt% ^{235}U. Of these, there are 567 critical experiments between 4 and 11 wt% ^{235}U. However, most of these experiments are at thermal neutron energies and not all possible physical forms in the fuel cycle have been benchmarked.

As part of the computer code validation process mandated by the ANSI/ANS-8 standards, a given computer code system (with its associated cross section data) must be used to evaluate known critical experiments that are similar to the configuration being analyzed, and then the results statistically analyzed to determine an appropriate upper subcritical limit (USL) to be used in the analysis. The traditional way of determining the similarity of critical experiments to a given configuration to be analyzed has been through a comparison of important physical parameters (e.g., fuel type, fuel form, neutron spectra, moderating materials, reflection materials, absorbers, etc.). This comparison process has, of necessity, been fairly subjective.

In recent years, the ORNL SCALE system has been expanded to include a sensitivity/uncertainty analysis capability through the development of the TSUNAMI[2] family of modules, capable of providing a more objective comparison of configuration.

I.B. Objective

The objective of the project is to use the TSUNAMI family of SCALE modules to examine the applicability of currently available critical experiments in support of the licensing of nuclear reactor uranium fuel enriched to the 5-10% range and to develop a plan for future experiments, if new experiments are needed. This project is expected to benefit NRC Nuclear Criticality Safety (NCS) staff and the NCS community throughout the world by either providing justification for using the current experimental data or by providing new experimental data that can be used to fill the gap for benchmarking and validation purposes.

I.C. Statement of Work

The original proposal was to provide two M.S. level students (one per year) and a portion of Dr. Ronald E. Pevey's time in a two year project to examine the current experimental basis in the 5-10% enrichment range and, if necessary, to develop a plan for future experiments.

There were five specific tasks originally envisioned for the project:

Task 1. Establishment of the Important Parameters of the Licensing Process and Examination of Available Critical Experiments.

The project was to begin with a determination of the specific role that the benchmark experiments will play in higher-enrichment fuel licensing. The primary output of this step was to be a set of base cases that would adequately cover the range of fuel properties and parameters that would be important during fuel fabrication activities involving the higher enrichments. These base cases were to be compared to the available critical experiments.

This step was to continue with the gathering of information on available critical experiments and an initial statistical analysis, in order to establish what parameters are sufficiently covered in the 5-10 wt% ^{235}U enrichment range, including statistical analyses.

Task 2. Analysis of Currently Available Critical Benchmarking Experiments

In the second task, currently available critical benchmarking experiments documented in the ICSBEP Handbook were to be analyzed using the TSUNAMI modules of the SCALE system. This step included funding the graduate student's attendance at an ORNL 4-day course on the theory and use of TSUNAMI.

If the results of the Task 2 analysis showed that the existing experimental benchmark set is inadequate to cover the extended enrichment range, the project was to continue with three additional tasks.

Task 3. Determination of Principal Physical Characteristics Needed by New Experiments. In this step TSUNAMI analyses were to be used to identify which nuclides, reactions, spectra, and temperature ranges need to be covered by additional experiments.

Task 4. Review of Experimental Facilities Available. This task was to review experimental facilities available for this work both in the U.S. and abroad, including facility availability, flexibility, and cost factors.

Task 5. Design of New Experiments. The final task was to design any new experiments required from the results of the foregoing tasks with accompanying TSUNAMI analyses to verify their suitability, culminating in a prioritized plan for the additional experiments, including schedule constraints and cost estimates.

I.D. Summary of Progress of the Project

The first two tasks of the project were performed as planned, with:

1. Definition of six base cases to cover the range of parameters in the nuclear fuel fabrications steps, all at room temperature and without burnup. These cases were presented to the NRC in the first 6-month written progress report. The resulting base cases, defined under non-accident conditions, were analyzed with the TSUNAMI-3D module of SCALE to create SDF files for comparison to critical experiments. The analysis of these normal cases indicated that the non-accident conditions resulted in k_{eff} values that were far subcritical.

2. Determination of reasonably expected accident contingency cases (involving moderation addition) to bring the base cases up to the 0.85-0.95 k_{eff} range expected to bound the range of expected upper subcritical limits. These contingency cases were analyzed with TSUNAMI for the creation of the SDF files. This concluded Task 1.

3. Search of the ICSBEP benchmark book for candidate critical experiments. Following the identification of candidate experiments, a search was made of the availability of SDF files for the experiments. Several hundred of these were identified from previous NRC-funded research at ORNL and were made available to this project. In addition, 41 additional experiments were analyzed with TSUNAMI by modifying KENO input decks provided by the ICSBEP benchmark book. In the end, all available SDF files for uranium systems were utilized. The comparison to the results of the ICSBEP search was utilized to get a feel for how comprehensive the collection of SDF files might be.

4. For both the normal and contingency cases, the SDF files from the experiments and base cases were compared to identify which experiments were suitable for use as validation benchmarks, using the TSUNAMI-IP module of SCALE. The result of each individual base case/experiment comparison produces a value of the c_k variable; the determination of applicability of individual experiments to the base case configurations was judged based on the criteria recommended in Reference 5. The result of this analysis was that each of the defined contingency base cases is adequately covered by the existing experimental benchmark cases (although the coverage of UF_6 cylinder cases requires an assumption that TSUNAMI analysis of more existing experiments will cover the shortfall), indicating that additional experiments are not needed just to cover the enrichment range extension. This concluded Task 2. Based on these results, it was decided that there was no need to continue with Tasks 3-5 of the project.

When the results of this project were presented to the NRC at the conclusion of the analysis (May 2008), a question arose about the absence of bulk UO_2 powder cases in the base case set which had been presented a year earlier, at the conclusion of Task 1. To provide a preliminary analysis of the effect that the inclusion of such cases might have had on the results of Task 2, a shortened analysis of a simplified-geometry bulk damp

powder case was performed. The significant physical feature of this cases was the lower moderation needed for criticality as enrichment increases, resulting in harder spectra than are covered by current experiments. This analysis resulted in an assessment that the experimental coverage of the cases analyzed was adequate up to 6% enrichment and that, like for the UF_6 cylinder cases, more TSUNAMI analyses of existing experiments would most like cover the inadequacies for the 8% and 10% cases.

II. THEORY

II.A. Use of sensitivity/uncertainty analysis in NCS Validation

Validation of nuclear criticality safety evaluations, both the traditional approach and the advanced techniques using the TSUNAMI modules of the SCALE system are well described in References 5 through 9. For the more rigorous TSUNAMI treatment, the important concept is that the methodology quantifies both of the physical effects by which cross section uncertainties can affect the accuracy of a k_{eff} calculation:

1. The uncertainty in group cross sections for each particular isotope, reaction, and energy group; and

2. The sensitivity of k_{eff} to this uncertainty.

These two effects are combined in a single parameter, c_k, which provides a metric of the similarity of the vulnerabilities of k_{eff} to cross-section uncertainties in two different systems (usually a proposed configuration and an existing experiment). This coefficient of correlation is a single value parameter between -1 and 1, with zero denoting no correlation between two systems and 1 denoting identical vulnerabilities.

Previous work on the applicability of this parameter (Reference 5) to generalized linear-least-squares validation methodology (GLLSM) has resulted in the following conclusion:

> *"Studies have indicated that 15 to 20 benchmarks with c_k values near or exceeding 0.9 are needed to ensure convergence in a GLLSM* [Note: Generalized least-square methodology] *procedure. Therefore, a corresponding number and type of systems should be considered a minimum to establish the area of applicability covering the design system. Under certain conditions, convergence can also be expected for 25 to 40 systems with c_k values >0.8. The type of conditions under which convergence can be produced with systems with c_k values <0.9 is the subject of current research."*

Based on this, the ability to validate an operational configuration will be assumed to depend on the availability of either:

1. at least 15 critical benchmarks with a c_k value exceeding 0.90 or

2. at least 25 systems with a c_k value exceeding 0.80. (However, it should be noted that the lower limit of acceptability for a single critical experiment as well as multiple marginal applicability experiments are still being contested.)

For validation of configurations that are near or below these minima, consideration is also given to the likelihood of identifying additional critical experiments for which SDF files were not available to this project (based on an estimate of the percentage of existing applicable experiments that were available to this project).

II.B. Use of the TSUNAMI modules of SCALE

The sensitivity/uncertainty analysis is implemented in Tools for Sensitivity/Uncertainty Analysis Methodology Implementation, (TSUNAMI[2]), which is a SCALE module that utilizes first order linear perturbation theory to calculate sensitivities of a computed k_{eff} value to material cross-section data. This module was released publicly with the SCALE 5 package in June 2004; further enhancements, including html output coupled with graphical capabilities using JavaPENO was released with SCALE 5.1 in 2006. TSUNAMI has two separate modules, TSUNAMI-1D and TSUNAMI-3D, that are used for one and three-dimensional analyses, respectively.

For TSUNAMI-3D, KENO V.a is used to solve for the forward and adjoint system k_{eff} and flux profiles. As with other CSAS (Criticality Safety Analysis Sequence) modules within SCALE, TSUNAMI-3D creates problem-dependent cross-section data using resonance processing for both resolved and unresolved ranges. The TSUNAMI-3D input is based on the input of the CSAS25 control module, with some additional information provided by the user to guide the sensitivity analysis; this module was used for the base cases analysis. The simpler 1D transport calculations of TSUNAMI-1D are based on the CSAS1 control module input, utilizing XSDRNPM transport calculations; this module was used for the extra powder cases added late in the analysis.

After criticality calculations using both the adjoint and forward methods with KENO V.a, the SAMS module is called by TSUNAMI-3D. The SAMS module calculates nuclide and reaction sensitivities to the system k_{eff}. SAMS also prints energy integrated sensitivity coefficients to the SCALE output file (denoted with .out) as well as another file containing only these integrated sensitivity coefficients called a sensitivity data file (denoted with .sdf). These important output files will be denoted as "SDF files" in the remainder of this report. A flowchart of the calculation sequence is given in Figure 1.

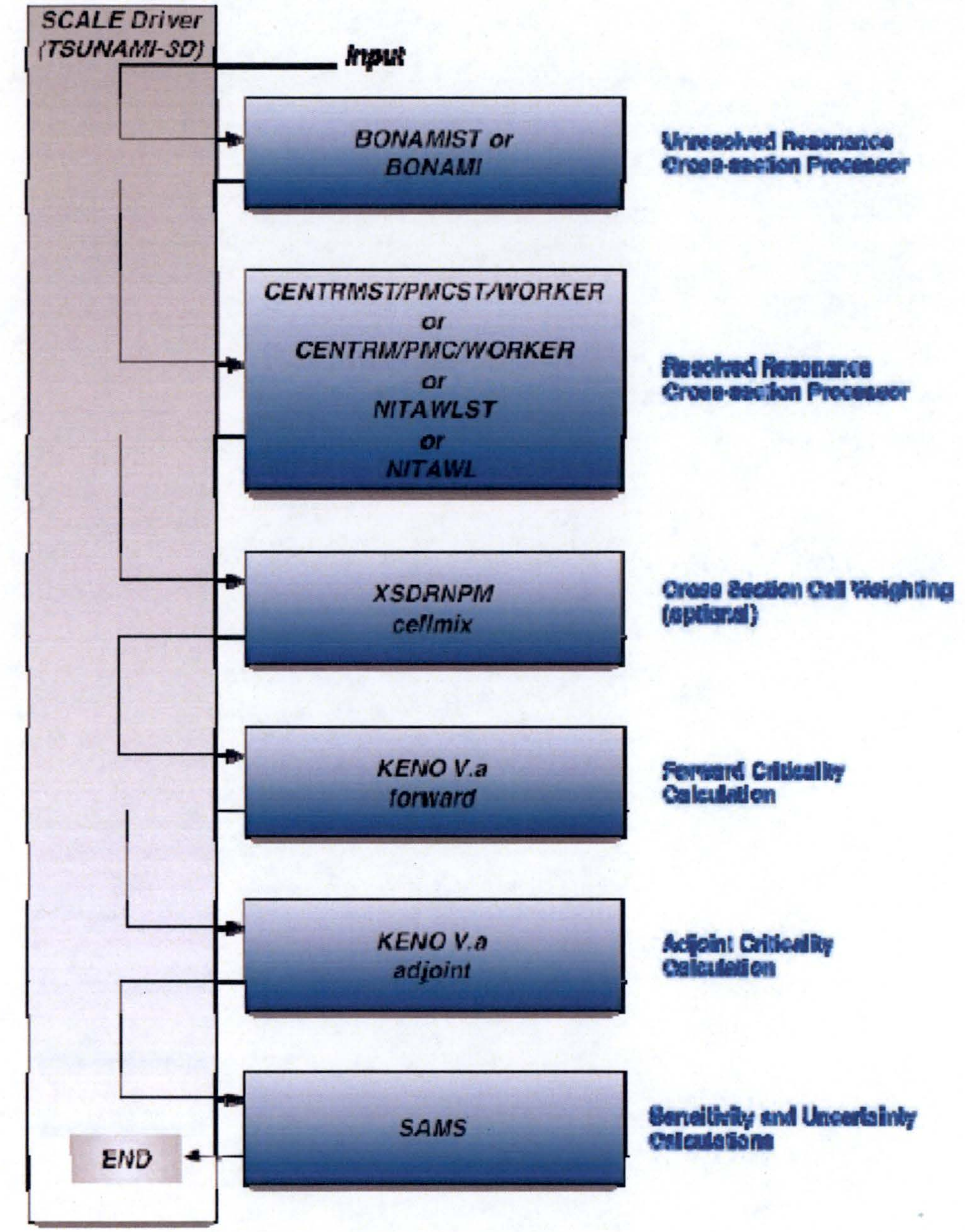

Figure 1. Flow Diagram of TSUNAMI-3D

Sensitivity data files can be used to compare the similarity of a system to some base case sensitivity data file by means of a similarity coefficient using TSUNAMI-IP. TSUNAMI-IP allows for a user to compare a system to an entire library of evaluated experiments using TSUNAMI-3D SDF output files.

III. DISCUSSION

III.A. Base Case Definitions

In the first task of the project, base cases were defined for comparison to existing critical experiments. These base cases represent points (or "snapshots") in the nuclear fuel production cycle, with subcases allowing for varying enrichment levels between 5-10% ^{235}U.

As fuel reprocessing is not used by the nuclear fuel processing industry in the United States, it is assumed that the once-through fuel cycle typical of current light water reactor fuel pins will be used for fuel processing. Also, points in the nuclear fuel cycle such as mining and milling of U_3O_8 ore, its conversion to uranium hexafluoride (UF_6), and enrichment have been eliminated as possible base cases due to natural uranium from the mining and UF_6 conversion process being well-known and benchmarked. The actual fuel enrichment stages of the nuclear fuel cycle were also ruled out as potential base cases, as these processes generally involve less concentrated (primarily gaseous) fissile isotopes.

The current nuclear fuel cycle[4] begins with the mining of uranium ore and its purification before being converted by dry hydrofluor processing or wet solvent extraction to uranium hexafluoride for enrichment. The natural uranium UF_6 is then enriched to a desired enrichment level by means of gaseous diffusion or centrifugation.

The enriched UF_6 is then shipped to a fuel fabrication facility, where it is eventually converted and processed into UO_2 fuel bundles and shipped to a reactor. The main processes can be seen in Figure 2.

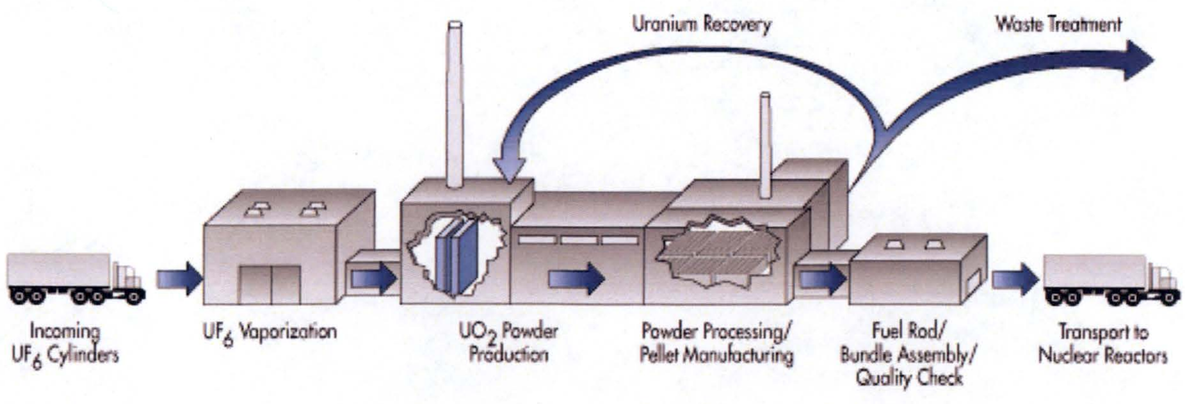

Figure 2. Diagram of Fuel Fabrication Facility[3]

As can be seen from this figure, enriched UF_6 is brought to the facility in cylinders. This represents the first base case selected in the fuel production cycle. These cylinders were modeled as stored in a large room or storage facility.

The enriched UF_6 is then vaporized into a gas to be converted to UO_2 powder. This point in the fuel fabrication cycle represents the second selected base case for the project. The UO_2 powder is then pressed into smaller pellets and sintered into a ceramic, forming the third and fourth base cases. These pellets are then loaded into (assumed) zircaloy tubes and assembled into a fuel bundle. This last stage of the fuel production cycle represents the fifth and sixth base case selected in the fuel production cycle.

The division of the fuel pellet and fuel rod cases into two cases each was driven by consideration of the modeling of finished fuel in shipping casks. It was originally anticipated that the design for the finished fuel for all enrichments would be similar to typical dimensions of PWR designs. During the initial process of evaluating these hypothetical reactor cores with increased enrichments, positive void coefficients were encountered. Because of this, it was decided to break the fuel pellet and fuel pin situations into two cases each. The original UO_2 materials were retained as Cases 3 and 5 (for the pellet and fuel assembly cases, respectively), but an additional specification of advanced high temperature reactor style designs utilizing graphite as the moderator and using TRISO style fuel kernels as the fuel were also included as Cases 4 and 6, respectively. Although the preliminary calculations indicated that the UO_2 pellets were more appropriate for the lower enrichments (5% and 6%) and the TRISO kernels for the 8% and 10% cases, all of the cases were executed at all four enrichment values so that the dependence of coverage on enrichment could be evaluated.

These six generic fuel production base cases were modeled using TSUNAMI-3D, both to determine the k_{eff} value and to produce the SDF files needed for later comparison with critical experiments. While consideration was given to criticality safety concerns for the designs of these base cases, the primary concerns in the selection of base cases were for representative materials and geometries under normal (non-accident) conditions. The details of the models of each of the six normal cases will now be presented.

Base Case 1: Stored UF_6 cylinders

The storage of enriched uranium hexafluoride were modeled using the 12B cylinder model for the 5.0 wt.% enrichment and the 8A cylinder model for enrichments of 6, 8 and 10 wt% ^{235}U. A cross-section of this type of cask can be seen in Figure 3 below.

The resulting cylinders were modeled as being stored in a large warehouse with spacing to allow cask movement machinery to operate between the rows of casks. Stacking of cylinders was considered unlikely for this type of application. This floor design can be seen below in Figure 4.

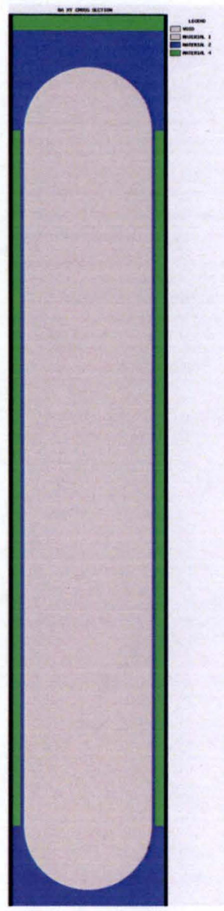

Figure 3. Cross Section of UF_6 Cylinder

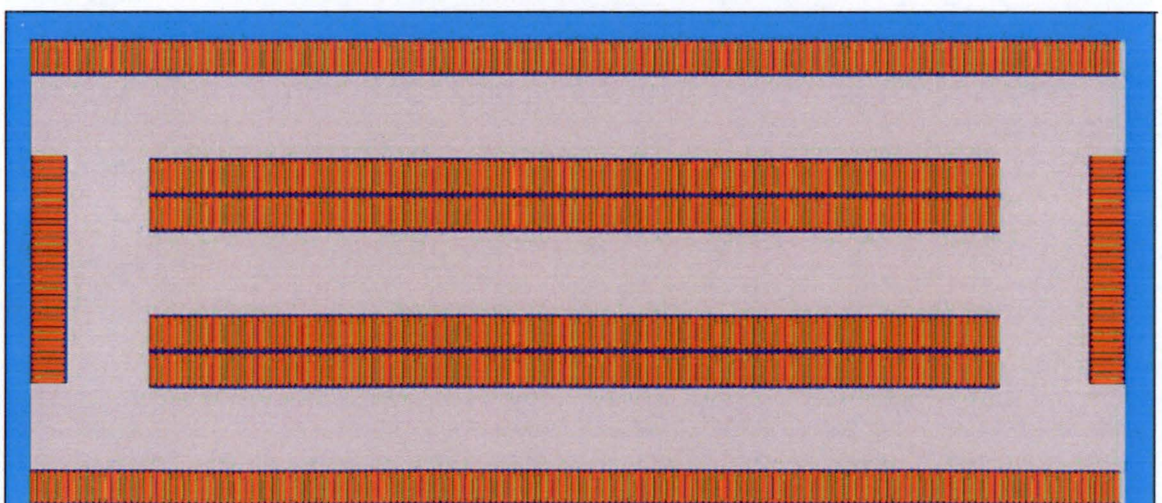

Figure 4. Floor Layout of UF_6 Storage Casks

Base Case 2: UO_2 powder in storage rack arrays

The base case representative storage configuration for UO_2 powders prior to being pressed into pellets also uses a warehouse room style configuration. The powders of each enrichment of interest are modeled as being stored in cylindrical canisters made of stainless steel. These containers are stored on long rows of aluminum shelves that begin 30 cm above the concrete floor. This storage configuration was tested with an air/6% water mixture to determine if subcriticality could be assured if the sprinkler system was activated in the room. There is no water in the models used for comparison against the benchmark database. The room layout can be seen in Figure 5. An individual storage rack can be seen in Figure 6.

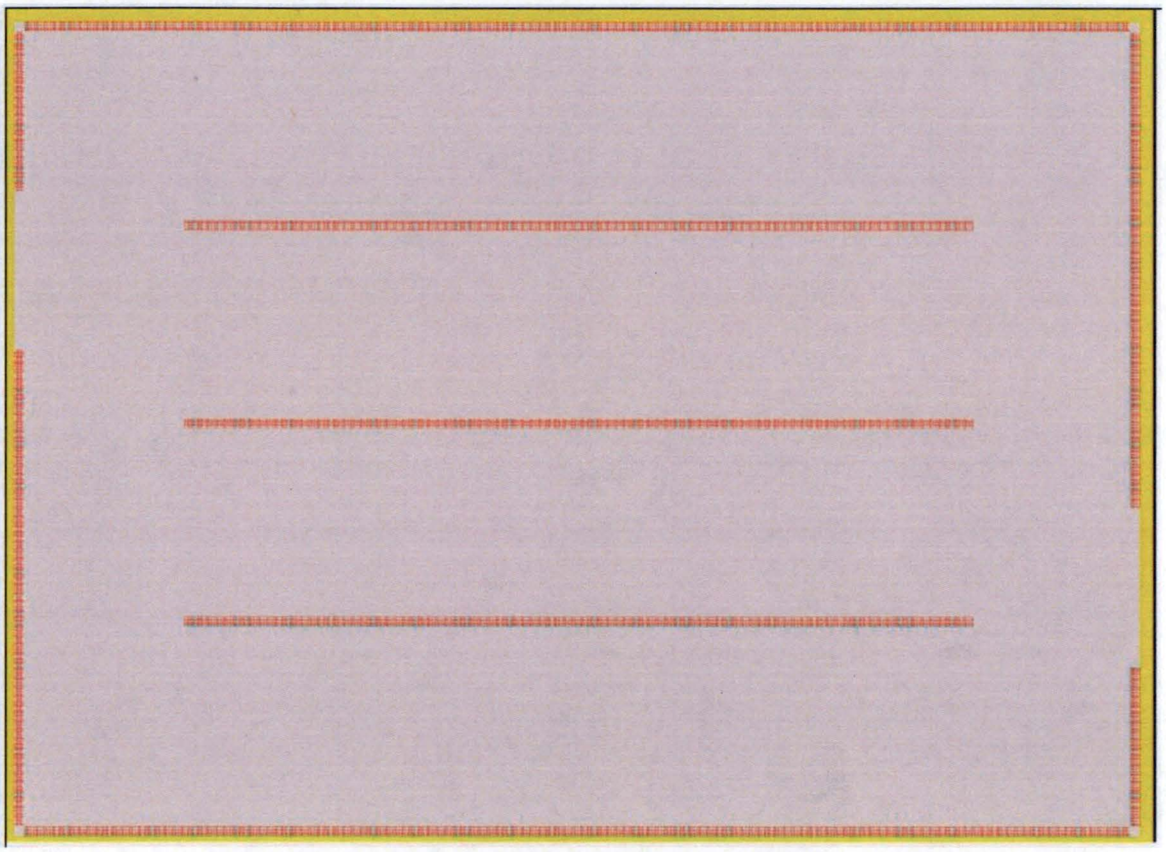

Figure 5. Floor Layout of UO_2 Powder Storage

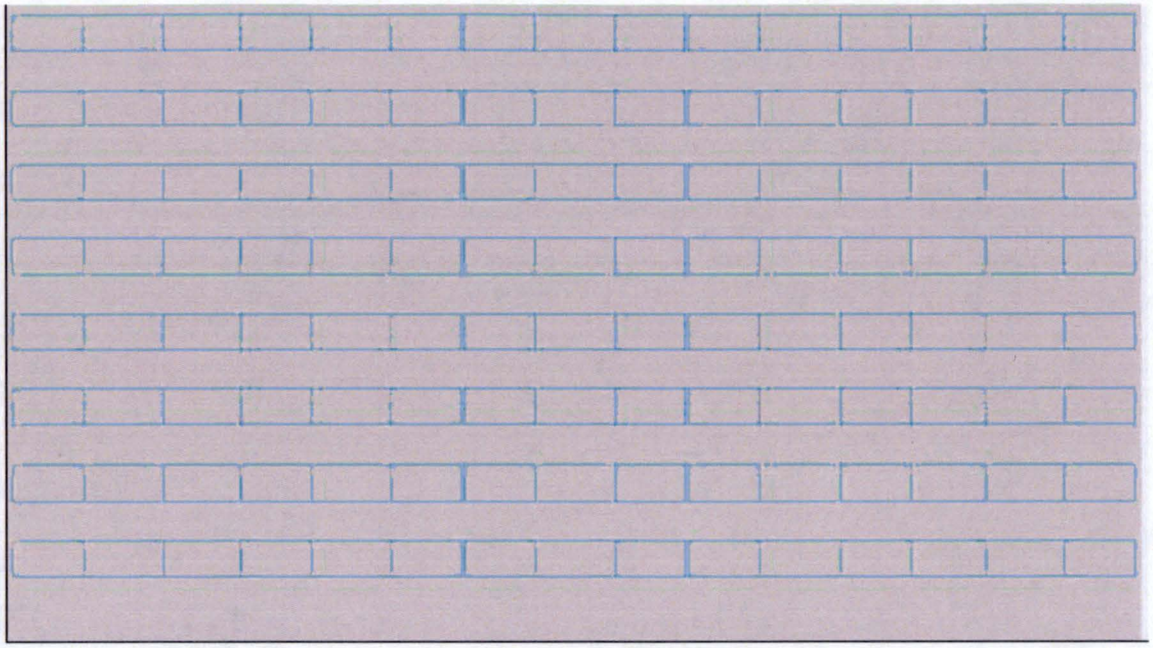

Figure 6. UO_2 Powder Storage Rack Configuration.

Base Cases 3 and 4: Pressed ceramic UO_2 /TRISO fuel pellets in boxes

The storage configuration for pressed UO_2 (Case 3) and TRISO pellets (Case 4) prior to being loaded into fuel pins or graphite blocks is very similar to that of storage of unpressed UO_2 pellets. Once again, a large warehouse style room (shown in Figures 5 and 6) is used to store metal boxes of pellets using the same shelf configuration used for Case 2. The pellet contents of the individual storage boxes can be seen in Figure 7.

Base Cases 5 and 6: UO_2, zircaloy clad/TRISO fuel pin array in shipping cask

PWR fuel assemblies for lower enriched fuel (Case 5) were modeled with consideration given to ensure that the lattice is an undermoderated design and would have k_{eff} values less than 0.95 in the event of a flooded cask. In order for higher enriched fresh fuel to remain undermoderated, Case 6 was introduced to model graphite moderated reactors similar to high temperature gas reactors. The graphite prisms were modeled as being stored in a shipping cask similar to those used for the PWR fuel rods used for the lower enrichments. Figure 8 shows a finished PWR style fuel assembly cask.

The assumed model of the high temperature gas reactor fuel consists of a graphite moderated hexagonal fuel design. TSUNAMI-3D does not currently support hexagonal geometry, so this was approximated by making an equivalent cylinder of graphite moderator to surround the TRISO based fuel. Figure 9 shows a cross section of this design.

Each of the base cases were modeled at enrichments of 5% (subcase a), 6% (subcase b), 8% (subcase c) and 10% (subcase d). Table 1 provides a summary of the base cases.

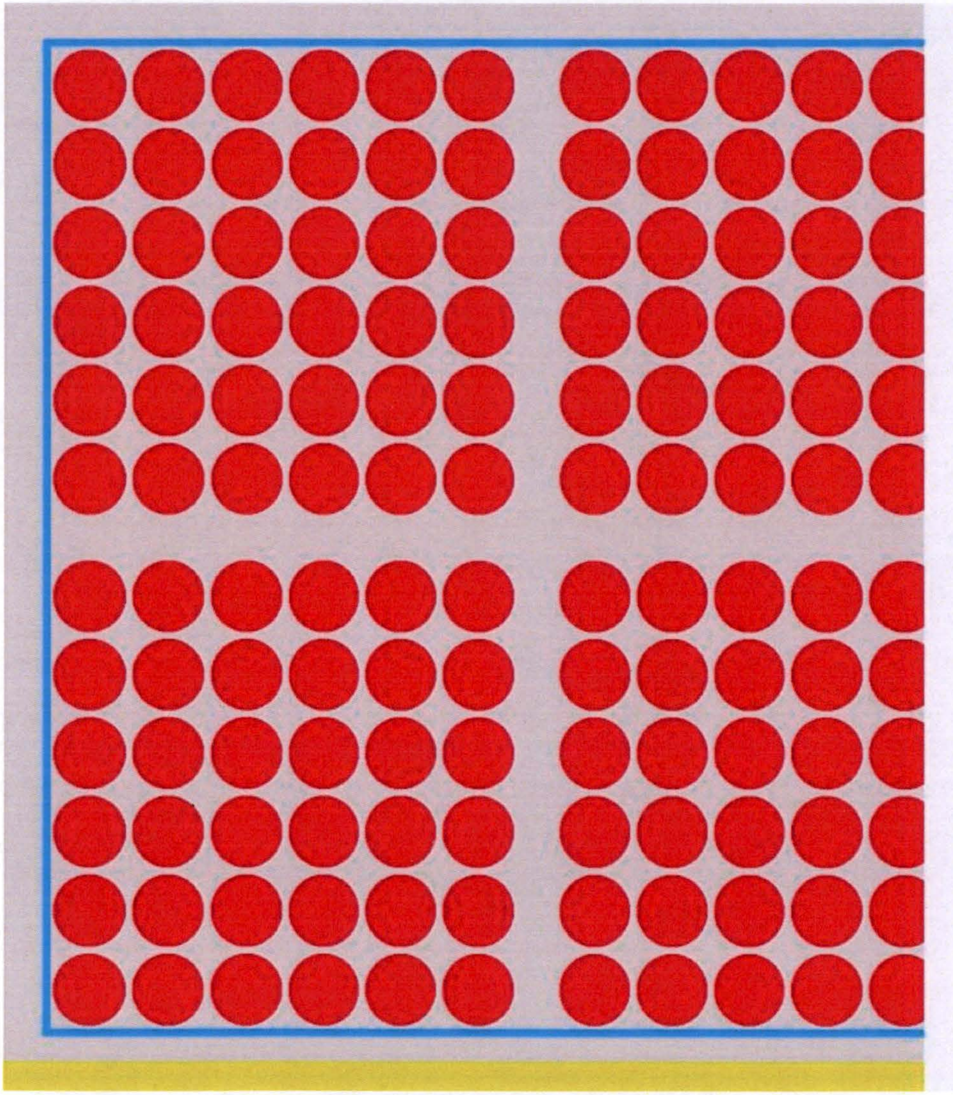

Figure 7. Pellet Storage Box

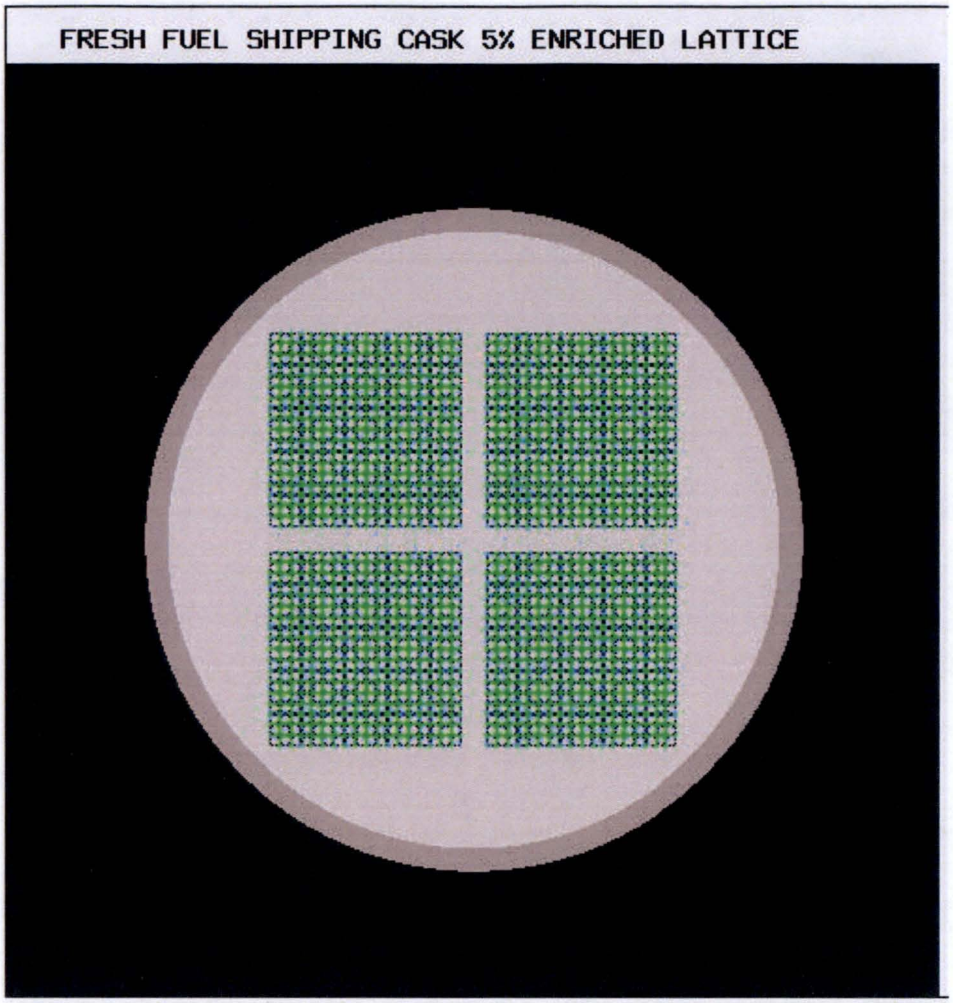

Figure 8. PWR Style Fresh Fuel Shipping Cask

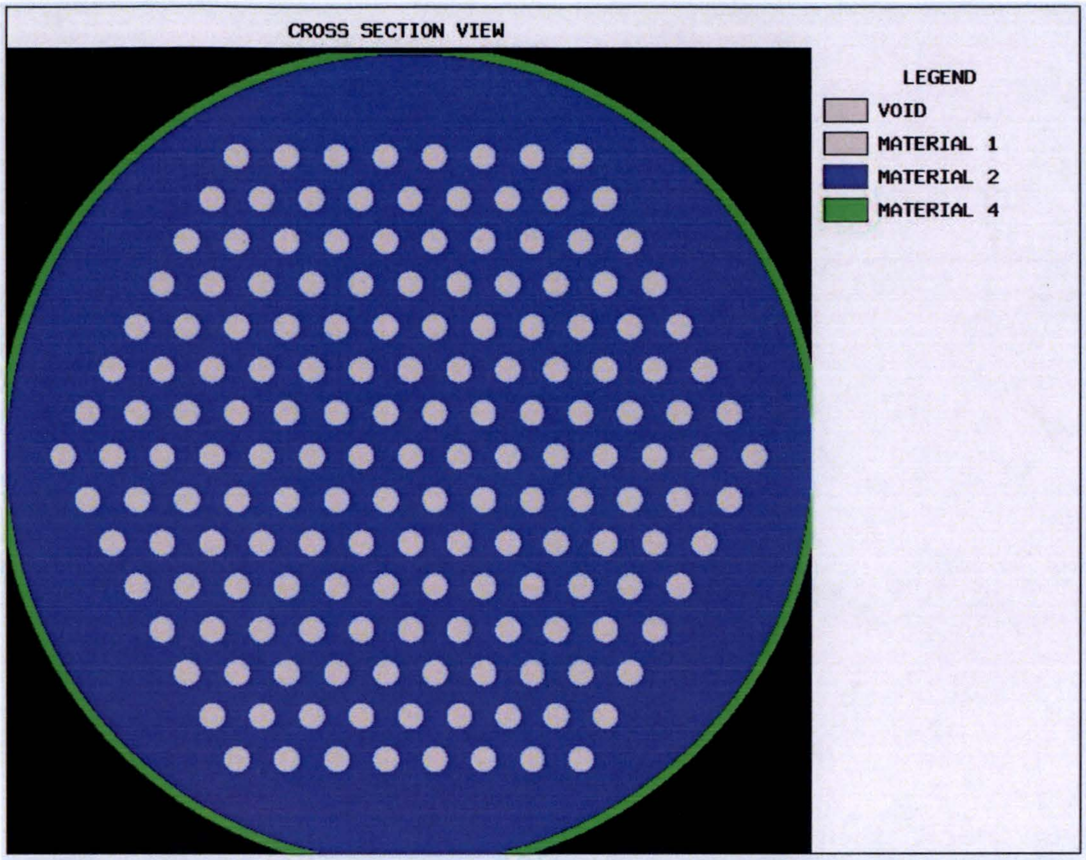

Figure 9. Shipping Cask of Finished TRISO Fuel.

Table 1. Summary of the Base Cases with enrichment

Base Case	Description
1a	5% enriched UF6 cylinder
1b	6% enriched UF6 cylinder
1c	8% enriched UF6 cylinder
1d	10% enriched UF6 cylinder
2a	Storage of 5% enriched UO2 powder in storage rack arrays
2b	Storage of 6% enriched UO2 powder in storage rack arrays
2c	Storage of 8% enriched UO2 powder in storage rack arrays
2d	Storage of 10% enriched UO2 powder in storage rack arrays
3a	Storage of 5% enriched UO2 pellets in boxes
3b	Storage of 6% enriched UO2 pellets in boxes
3c	Storage of 8% enriched UO2 pellets in boxes
3d	Storage of 10% enriched UO2 pellets in boxes
4a	Storage of 5% enriched TRISO pellets in boxes
4b	Storage of 6% enriched TRISO pellets in boxes
4c	Storage of 8% enriched TRISO pellets in boxes
4d	Storage of 10% enriched TRISO pellets in boxes
5a	17x17 array of 5% enriched PWR fuel pins in shipping cask
5b	17x17 array of 6% enriched PWR fuel pins in shipping cask
5c	17x17 array of 8% enriched PWR fuel pins in shipping cask
5d	17x17 array of 10% enriched PWR fuel pins in shipping cask
6a	Graphite moderated cask - hexagonal lattice modeled as cylinder @ 5% enrich
6b	Graphite moderated cask - hexagonal lattice modeled as cylinder @ 6% enrich
6c	Graphite moderated cask - hexagonal lattice modeled as cylinder @ 8% enrich
6d	Graphite moderated cask - hexagonal lattice modeled as cylinder @ 10% enrich

III.B. Contingency Versions of Base Cases

The normal versions of the base cases represent configurations that the nuclear material will be in during normal operations of the fuel processing steps. In a nuclear criticality safety analysis per ANSI/ANS-8.1[4], these operations will have to be shown to be subcritical after any credible contingency. Because of this requirement, the base cases previously defined will be quite subcritical when normal conditions prevail (as shown in Section IV). From the point of view of validation, two points are usually true about normal cases:

1. They often fall outside the area of applicability defined by a validation effort depending on critical experiments (primarily because the neutrons spectrum of the subcritical case differs so much from the spectra of the critical benchmarks); and

2. This shortcoming is unimportant because the base cases are so far subcritical as to minimize the importance of a well-defined upper subcritical limit. The normal base cases will not be the limiting cases in the criticality analysis.

For this reason, it is important in this project to try to approximate the contingencies that are likely to be the limiting cases. Because of the epithermal spectra of all six of the normal base cases, as illustrated in the values of the energy of the average lethargy of fission (EALF) parameter shown in Table 13, it was decided that the contingency that is most likely to be limiting is one that involves the addition of moderation to the fuel material, softening the spectrum, decreasing neutron leakage, and increasing reactivity. Therefore, contingency cases involving an addition of water to the fuel material matrix and/or flooding was defined for each of the six base cases, using the following model changes:

Base Case 1: Stored UF_6 **cylinders.** 10% (by volume) water added to each cylinder, infinite array of cylinders, completely flooded outside. Search was made for the limiting cylinder spacing for k_{eff} of 0.85-0.95.

Base Case 2: UO_2 **powder in storage rack arrays**—50% Powder, 50% water inside, Infinite series of shelves, flooded outside each canister. Search was made for limiting shelf spacing for k_{eff} of 0.85-0.95.

Base Case 3: Pressed ceramic UO_2 **fuel pellets in boxes**—Pin boxes flooded, infinite series of shelves, flooded outside. Search was made for limiting shelf spacing for k_{eff} of 0.85-0.95.

Base Case 4: TRISO pellets in boxes— Pin boxes flooded, infinite series of shelves, flooded outside. Search was made for limiting shelf spacing for k_{eff} of 0.85-0.95.

Base Case 5: UO_2**, zircaloy clad fuel pin array in shipping cask**—Flooded cask inside and out, infinite planar array of casks. Search for limiting cask spacing for k_{eff} of 0.85-0.95.

Base Case 6: Graphite-moderated TRISO fuel pins in hexagonal lattice—Flooded cask inside and out, infinite planar array of casks. Search for limiting cask spacing for k_{eff} of 0.85-0.95.

III.C. Additional Powdered Cases

When the results of this project were presented to the NRC at the conclusion of the analysis (May 2008), a question arose about the absence of bulk UO_2 powder cases in the base case set which were developed and presented at the conclusion of Task 1. It was felt by some in the presentation audience that the UO_2 powder Base Case 2 being confined to small storage canisters did not consider possible accident scenarios involving larger processing vessels.

To provide a preliminary analysis of the effect that the inclusion of such cases might have had on the results of Task 2, a shortened analysis of some simplified-geometry damp

powder cases was performed. Because of the availability of a kinetics study of a similar configuration[13] at low enrichment, similar conditions were chosen for this simplified study:

1. UO_2 density of 2.5 g/cm^3;

2. Volume of 1200 liters (simplified into a sphere of radius 66 cm);

3. No external reflection; and

4. Internal water (homogeneously mixed with the uranium) sufficient to bring k_{eff} to ~0.90.

III.D. Available Benchmark Experiments

ICSBEP Benchmark Handbook

The International Handbook of Evaluated Criticality Safety Benchmark Experiments (ICSBEP Handbook[1]) documents many ^{235}U critical experiments of all enrichment ranges as well as ^{233}U, ^{239}Pu, and MOX experiments and is representative of configurations encountered in the nuclear fuel cycle. These data is commonly used for the validation of neutronics codes and nuclear data libraries used in criticality safety analysis. The handbook is currently distributed in DVD format with each experiment categorized by fissile material, fuel form, and neutron spectrum.

DICE is a Java tool that is included on the DVD and used to efficiently navigate and search for experimental data given a set of search parameters. This program allows for a user to give critical experiment parameters or data ranges and find experiments that match the search criteria. DICE also allows the user to read short summaries for each selected experiment as well as the entire report for any experiment. System characteristics of this data can be exported to text files and plotted or put into tables as needed using appropriate software.

In a traditional validation effort, such a search is used to identify critical experiments with similar properties to the system being analyzed, with a subjective parameter-by-parameter comparison, as mentioned previously.

For this project, all ^{235}U experiments for which SDF files were available (and a few that weren't) were included as candidate experiments—with the idea that TSUNAMI would sort them out and identify the applicable experiments, with no need to cull the list beforehand.

Nevertheless, a DICE search was performed to estimate the quality of coverage that the available experiments provided. To make this estimate, a DICE search was performed to identify cases that satisfy various combinations of the following criteria:

1. Low enriched uranium (LEU) fuel;

2. Enrichment in the range 4-11% ^{235}U;

3. Energy of the average energy of fission (EALF) in the range 0-10 eV; and

4. KENO input deck available in the database.

DICE Search Results

The results of the ICSBEP database search are shown in Table 2. The first few columns of the table are given by:

(1) The name of the evaluation series (most of them having multiple variations);

(2) The number of LEU cases in each series;

(3) The number of LEU cases that fit the enrichment criterion of 4-11% ^{235}U;

(4) The number of LEU cases that fit the EALF criterion of 0-10 eV;

(5) The number of LEU cases that fit both the enrichment and the EALF criteria; and

(6) The number of LEU cases that include KENO input decks in the database.

III.E. Availability of SDF Files from previous TSUNAMI studies

From previous NRC-funded work at the Oak Ridge National Laboratory (ORNL)—plus a few other experiments that had been analyzed in previous University of Tennessee studies—, a total of 378 TSUNAMI-produced SDF files from critical experiments previously analyzed by ORNL researchers were made available to this project. The 253 LEU cases from this group are listed in Table 3. In addition, there were 125 SDF files from intermediate and high enriched uranium experiments (IEU and HEU, respectively) which were included in the analysis (simply because they were available); these are listed in Table 4.

Table 2. Results of DICE search of ICSBEP data base (2007)

(1) Evaluation Identification	(2) LEU cases	(3) Fits Enrich	(4) Fits EALF	(5) Fits both	(6) # with KENO	(7) SDFs avail	(8) New KENOs	(9) SDFs fit
LEU-COMP-THERM-001	8		8		8			
LEU-COMP-THERM-002	5	5	5	5	5		5	
LEU-COMP-THERM-003	23		23		23			
LEU-COMP-THERM-004	20	20	20	20	20		20	
LEU-COMP-THERM-005	16	13						
LEU-COMP-THERM-006	18		18					
LEU-COMP-THERM-007	10	10	9	9				
LEU-COMP-THERM-008	17		17		17			
LEU-COMP-THERM-009	27	27	27	27	27	26	1	26
LEU-COMP-THERM-010	30	30	30	30	30	30		30
LEU-COMP-THERM-011	15		15		15			
LEU-COMP-THERM-012	10		10		10	10		
LEU-COMP-THERM-013	7	7	7	7	7	1	6	1
LEU-COMP-THERM-014	5	5	5	5	5		5	
LEU-COMP-THERM-015	165	22	165	9	165		9	
LEU-COMP-THERM-016	32		32		32			
LEU-COMP-THERM-017	29		29		29	29		
LEU-COMP-THERM-018	1	1	1	1		1		1
LEU-COMP-THERM-019	3	3	3	3		3		3
LEU-COMP-THERM-020	7	7	7	7		7		7
LEU-COMP-THERM-021	6	6	6	6		6		6
LEU-COMP-THERM-022	7	7	7	7		7		7
LEU-COMP-THERM-023	6	6	6	6		6		6
LEU-COMP-THERM-024	2	2	2	2		2		2
LEU-COMP-THERM-025	4	4	4	4		4		4
LEU-COMP-THERM-026	6	6	6	6		4		4
LEU-COMP-THERM-027	4	4	4	4				
LEU-COMP-THERM-029	12	12	12	12				
LEU-COMP-THERM-031	6	6	6	6	6		6	
LEU-COMP-THERM-032	9	9	9	9		9		9
LEU-COMP-THERM-033	52		52		52	36		
LEU-COMP-THERM-034	24	24	24	24				
LEU-COMP-THERM-035	3		3					
LEU-COMP-THERM-036	69		69		69			
LEU-COMP-THERM-037	11	11	11	11				
LEU-COMP-THERM-038	14	14	14	14				
LEU-COMP-THERM-039	17	17	17	17	17	17		17
LEU-COMP-THERM-040	10	10	10	10		3		3
LEU-COMP-THERM-041	5		5					

LEU-COMP-THERM-042	7		7		7	7		
LEU-COMP-THERM-045	21	21	21	21	21	8	13	8
LEU-COMP-THERM-047	3	2						
LEU-COMP-THERM-048	5		5		5			
LEU-COMP-THERM-049	18	18	18	18	18		18	
LEU-COMP-THERM-050	18	18	18	18	18		18	
LEU-COMP-THERM-051	19		19		18			
LEU-COMP-THERM-052	6	6	6	6	6		6	
LEU-COMP-THERM-053	14	14	14	14				
LEU-COMP-THERM-055	2				2			
LEU-COMP-THERM-056	1	1			1			
LEU-COMP-THERM-060	28							
LEU-COMP-THERM-061	10	10	10	10	10		10	
LEU-COMP-THERM-062	15		15					
LEU-COMP-THERM-063	12				12			
LEU-COMP-THERM-065	17		17					
LEU-COMP-THERM-066	10	10	7	7	10		7	
LEU-COMP-THERM-068	17	17	14	14	17		14	
LEU-COMP-THERM-069	5	5	5	5	5		5	
LEU-COMP-THERM-070	12	12	12	12	12		12	
LEU-COMP-THERM-071	4	4			4			
LEU-COMP-THERM-075	6	6	6	6	6		6	
LEU-COMP-THERM-076	7	3			7			
LEU-COMP-THERM-077	5	5	5	5	5		5	
LEU-COMP-THERM-079	10	10	10	10	10		10	
LEU-COMP-THERM-081	1	1						
LEU-COMP-THERM-082	6	6	6	6	6		6	
LEU-COMP-THERM-083	3	3	3	3	3		3	
LEU-COMP-THERM-084	1	1	1	1	1		1	
LEU-COMP-THERM-085	13	13	13	13	13		13	
LEU-COMP-THERM-086	10	6						
LEU-COMP-THERM-087	17							
LEU-COMP-THERM-089	4	4	4	4	4		4	
LEU-COMP-THERM-090	9	9	9	9	9		9	
LEU-COMP-THERM-091	9	9	9	9	9		9	
LEU-COMP-THERM-093	8							
LEU-COMP-THERM-094	11	11	11	11				
LEU-MET-THERM-001	1				1			
LEU-MET-THERM-002	12							
LEU-MET-THERM-006	30		30		30			
LEU-MET-THERM-015	22							
LEU-MISC-THERM-001	5	5						
LEU-MISC-THERM-002	6	6						
LEU-MISC-THERM-003	15	15						

LEU-SOL-THERM-001	1	1	1	1	1	1		1
LEU-SOL-THERM-002	3	3	3	3	3		3	
LEU-SOL-THERM-003	9	9	9	9	9	9		9
LEU-SOL-THERM-004	7	7	7	7		7		7
LEU-SOL-THERM-005	3	3	3	3	3	3		3
LEU-SOL-THERM-006	5	5	5	5	5	5		5
LEU-SOL-THERM-007	5	5	5	5	5	5		5
LEU-SOL-THERM-008	4	4	4	4	4	4		4
LEU-SOL-THERM-009	3	3	3	3	3	3		3
LEU-SOL-THERM-010	4	4	4	4	4	4		4
LEU-SOL-THERM-016	7	7	7	7	7	7		7
LEU-SOL-THERM-017	6	6	6	6	6	6		6
LEU-SOL-THERM-018	6	6	6	6	6	5	1	5
LEU-SOL-THERM-019	6	6	6	6		6		6
LEU-SOL-THERM-020	4	4	4	4	4	4		4
LEU-SOL-THERM-021	4	4	4	4	4	4		4
LEU-SOL-THERM-022	4	4	4	4	4	4		4
LEU-SOL-THERM-023	9	9	9	9				
LEU-SOL-THERM-024	7	7	7	7				
LEU-SOL-THERM-025	7	7	7	7				
SUB-LEU-COMP-THERM-001	15							
TOTAL	1289	643	1097	567	875	293	225	211

Table 3. LEU cases whose SDF files were made available to the project

Evaluation Identification	SDFs	Evaluation Identification	SDFs	Evaluation Identification	SDFs
LEU-COMP-THERM-009	26	LEU-COMP-THERM-023	6	LEU-SOL-THERM-003	9
LEU-COMP-THERM-010	30	LEU-COMP-THERM-024	2	LEU-SOL-THERM-004	7
LEU-COMP-THERM-012	10	LEU-COMP-THERM-025	4	LEU-SOL-THERM-005	3
LEU-COMP-THERM-013	1	LEU-COMP-THERM-026	4	LEU-SOL-THERM-006	5
LEU-COMP-THERM-017	29	LEU-COMP-THERM-032	9	LEU-SOL-THERM-007	5
LEU-COMP-THERM-018	1	LEU-COMP-THERM-033	36	LEU-SOL-THERM-008	4
LEU-COMP-THERM-019	3	LEU-COMP-THERM-040	3	LEU-SOL-THERM-009	3
LEU-COMP-THERM-020	7	LEU-COMP-THERM-042	7	LEU-SOL-THERM-010	4
LEU-COMP-THERM-021	6	LEU-COMP-THERM-045	8	LEU-SOL-THERM-016	7
LEU-COMP-THERM-022	7	LEU-SOL-THERM-001	1	LEU-SOL-THERM-017	6
Total	253				

Table 4. IEU and HEU cases whose SDF files were made available to the project

Evaluation Identification	SDFs	Evaluation	SDFs	Evaluation	SDFs

		Identification		Identification	
HEU-COMP-THERM-010	15	HEU-SOL-THERM-009	4	HEU-SOL-THERM-019	1
HEU-COMP-THERM-011	3	HEU-SOL-THERM-010	4	HEU-SOL-THERM-025	4
HEU-COMP-THERM-012	2	HEU-SOL-THERM-011	2	HEU-SOL-THERM-027	1
HEU-COMP-THERM-013	2	HEU-SOL-THERM-012	1	HEU-SOL-THERM-032	1
HEU-COMP-THERM-014	2	HEU-SOL-THERM-013	1	HEU-SOL-THERM-033	9
HEU-MET-THERM-006	23	HEU-SOL-THERM-014	1	IEU-MET-FAST-003	1
HEU-SOL-THERM-001	10	HEU-SOL-THERM-015	2	IEU-MET-FAST-004	1
HEU-SOL-THERM-005	5	HEU-SOL-THERM-016	1	IEU-MET-FAST-005	1
HEU-SOL-THERM-006	4	HEU-SOL-THERM-017	3	IEU-MET-FAST-006	1
HEU-SOL-THERM-007	17	HEU-SOL-THERM-018	3		
Total	125				

III.F. Creation of New SDF Files

In addition to the experiments represented by the SDF files made available to the project from previous work, additional experiments were identified by the DICE search for which KENO (SCALE) input decks were available from the data base. As most of these input decks were used for older versions than the current version of SCALE, each input deck had to be translated to fit the input format of SCALE 5.1. Using the GeeWhiz graphical user interface as well as manual translation, several sets of working TSUNAMI-3D input decks were translated. Some of these decks could not be translated, as efforts using manual translation as well as GeeWhiz proved futile.

After this comparison and translation, a set of 40 experiments were selected to be modeled for this project using TSUNAMI-3D. The experiments with working SCALE input decks can be seen in Table 5. (These cases are also included in Table 2.)

Table 5. Critical Benchmark Experiment Inputs Selected for TSUNAMI-3D Modeling.

Experiment Listing	Number of Cases
LEU-COMP-THERM-039	17
LEU-SOL-THERM-018	5
LEU-SOL-THERM-019	6
LEU-SOL-THERM-020	4
LEU-SOL-THERM-021	4
LEU-SOL-THERM-022	4

Explanation of Direct Perturbation Calculations

In order to verify that TSUNAMI-3D has accurately generated sensitivity data of a critical configuration, the direct perturbation test was applied to each model. Due to

factors such as resonance self-shielding, additional flux meshing may be required in a SCALE model to more accurately describe the sensitivity of a system k_{eff} value to a given nuclide. To ensure that TSUNAMI-3D has accurately calculated system sensitivities, direct changes in atom density of the two most sensitive nuclides is performed.

For this comparison, after TSUNAMI-3D has been used to model a benchmark experiment, the two most sensitive nuclides and its respective zone are noted. KENO V.a is used to calculate the k_{eff} of these systems, with slight perturbations to the atom densities in the zone of interest. For these analyses, +/- 3% changes in atom density were used.

Using the direct difference method, the change in KENO V.a calculated k_{eff} of a system is divided by the change in nuclide atom density as shown:

$$S_{nuclide} = \frac{\Delta k_{eff}}{\Delta \rho_{nuclide}}$$

This calculated value is compared to the estimated sensitivity of k_{eff} of the system by TSUNAMI-3D. If both values are within their uncertainty ranges of each other, then the system can be considered to be accurately modeled. If this is not true, then further adjustments must be made to the TSUNAMI-3D input deck to correct this.

There are a few "rules of thumb" that can be followed to help with this process. For example, a model with a large pin fueled lattice would need to be meshed using the MSH = parameter option in TSUNAMI. This parameter gives the number of meshes to be superimposed over the entire unit. Since the unit is only composed of a fueled lattice, this option is a viable one. It is recommended that the MSH value be set approximately equal to 1/10th the fueled length of the region. More or less meshing may be appropriate to accurately calculate the sensitivity.

In the event that a model reflects unevenly distributed fueled materials, or small fissile masses in a large room, manual meshing may be necessary to add to the input deck. For manual meshing to be executed, the fissile unit must be built from the center to the outside in successive layers of the same material. These boundaries will cause TSUNAMI-3D to calculate fluxes at these boundaries, thereby reducing the resonance self-shielding with additional calculations.

Aside from these changes, one can always add more particles per history and more histories during the transport calculations to drive the uncertainties down and improve the quality of the calculation.

This method was followed for the two most sensitive nuclides present in each system and compared to their respective direct difference calculations of these nuclides.

The results of the direct perturbation analysis in comparison to TSUNAMI-3D calculations of nuclide sensitivity are compared for each set of experiments modeled. It is the goal of this exercise for both TSUNAMI-3D sensitivity calculations as well as

direct perturbation calculations to be within their uncertainty ranges of each other to determine the validity of the TSUNAMI-3D calculations.

LEU-COMP-THERM-039 (17 Cases)

The first experiment modeled is LEU-COMP-THERM-039. This experiment consists of 17 separate experiments using 4.378% ^{235}U enriched fuel rods (UO_2) in a single array with some HOLE positions in the array. These rods were water moderated and water reflected with criticality being controlled by the water level in the tank. These experiments took place on testing equipment called "Apparatus B" in the IPSN facility at Valduc, France in 1978. These experiments are considered to be acceptable for use as benchmark experiments.

The seventeen experiments were part of a larger program to qualify criticality codes for light water reactor fuel cycle. This includes pool storage, shipping casks and reprocessing.

The experiments in this configuration used a 1.26 cm square pitch fuel lattice with the varying parameter for each case being the number and position of holes in the lattice. The fueled lattice was dropped into a parallelepiped tank with a variable water level. The water level inside the tank was increased until a critical configuration was found using the 1/M approach to critical using BF_3 counters. The experimental configuration is shown in Figure 10.

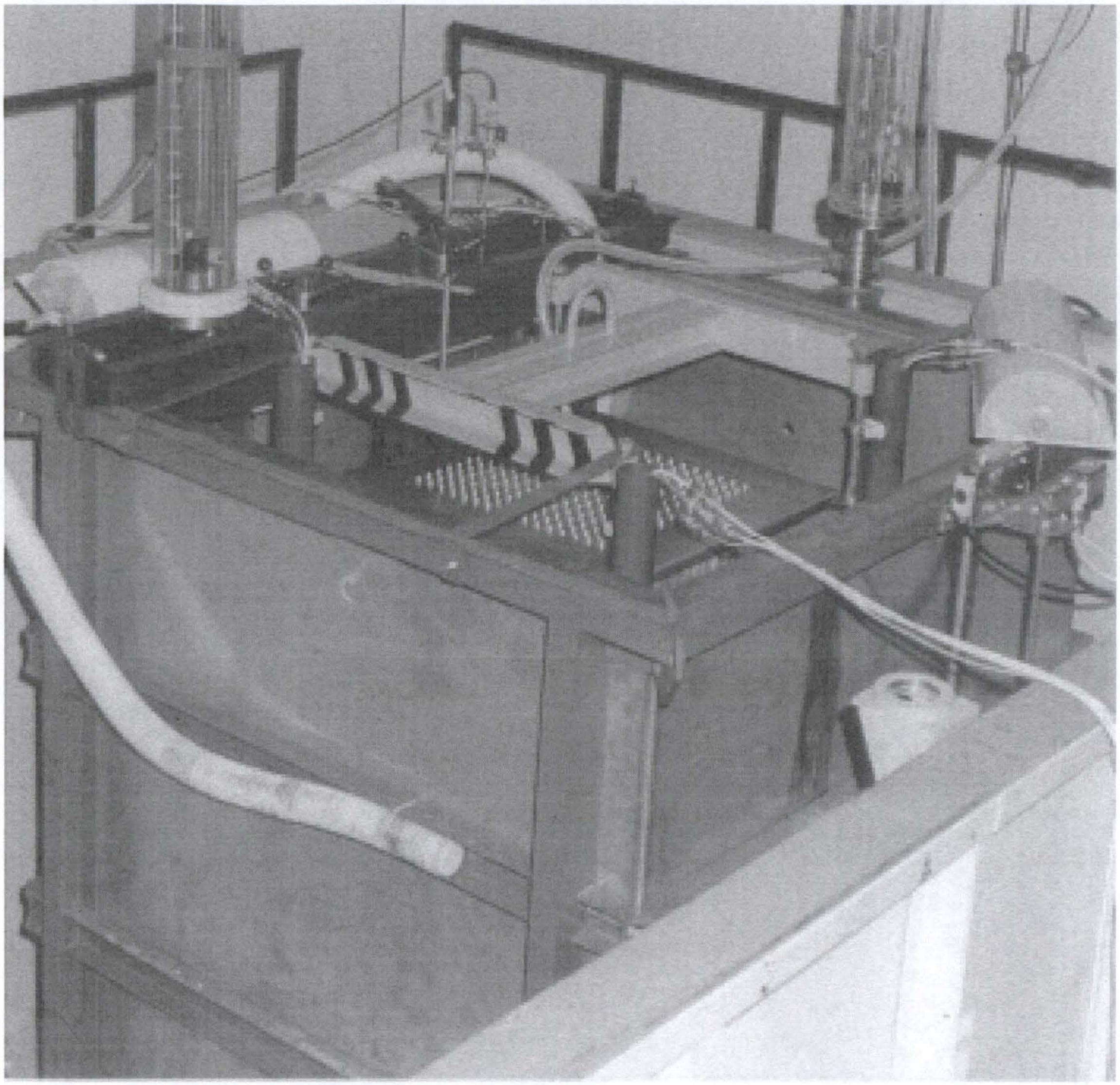

Figure 10: Assembly Configuration for LEU-COMP-THERM-039 Benchmark Experiments.[10]

As these experiments were of a fueled lattice, the parameter within TSUNAMI-3D used to adequately model the sensitivity of this configuration was the meshing input parameter. Starting with setting this parameter to 1/10th the fueled length of the assembly, TSUNAMI-3D calculated the sensitivity of each nuclide in the system. This was done until the sensitivity of the direct perturbation calculations matched those returned by TSUNAMI-3D for the two most sensitive nuclides. These results can be seen in Table 6.

Table 6. Sensitivity Calculations for LEU-COMP-THERM-039

	TSUNAMI-3D Calculations				Direct Perturbation Test			
Case	S - U-235	Uncertainty	S - H-1	Uncertainty	S - U-235	Uncertainty	S - 1-H	Uncertainty
1	0.1411	0.0020652	0.2856	0.1079	0.141638	0.139	0.342738	0.0207

2	0.1489	0.002029	0.27137	0.074206	0.11331	0.0207	0.217077	0.0211
3	0.14609	0.0020811	0.24519	0.0828	0.168887	0.0289	0.291011	0.0334
4	0.15436	0.0021137	0.23245	0.10757	0.176964	0.0347	0.330333	0.0335
5	0.17132	0.002212	0.15644	0.09017	0.18443	0.0297	0.276604	0.0333
6	0.17199	0.0022537	0.1597	0.11152	0.142809	0.0357	0.26377	0.0309
7	0.15848	0.0020511	0.26629	0.11244	0.180234	0.0213	0.359795	0.0224
8	0.15439	0.00203	0.2483	0.075088	0.142829	0.0227	0.335111	0.0199
9	0.16396	0.0020869	0.23455	0.11688	0.160792	0.0207	0.342607	0.0222
10	0.15306	0.001991	0.20734	0.070904	0.166142	0.0215	0.312441	0.0203
11	0.15473	0.0021336	0.27247	0.12652	0.149286	0.0205	0.30766	0.0187
12	0.13946	0.0020979	0.28368	0.068079	0.134419	0.0234	0.341699	0.0193
13	0.14573	0.0021669	0.27395	0.11357	0.167633	0.0209	0.307777	0.0225
14	0.15033	0.0021187	0.2643	0.09133	0.122844	0.0219	0.340596	0.0221
15	0.16242	0.0021318	0.25307	0.11937	0.171246	0.0223	0.345526	0.021
16	0.15188	0.0020773	0.2624	0.075497	0.147639	0.0201	0.342919	0.022
17	0.15539	0.0021067	0.25697	0.11855	0.172776	0.0223	0.335785	0.0208

As can be seen from the previous table, the hydrogen from the moderator and the ^{235}U from the fuel are the two most sensitive nuclides present in the experiment. Based on calculations from TSUNAMI-3D and direct perturbation tests, the sensitivity output data from TSUNAMI-3D is adequate.

LEU-SOL-THERM-018 (5 Cases)

From the LEU-SOL-THERM-018 experiment set, five critical configurations were performed at the STACY (Static Experiment Critical Facility) between 1997 and 1998 at Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF) in the Tokai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). The experiment utilizes a 28 cm thick, 69 cm wide slab core tank with 10% enriched uranyl nitration solution. Criticality is approached by controlling the height of the slab within the concrete reflected tank. A diagram with further detail of this experiment can be seen in Figure 11[11].

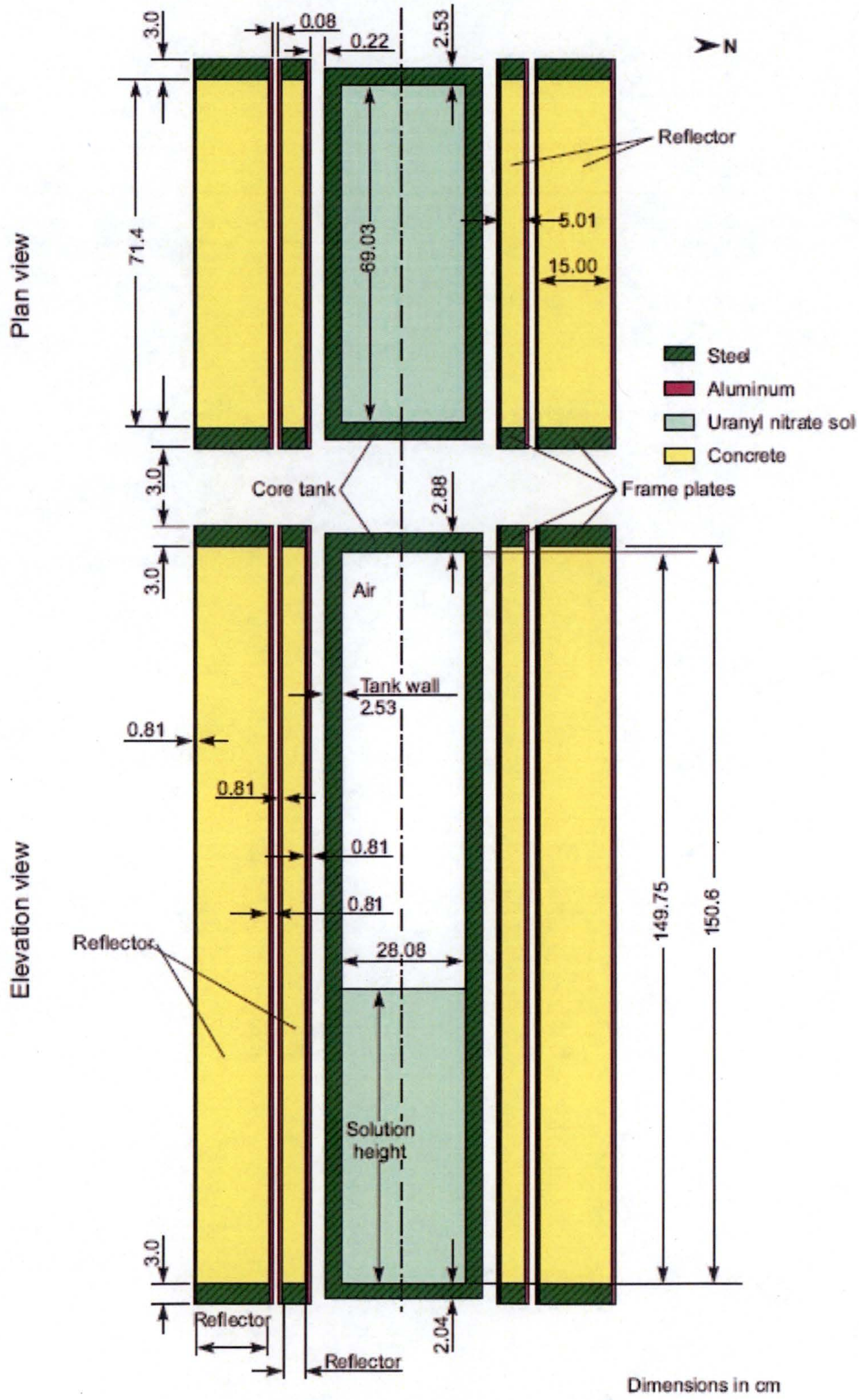

Figure 11: Configuration for LEU-SOL-THERM-018[11]

Utilizing the direct difference method, the TSUNAMI-3D sensitivity calculations are compared to the manual sensitivity calculations to verify the accuracy of TSUNAMI-3D. As this experiment is of a homogenous critical, the meshing of the solution by TSUNAMI-3D will not be needed to account for resonance self-shielding. The results can be seen in Table 7.

Table 7. Sensitivity Calculations for LEU-SOL-THERM-018

	TSUNAMI-3D Calculations				Direct Perturbation Test			
Case	S - U-235	Uncertainty	S - H-1	Uncertainty	S - U-235	Uncertainty	S - 1-H	Uncertainty
1	0.36839	0.00129	0.06108	0.045249	0.354154	0.0142	0.091738	0.015
2	0.36622	0.001148	0.06356	0.03942	0.347558	0.0128	0.070543	0.0127
3	0.36432	0.001408	0.067307	0.042519	0.335008	0.0141	0.090354	0.0112
4	0.36385	0.001886	0.066044	0.041989	0.351243	0.0121	0.058623	0.0136
5	0.36487	0.001848	0.068479	0.041342	0.330393	0.0122	0.100829	0.0136

Again, as TSUNAMI-3D calculations are within uncertainties of the manual values turned out by using the direct perturbation method. These TSUNAMI-3D sensitivity calculations are acceptable.

LEU-SOL-THERM-019 (6 Cases)

The LEU-SOL-THERM-019 experiment set is much like the previous experimental set LEU-SOL-THERM-018 as it took place at the JAERI NUCEF facility using the STACY apparatus. Instead of reflecting a uranyl nitrate solution with concrete, this experiment set uses polyethylene reflector. Again, using slab geometry, the 28 cm thick, 69 cm wide solution core tank was reflected with polyethylene blocks of six separate thicknesses, one for each experiment. A diagram showing the configuration of this experiment can be seen in Figure 12.

TSUNAMI-3D calculations were again checked against manual direct perturbation figures to ensure that the sensitivity data output was valid. This data can be seen in Table 8.

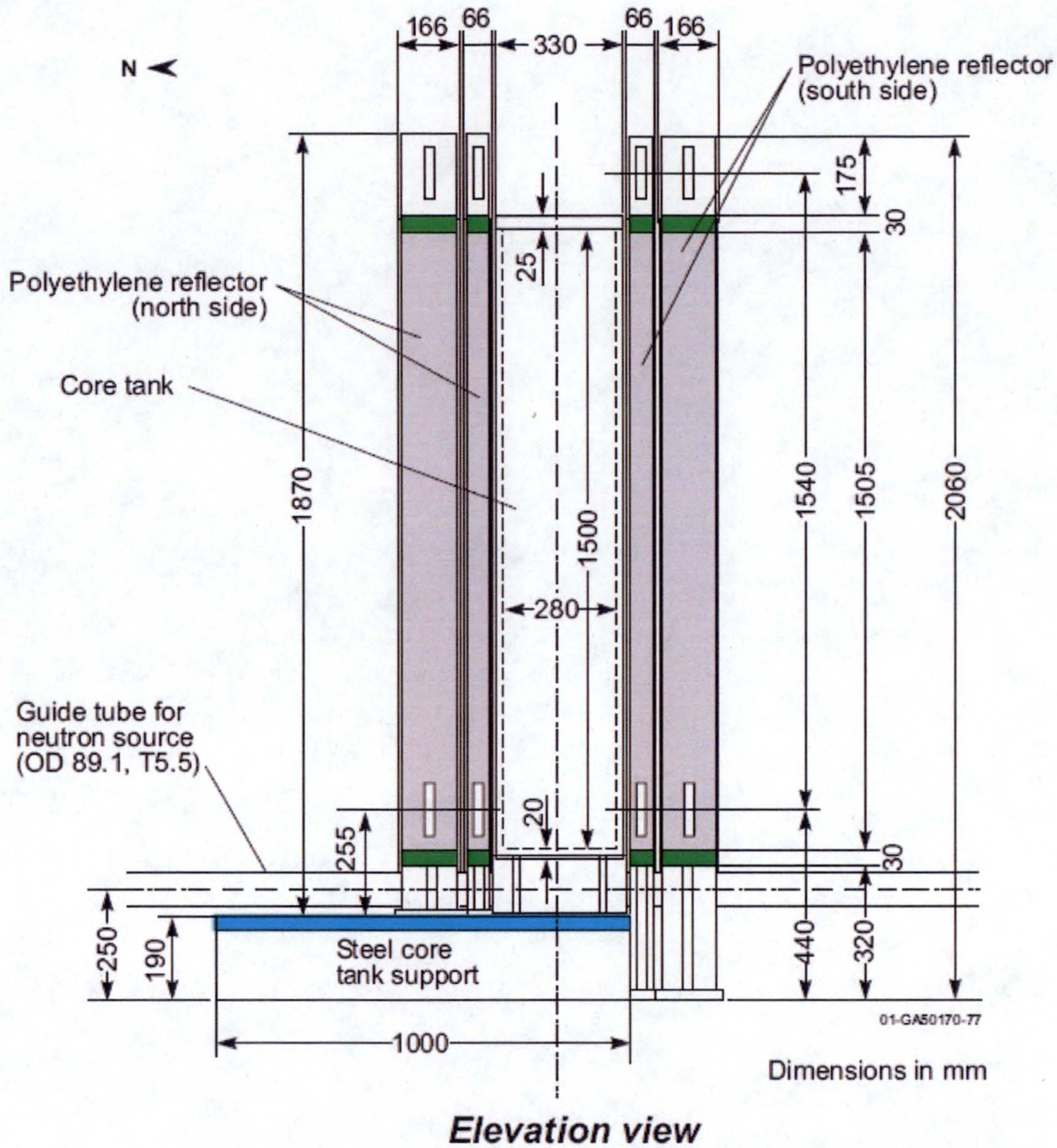

Figure 12: Configuration of LEU-SOL-THERM-019[12]

Table 8. Sensitivity Calculations for LEU-SOL-THERM-019

	TSUNAMI-3D Calculations				Direct Perturbation Test			
Case	S - U-235	Uncertainty	S - H-1	Uncertainty	S - U-235	Uncertainty	S - 1-H	Uncertainty
1	0.36026	0.00117	0.071962	0.039702	0.343871	0.0194	0.154384	0.0189
2	0.36118	0.001183	0.070028	0.040233	0.371802	0.0219	0.112255	0.0177
3	0.35958	0.001167	0.07135	0.039501	0.337424	0.0163	0.066689	0.122
4	0.36240	0.0019072	0.068117	0.064742	0.346355	0.0179	0.082402	0.02
5	0.35795	0.0016439	0.073085	0.055660	0.338139	0.0179	0.097703	0.0169
6	0.36025	0.001674	0.073492	0.056525	0.367791	0.0201	0.097635	0.0201

Upon comparison, the calculated sensitivities for the two most sensitive nuclides in the system are within the range of uncertainty of both parameters. Therefore, the TSUNAMI-3D calculation for this experiment set is valid.

LEU-SOL-THERM-020 (4 Cases)

The LEU-SOL-THERM-020 experiment set is represented by four separate critical configurations using STACY at the NUCEF facility at JAERI in Tokai, Japan in 1999. Instead of slab geometry, this experiment utilizes an 80 cm diameter cylindrical core of 10% ^{235}U enriched uranyl nitrate solution. This experiment uses light water as the primary reflector around the cylindrical solution tank, and criticality was achieved by varying the height of the UN solution within the cylindrical tank. A diagram showing the dimensions of the experiment can be seen in Figure 13.

TSUNAMI-3D calculations of the sensitivity of each nuclide to k_{eff} of the system was then compared to manual direct perturbations of the experiments and compared. The results of this comparison can be seen in Table 9.

Table 9. Sensitivity Data for LEU-SOL-THERM-020.

Case	S – U-235	Uncertainty	S - O-16	Uncertainty	S - U-235	Uncertainty	S - O-16	Uncertainty
1	0.39665	0.001882	0.04634	0.003532	0.420616	0.0301	0.056716	0.0178
2	0.41009	0.001791	0.055816	0.004854	0.42243	0.0162	0.053679	0.0149
3	0.42962	0.001599	0.041544	0.004658	0.390436	0.0154	0.035114	0.0165
4	0.4389	0.001559	0.036127	0.004737	0.433656	0.0151	0.036847	0.0171

As the calculated sensitivities for both nuclides using the direct perturbation test are within the range of uncertainty of the TSUNAMI-3D calculations, the sensitivity data generated by TSUNAMI-3D is valid.

LEU-SOL-THERM-021 (4 Cases)

The LEU-SOL-THERM-021 experiment set consists of 4 separate critical benchmark experiments. Using the same type of 80 cm diameter cylindrical tank as was seen in the previous set of benchmark experiments, these experiments measure the critical height of 10% ^{235}U enriched UN solution within the tank with no outer neutron reflector used on the STACY apparatus. The dimensions of the experiments can be seen in Figure 14.

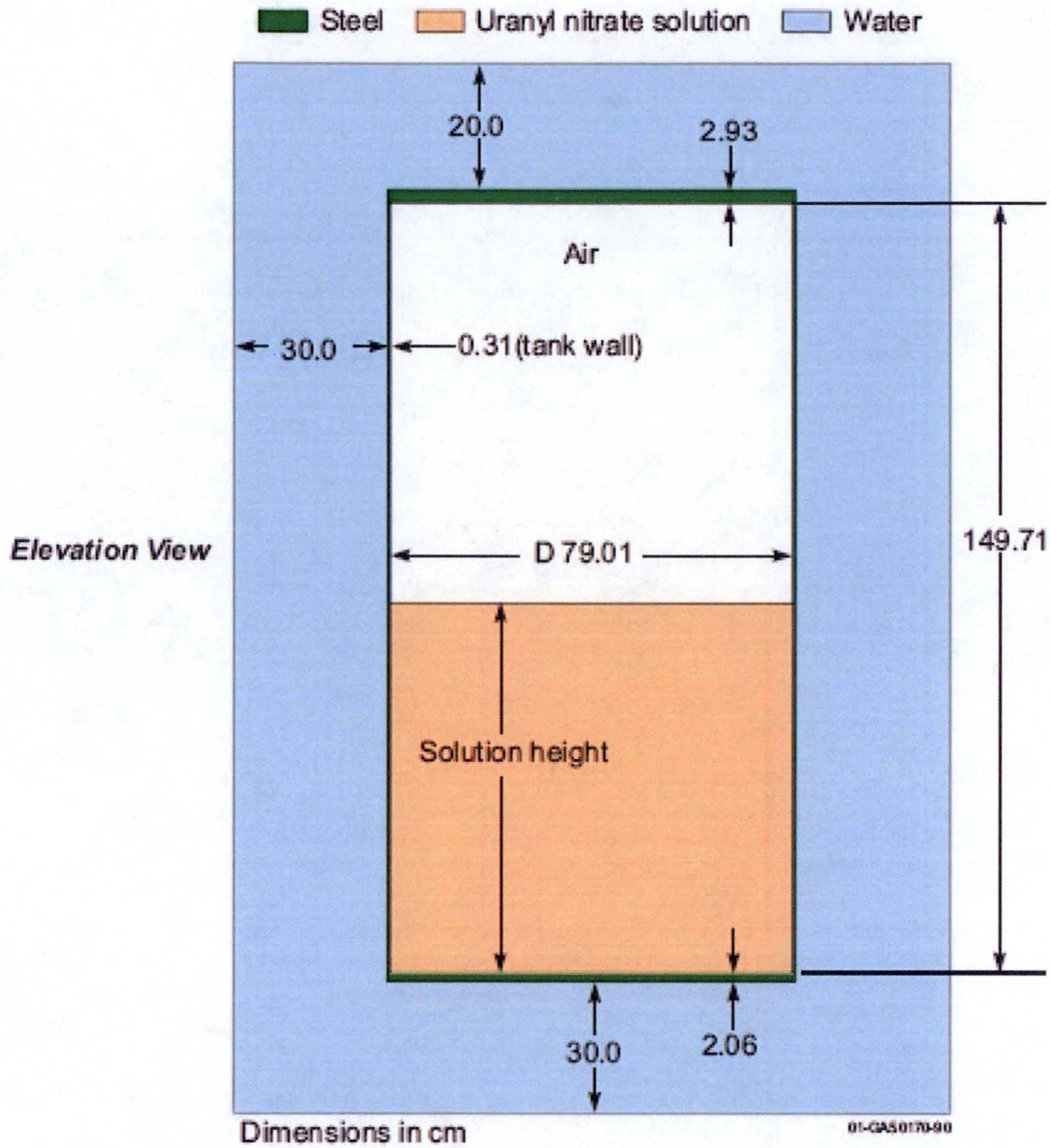

Figure 13: Configuration of LEU-SOL-THERM-020 experiments.[11]

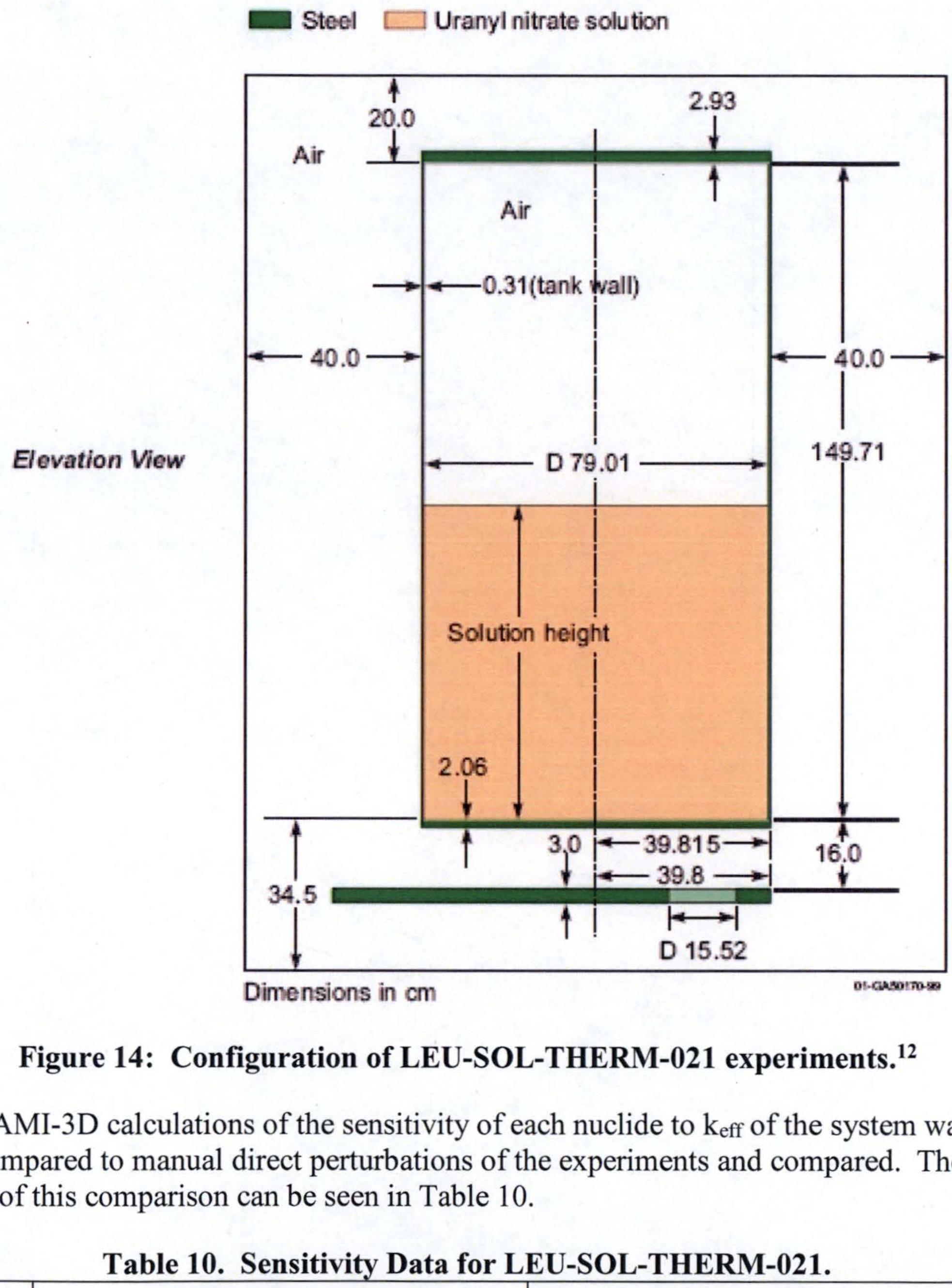

Figure 14: Configuration of LEU-SOL-THERM-021 experiments.[12]

TSUNAMI-3D calculations of the sensitivity of each nuclide to k_{eff} of the system was then compared to manual direct perturbations of the experiments and compared. The results of this comparison can be seen in Table 10.

Table 10. Sensitivity Data for LEU-SOL-THERM-021.

	TSUNAMI-3D Calculations				Direct Perturbation Test			
Case	S - U-235	Uncertainty	S - H-1	Uncertainty	S - U-235	Uncertainty	S - H-1	Uncertainty
1	0.36991	0.001213	0.059172	0.042478	0.379734	0.0295	0.082759	0.0114
2	0.36627	0.001141	0.060803	0.039717	0.364751	0.0114	0.058025	0.0216
3	0.36682	0.001226	0.061429	0.04281	0.430535	0.0149	0.078231	0.012
4	0.36529	0.001218	0.040966	0.005341	0.395122	0.033	0.03341	0.00984

Based on data returned from TSUNAMI-3D and direct perturbation tests, the sensitivity data generated are within the uncertainty ranges of each other. Thus, the sensitivity data generated by TSUNAMI-3D is valid.

LEU-SOL-THERM-022 (4 Cases)

The final experiment set analyzed in this project is LEU-SOL-THERM-022. These four benchmark experiments were performed in Tokai, Japan at JAERI at the NUCEF facility using STACY. Again, utilizing the rectangular slab with dimensions of 28 cm x 69 cm, a 10% ^{235}U enriched UN solution was used. The fueled portion was reflected with borated concrete on the two flat sides of the slab (north and south sides). The borated concrete used to reflect the UN solution was composed of four separate boron content levels, one for each experiment. The height of the slab was adjusted to find the critical height of the solution for each type of borated concrete used. This configuration can be seen in Figure 15.

Sensitivity to k_{eff} for the two most sensitive nuclides was then calculated using TSUNAMI-3D as well as the direct perturbation test. The data calculated can be seen in Table 11.

Table 11. Sensitivity Data for LEU-SOL-THERM-022.

	TSUNAMI-3D Calculations				Direct Perturbation Test			
Case	S - U-235	Uncertainty	S - H-1	Uncertainty	S - U-235	Uncertainty	S - H-1	Uncertainty
1	0.36469	0.00179	0.059172	0.042478	0.361472	0.0197	0.082759	0.0114
2	0.36627	0.001141	0.060803	0.039717	0.364751	0.0114	0.058025	0.0216
3	0.36682	0.001226	0.061429	0.04281	0.350129	0.0118	0.078231	0.012
4	0.36204	0.001877	0.064692	0.042321	0.36761	0.0235	0.085892	0.0122

Data from the previous table shows that both nuclides are within sensitivity uncertainty limits calculated by TSUNAMI-3D and the direct perturbation testing of each experiment. Since these uncertainties are within limits, the output data from TSUNAMI-3D is adequate.

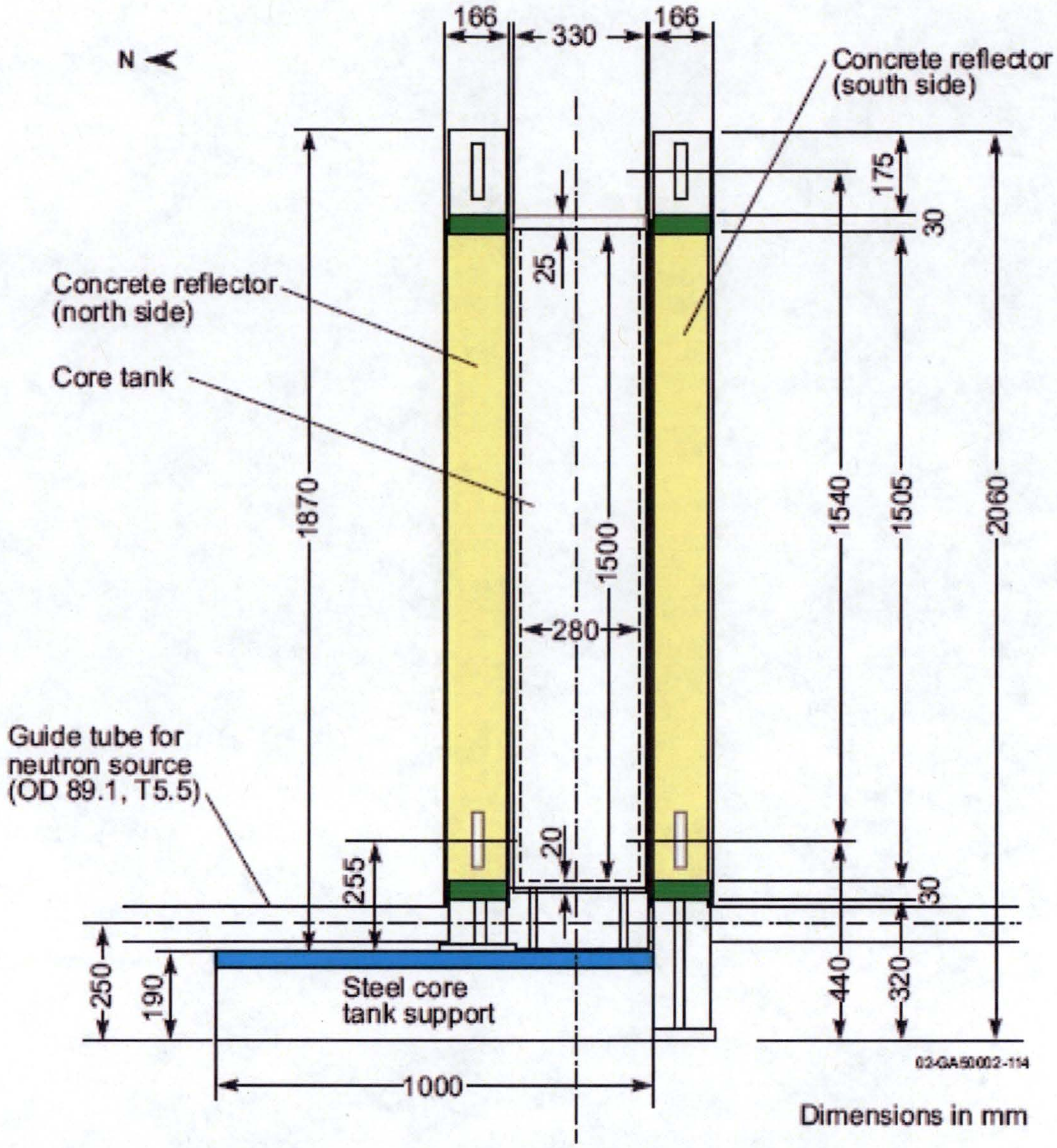

Figure 15: Configuration for LEU-SOL-THERM-022 Benchmark Experiments.[11]

Addition of the SDF files to the database

The 418 available SDF files (378 provided and 40 generated) were added to the compilation of critical experiments in Table 2, with the subsequent addition of the remaining columns of the table:

(7) The number of cases (in each evaluation) for which SDF files are available to the project;

(8) The number of SDF files available to the project that fit both the enrichment and the EALF criteria of the DICE search; and

(9) The approximate number of "new" KENO decks that fit the criteria and might be available after translation to SCALE5.1 and TSUNAMI-3D. (This is simply the minimum of columns 5 and 6 reduced by column 7.)

The bottom row of the Table 2 gives a summary of the data gathered:

- 1289 total LEU cases.
- 643 LEU cases that fit the enrichment criterion.
- 1097 LEU cases that fit the EALF criterion.
- 567 LEU cases that fit both criteria.
- 897 LEU cases that have KENO decks available.
- 293 LEU cases that have SDF files used in the project.
- 225 addition cases with KENO decks that fit the criteria and are not already used in the project. (39.7% of the LEU cases).
- 211 LEU cases that fit the criteria and are available to us (37.2% of the LEU cases).

The last two categories suggest that this project only considered about half the number of SDF cases that could be made available to a validation project for fuel processing configurations similar to those considered in this project.

IV. RESULTS

IV.A Normal (non-accident) Base Case Results

The basic k_{eff}, computer timing, and spectrum results for the 24 variations of the normal (non-accident) base cases is shown in Table 13, for both the KENO forward and adjoint calculations. Particularly striking is how low the k_{eff} values for the normal base cases are, ranging from 0.2468 to 0.6655. Examination of the EALF values indicates that all of the

cases are above the nominal thermal level (0.0253 eV) by a large margin, with the average energy of fission ranging from a low of 0.46 eV for the 5% enriched graphite-encased TRISO boxed fuel pins (Case 4B) to a high of 0.798 MeV for the 5% enriched UO_2 dry cask (Case 5A). Another striking figure is the last column, which indicates that the adjoint calculations are far less efficient than the forward calculations, with their Figure of Merits (FOM, a relative measure of computational efficiency of a Monte Carlo calculation) higher than the forward calculations by a factor of 26 to 183.

Table 13. Results of the normal base cases

	Forward calculations					Adjoint calculations				
Case	CPU Time (sec)	k-eff	Sigma	EALF	FOM	CPU Time (sec)	k-eff	Sigma	FOM	FOM Ratio
1A	291	0.3262	0.0013	232.49	2035	725	0.3245	0.0063	3469	59
1B	293	0.3523	0.0012	255.91	2369	685	0.3545	0.0067	32	73
1C	286	0.3886	0.0012	337.66	2430	574	0.3896	0.0077	29	83
1D	284	0.4223	0.0017	461.92	1217	527	0.4255	0.0086	25	48
2A	152	0.5481	0.0019	182.55	1822	1594	0.5480	0.0056	20	91
2B	149	0.5781	0.0021	211.83	1523	1378	0.5759	0.0056	23	66
2C	140	0.6258	0.0015	304.95	3166	1212	0.6191	0.0069	17	183
2D	138	0.6655	0.0019	415.59	2013	1117	0.6691	0.0074	16	123
3A	214	0.5008	0.0024	11.59	810	1160	0.5084	0.0082	12	63
3B	212	0.5209	0.0021	12.55	1067	1036	0.5276	0.0089	12	88
3C	211	0.5517	0.0021	17.40	1075	1615	0.5453	0.0074	11	95
3D	208	0.5788	0.0022	21.18	992	1411	0.5836	0.0078	11	85
4A	281	0.3001	0.0015	0.46	1580	4032	0.2974	0.0036	19	83
4B	264	0.3239	0.0015	0.46	1686	3156	0.3247	0.0045	15	108
4C	212	0.3555	0.0020	0.51	1178	2310	0.3525	0.0045	21	55
4D	209	0.3822	0.0016	0.57	1866	2035	0.3836	0.0059	14	132
5A	399	0.3074	0.0020	798449	627	1095	0.3009	0.0061	24	26
5B	399	0.3306	0.0013	722190	1483	992	0.3316	0.0066	23	64
5C	396	0.3723	0.0020	629705	630	765	0.3665	0.0094	14	43
5D	394	0.4166	0.0012	578034	1761	1435	0.4113	0.0071	13	127
6A	191	0.2468	0.0016	2.51	2050	4291	0.2411	0.0022	48	43
6B	185	0.2587	0.0015	3.17	2400	3826	0.2564	0.0027	36	67
6C	182	0.2915	0.0017	4.76	1902	3188	0.2935	0.0037	23	83
6D	180	0.3138	0.0016	6.89	2174	2728	0.3189	0.0047	17	131

Figures 16 through 21 show graphs of the c_k values for the highest c_k experiments for each of the six normal base cases, with the experiments arranged (x-axis) in order of decreasing c_k. (The order of the experiments differs for each of the base cases.)

The principal (and striking) result from these figures is that none of the base cases meets the criteria previous stated for acceptability of experiments for validation (i.e., 15

experiments of $c_k > 0.90$ or 25 experiments of $c_k > 0.80$). (Although the graphite-moderated cases 4 and 6 come close.)

This is actually of very little consequence because the low k_{eff} values for these cases clearly indicates that none of these cases are likely to be the limiting cases for the criticality safety analysis, unless no contingencies are identified. Even in this latter case, it would be fairly easy to argue for an upper subcritical limit that could be met, even with the lack of similar experiments. (The bottom line is that the physical characteristics of these cases are such that no critical experiments with similar characteristics could likely even be constructed.)

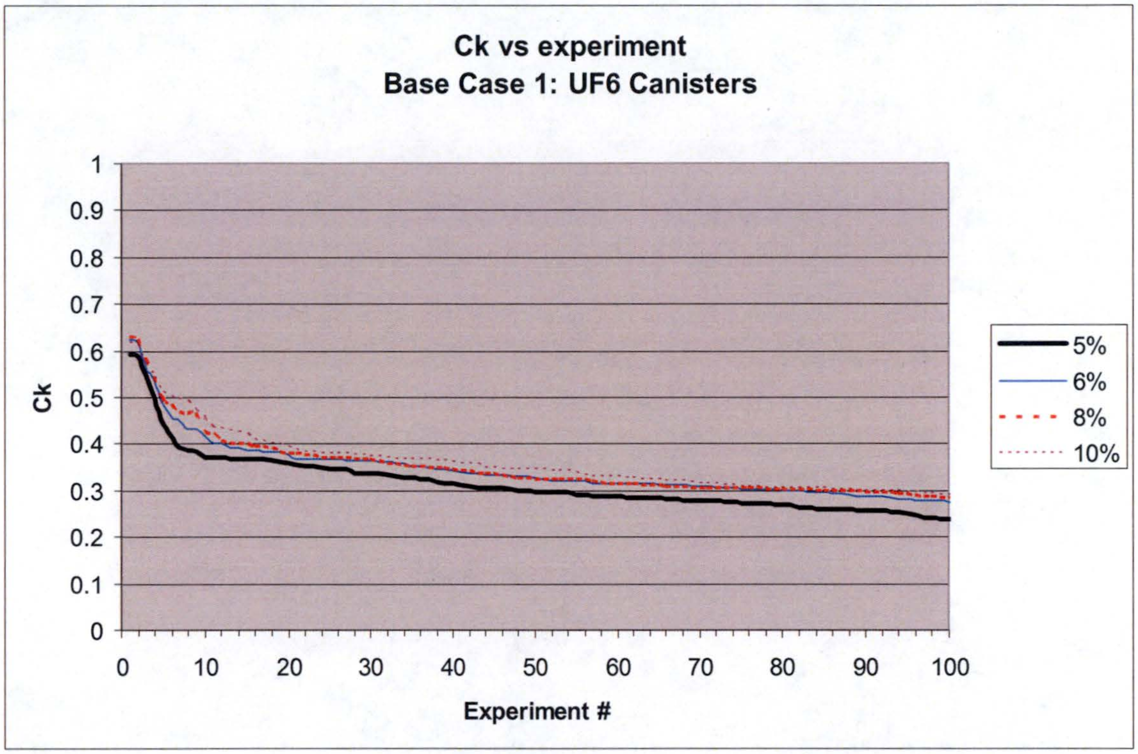

Figure 16. Comparison of experimental c_k values for normal Base Case 1 (Stored UF_6 cylinders)

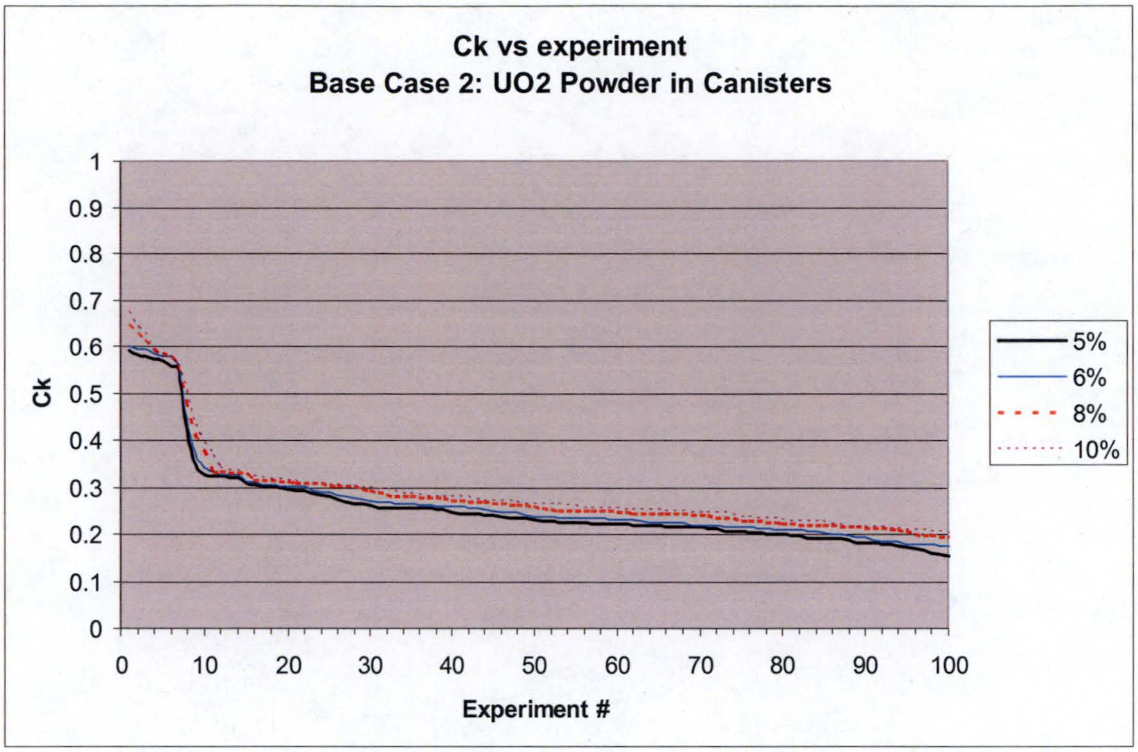

Figure 17. Comparison of experimental c_k values for normal Base Case 2 (UO_2 powder in storage rack arrays)

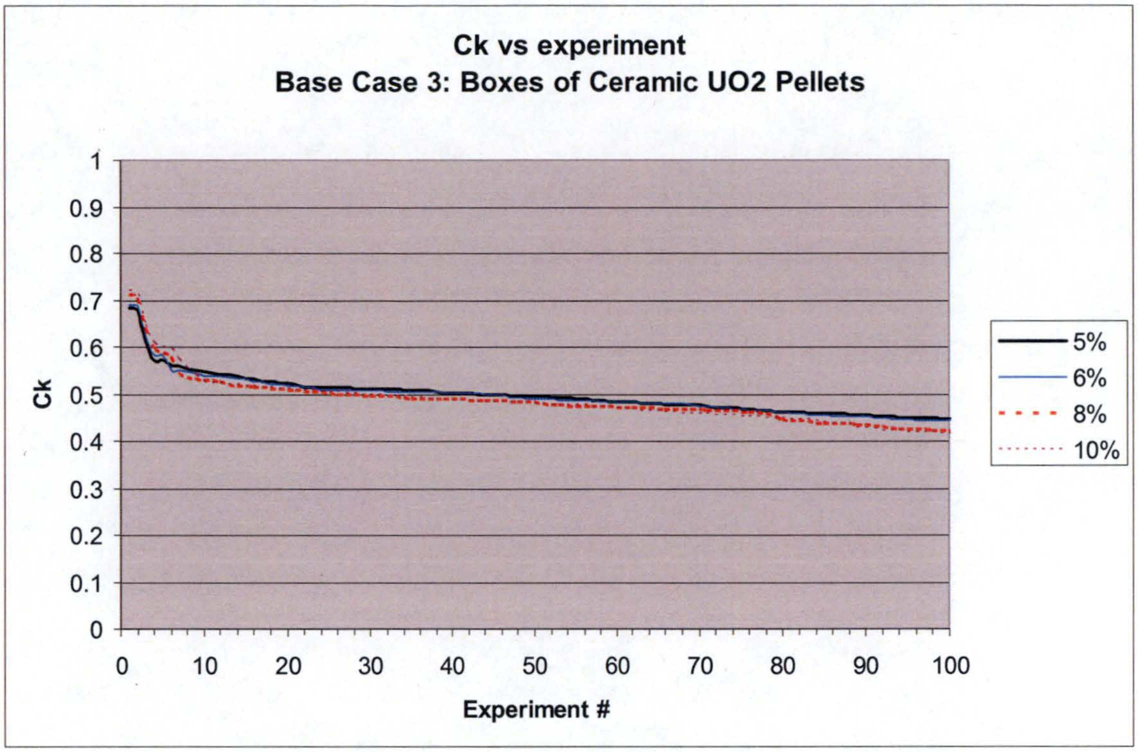

Figure 18. Comparison of experimental c_k values for normal Base Case 3 (Pressed ceramic UO_2 fuel pellets in boxes)

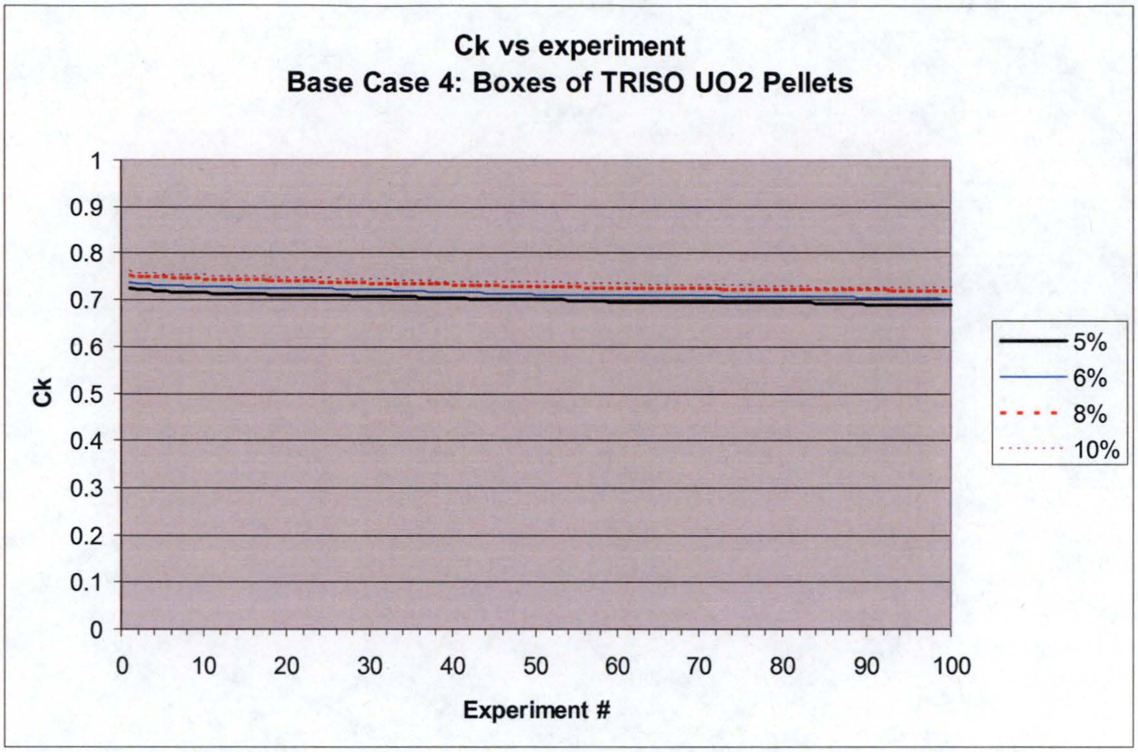

Figure19. Comparison of experimental c_k values for normal Base Case 4 (TRISO pellets in boxes c_k results)

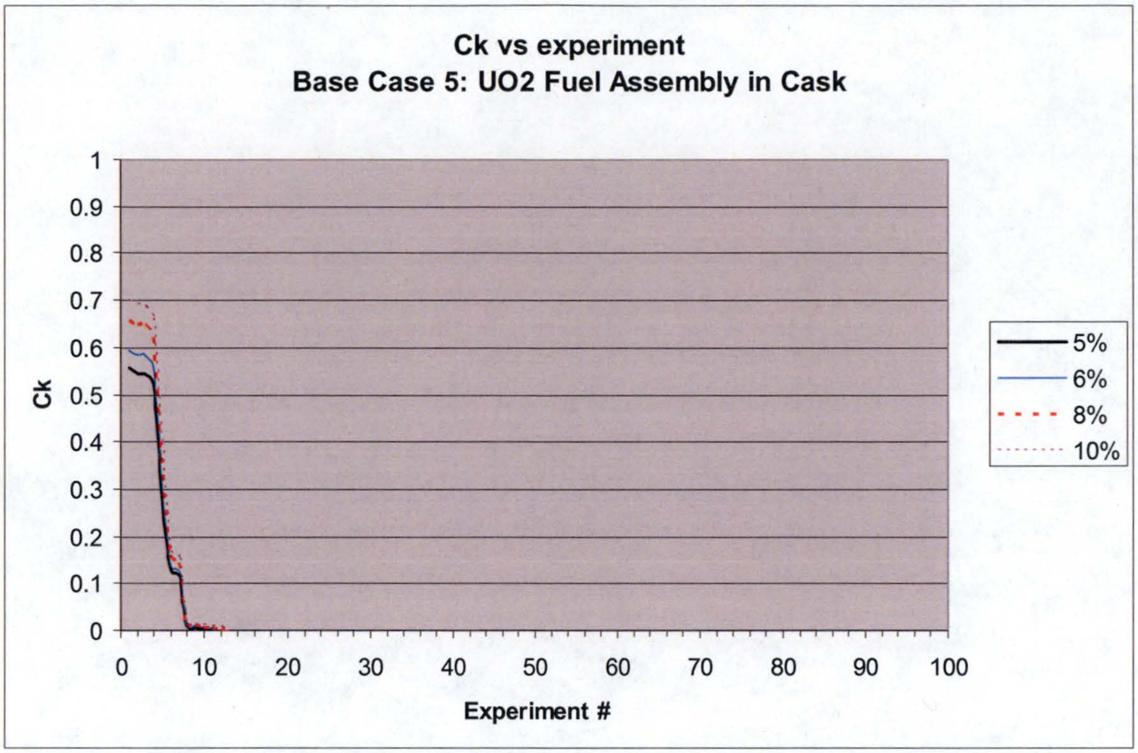

Figure 20. Comparison of experimental c_k values for normal Base Case 5 (UO_2, zircaloy clad fuel pin array in shipping cask)

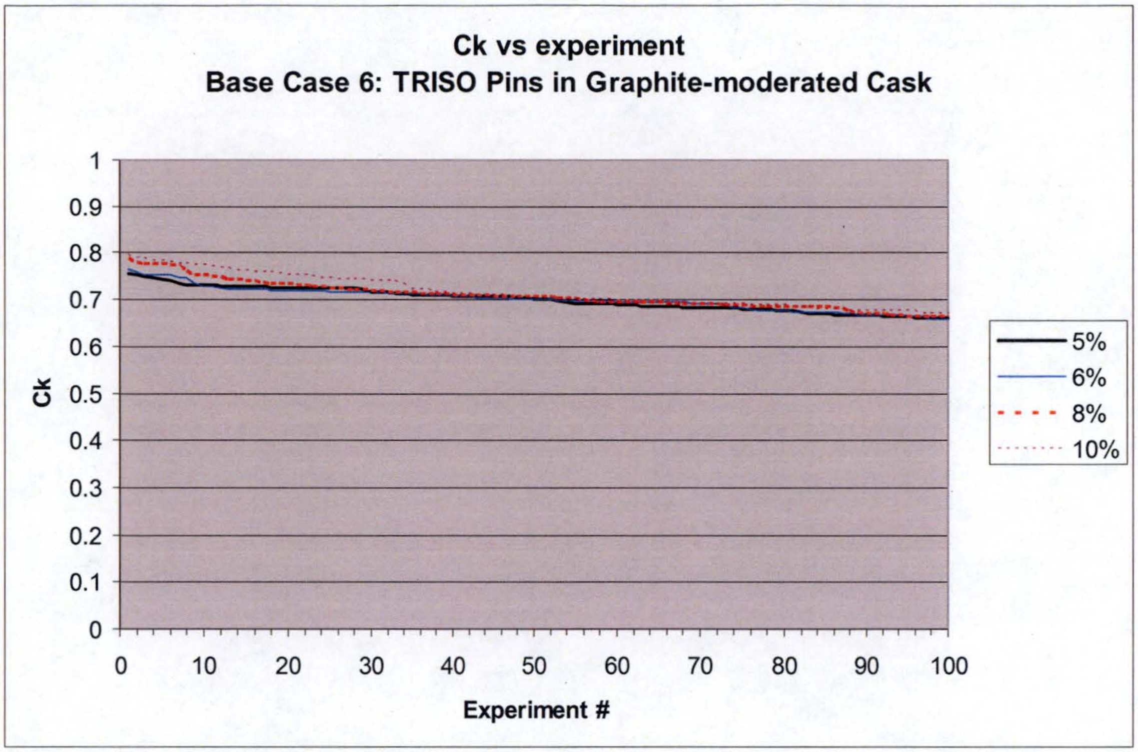

Figure 21. Comparison of experimental c_k values for normal Base Case 6 (Graphite-moderated TRISO fuel pins in hexagonal lattice c_k results)

IV.B. Contingency Case Results

Analysis of adequacy of experimental coverage of the base cases

The basic k_{eff}, computer timing, and spectrum results for the 24 variations of the contingency (accident) base cases is shown in Table 14, for both the KENO forward and adjoint calculations. As expected, the k_{eff} values have risen, ranging from 0.8555-0.9410 (which is not surprising, of course, since they were designed to be in this range). Also, as expected, the spectra have softened quite a bit with moderation, with EALF values now ranging from 0.09 eV for the TRISO pin case to 4.99 eV for the UF_6 cylinder cases (all within the DICE search criteria utilized in Section III.D). Again, the Figure of Merits (FOM) for the adjoint calculations are quite a bit larger than for the forward, with a ratio ranging from 44 to 1715 (an even higher relative inefficiency than for the normal cases).

Table 14. Results of the contingency base cases

Case	CPU Time (sec)	k-eff	Sigma	EALF	FOM	CPU Time (sec)	k-eff	Sigma	FOM	FOM Ratio
1A	44	0.8928	0.0016	4.76	8848	1065	0.8889	0.0038	65	136
1B	44	0.9321	0.0025	6.28	3663	967	0.9291	0.0040	64	57
1C	44	0.9240	0.0023	4.10	4257	1495	0.9251	0.0053	23	179
1D	45	0.9367	0.0021	4.99	5039	1689	0.9405	0.0046	28	180
2A	164	0.8852	0.0026	1.27	900	6176	0.8848	0.0028	21	44
2B	163	0.9124	0.0027	1.62	841	6882	0.9188	0.0036	118	75
2C	163	0.9546	0.0023	2.48	1159	4615	0.9595	0.0034	18	62
2D	161	0.9881	0.0025	3.61	995	4031	0.9861	0.0042	14	71
3A	144	0.9435	0.0024	1.32	1209	3246	0.9441	0.0049	13	94
3B	140	0.9287	0.0024	1.62	1239	2928	0.9285	0.0052	13	98
3C	151	0.9318	0.0024	2.32	1153	2955	0.9369	0.0054	12	99
3D	154	0.9263	0.0021	3.25	1472	3079	0.9325	0.0051	12	118
4A	387	0.8555	0.0019	0.09	715	42043	0.8469	0.0050	0.95	752
4B	376	0.9059	0.0019	0.09	737	37347	0.8965	0.0055	0.89	832
4C	393	0.9410	0.0023	0.11	481	47603	0.9355	0.0048	0.91	527
4D	340	0.9401	0.0017	0.13	1018	79565	0.9335	0.0046	0.59	1715
5A	567	0.8952	0.0023	1.58	333	17432	0.8806	0.0070	1.17	285
5B	542	0.8741	0.0023	2.26	348	31884	0.8743	0.0048	1.36	256
5C	411	0.9061	0.0023	3.39	460	25403	0.8986	0.0053	1.40	328
5D	403	0.9328	0.0023	4.88	469	18396	0.9295	0.0067	1.21	387
6A	399	0.8309	0.0020	0.12	626	33407	0.8219	0.0057	0.92	680
6B	372	0.8744	0.0021	0.14	609	47508	0.8654	0.0050	0.84	723
6C	348	0.9144	0.0020	0.18	719	37350	0.9030	0.0054	0.92	783
6D	329	0.9148	0.0019	0.23	841	44550	0.9119	0.0047	1.02	828

Table 15 lists the number of experiments meeting the two c_k criteria—the first number being the number of experiments exceeding c_k =0.90 and the second number the number of experiments exceeding c_k =0.80; the shaded cells indicate that neither the criteria of 15 and 25 cases, respectively, are met.

Table 15. Number of cases meeting the comparison criteria(for $c_k \geq 0.90$ and $c_k \geq 0.80$, respectively)

Enrich	Base Case #1	Base Case #2	Base Case #3	Base Case #4	Base Case #5	Base Case #6	Powder case
5%	2/6	26/136	54/410	5/70	39/211	39/211	9/67
6%	2/7	21/94	29/157	9/66	12/211	12/211	9/30
8%	2/7	13/52	28/151	8/31	8/194	8/194	7/14
10%	2/7	12/42	21/92	8/26	2/176	2/176	2/13

Figures 22 through 27 show the c_k values for the most applicable experiments for each of the six contingency base cases, with the experiments again arranged in order of decreasing c_k. (The order of the experiments differs for each of the base cases.) The actual experiments that these values refer to are listed in Appendix B (with the experiment number related to experiments in Appendix A.5.)

The principal result from these data is that each of the base cases now meets the criteria previous stated for acceptability of experiments for validation (i.e., 15 experiments of $c_k >$ 0.90 or 25 experiments of $c_k >$ 0.80), with the exception of Base Case 1, the UF_6 cylinders.

The most likely reason for this result is that the UF_6 cylinders were assumed to remain intact, so the result of flooding was to introduce water between the cylinders, but not within the cylinders (i.e., as an internal moderation). As a result, the spectrum for these four cases remains epithermal, with the EALF ranging from 4.1 eV to 6.8 eV (as shown in Table 13).

Although a strict application of the pre-established criteria would dictate the need for additional experiments for this case, this is not judged to be required for the following reasons:

1. Of the experiments used in this study, there are only 2 in the $c_k >$ 0.90 range and 6-7 in the $c_k >$0.80 range. This is below the criteria, but is based on available SDF files that include no UF_6 cases (of the 32 available on the ICSBEP database). So, it is likely that in a dedicated validation effort for this type of configuration, more applicable benchmarks could be identified than were available to this study.

2. The similarity of the graphs for the four different enrichments indicates that this situation is not particularly sensitive to enrichment. That is, UF_6 cylinders are currently being handled with enrichments approaching 5%, so the shortage of applicable benchmarks is currently being overcome with approved validations. It is therefore likely that existing validations for UF_6 cylinder handling could be extended to the higher enrichments with similar experimental coverage.

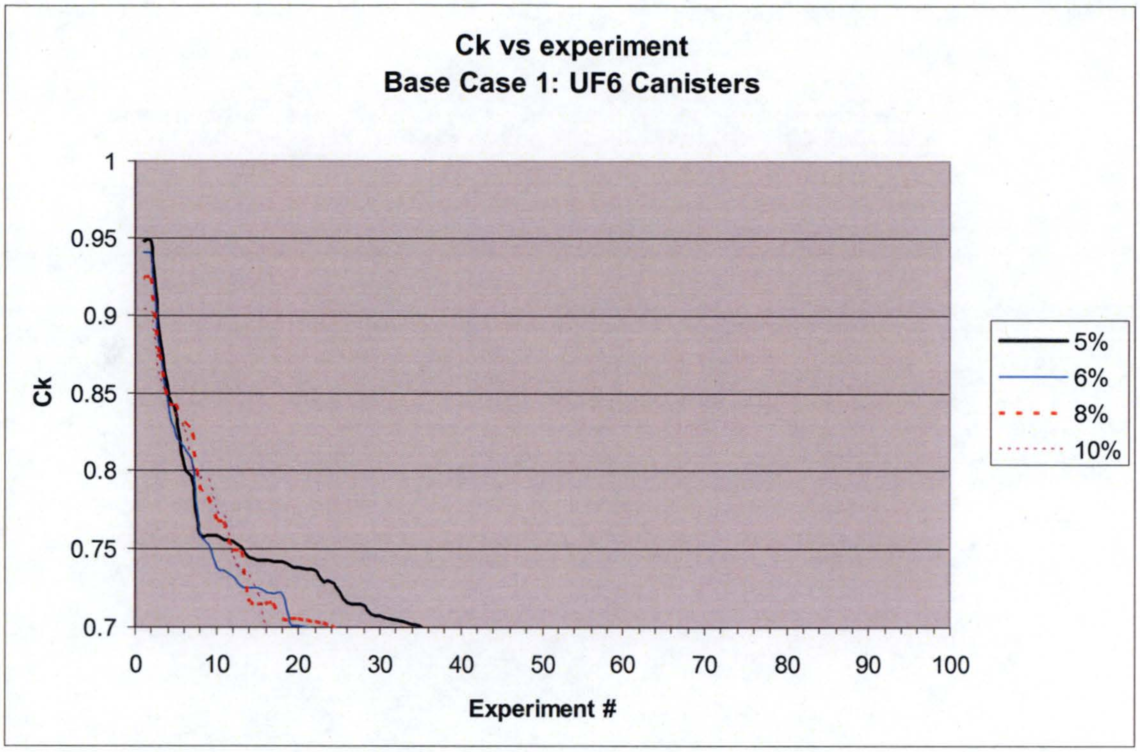

Figure 22. Comparison of experimental c_k values for contingency Base Case 1 (Stored UF_6 cylinders)

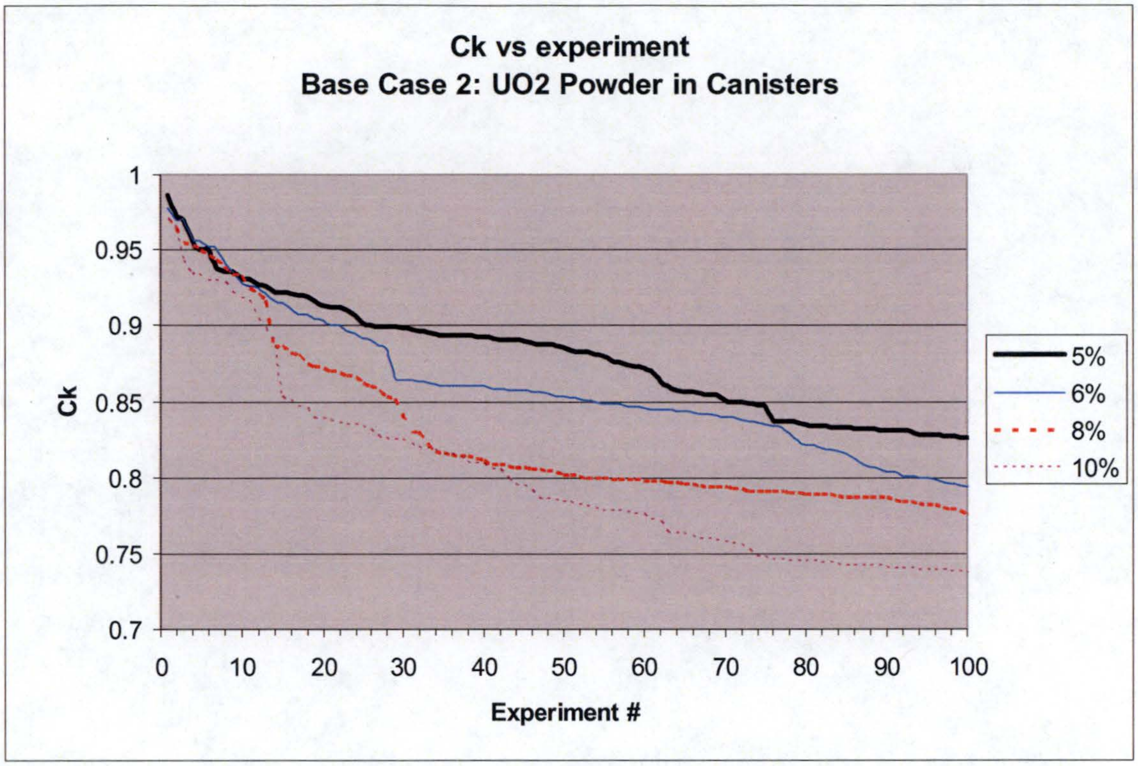

Figure 23. Comparison of experimental c_k values for contingency Base Case 2 (UO_2 powder in storage rack arrays)

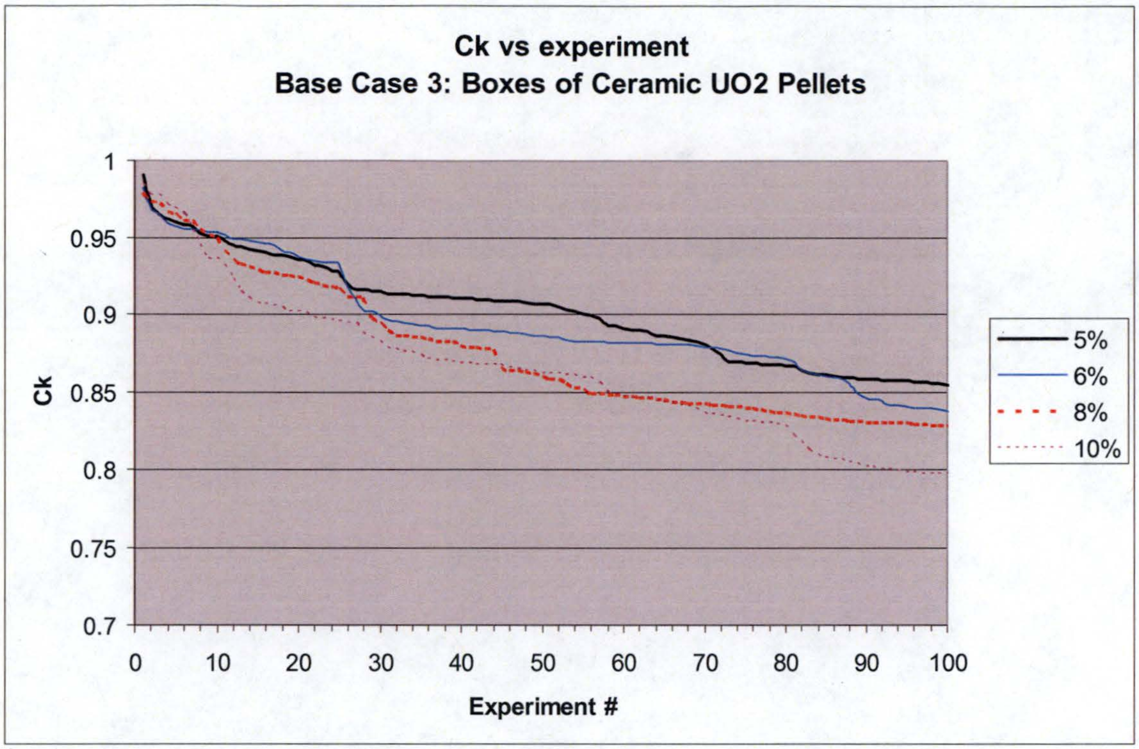

Figure 24. Comparison of experimental c_k values for contingency Base Case 3 (Pressed ceramic UO_2 fuel pellets in boxes)

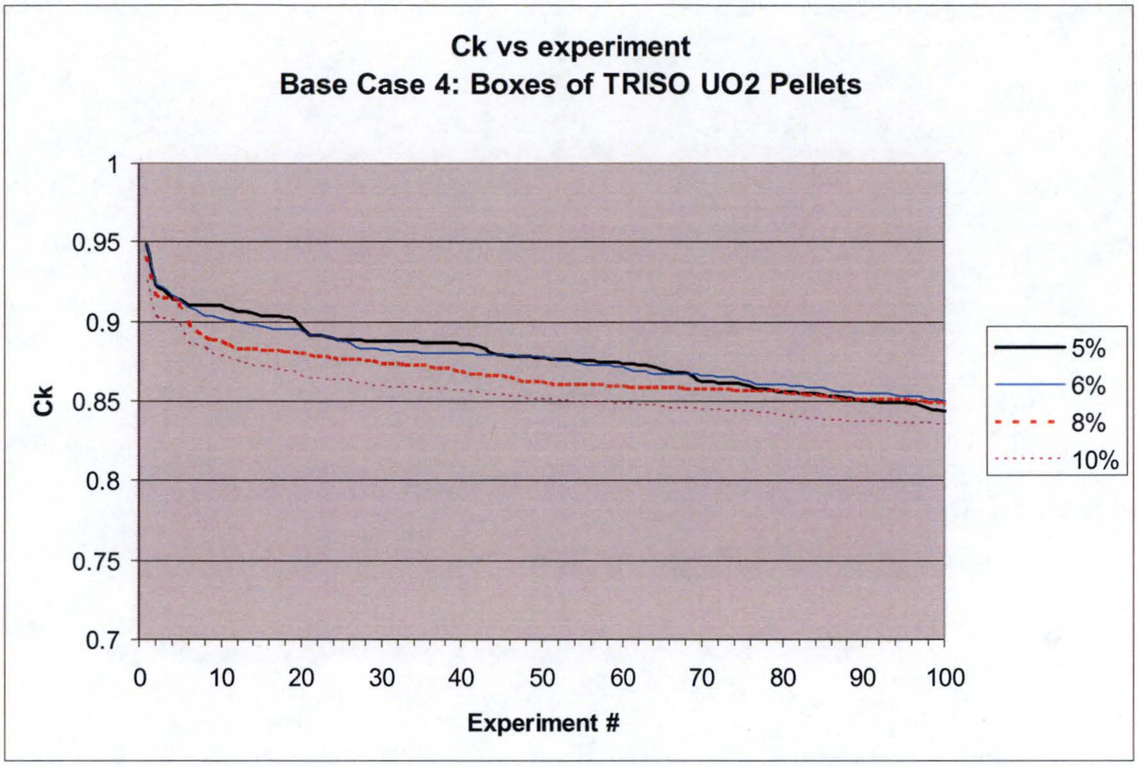

Figure 25. Comparison of experimental c_k values for contingency Base Case 4 (TRISO pellets in boxes c_k results)

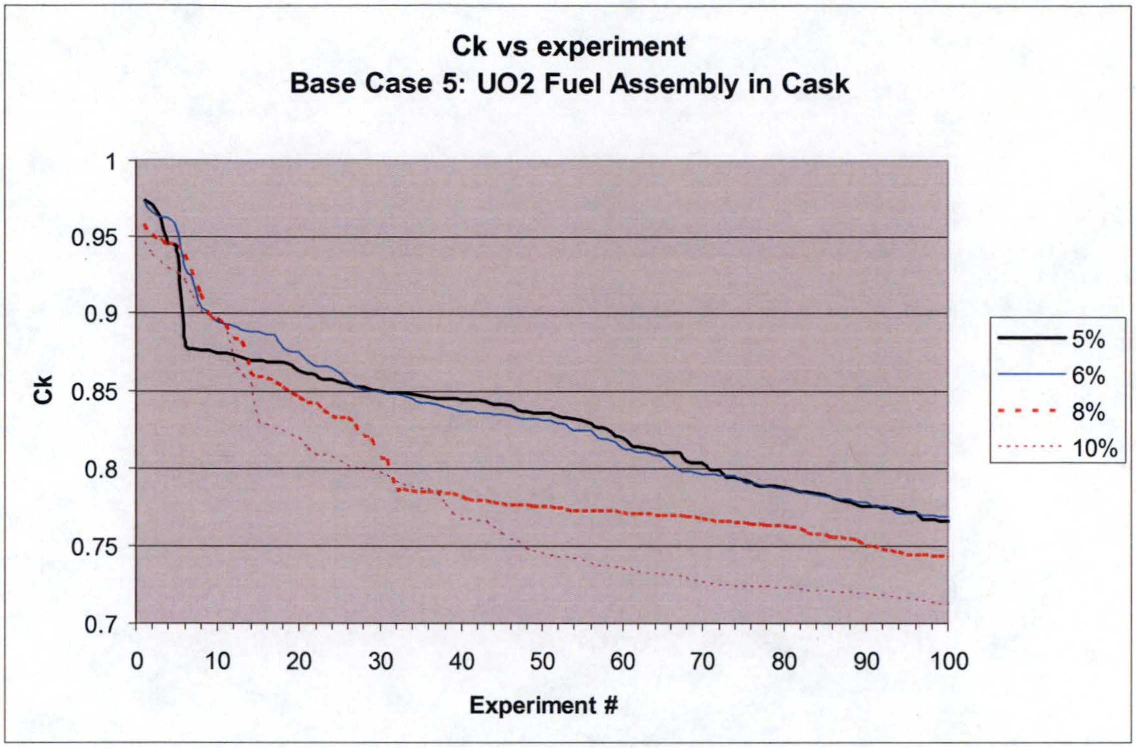

Figure 26. Comparison of experimental c_k values for contingency Base Case 5 (UO_2, zircaloy clad fuel pin array in shipping cask)

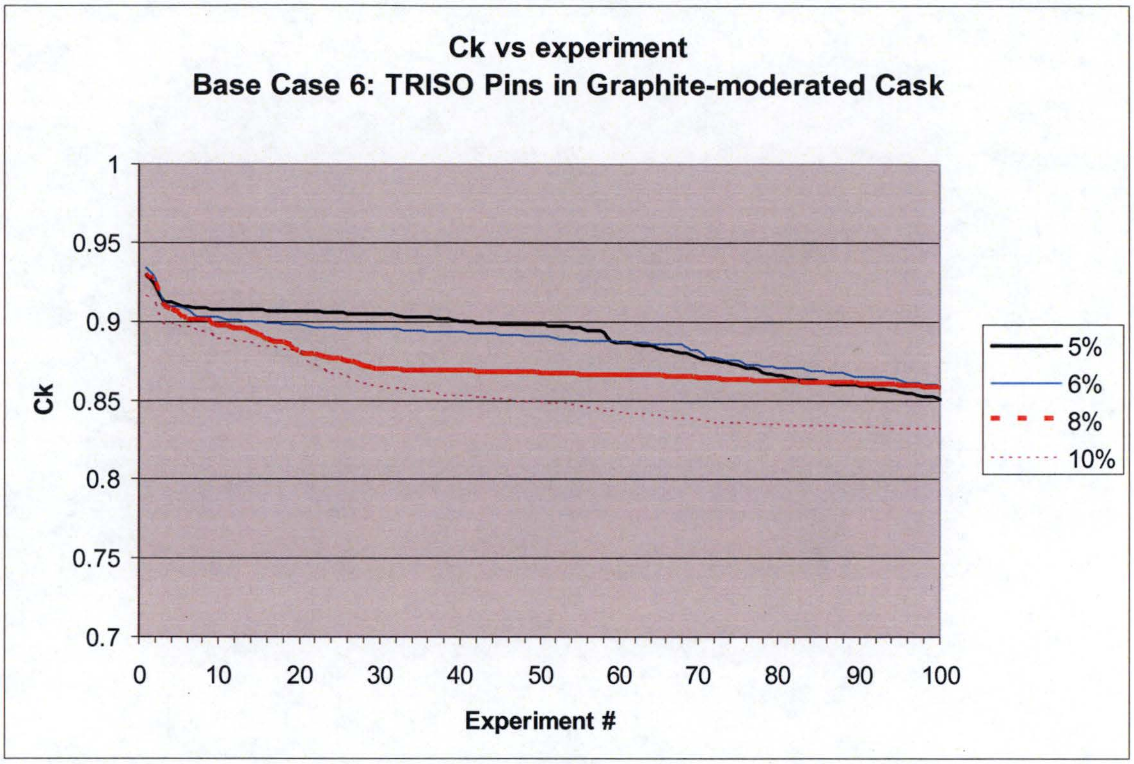

Figure 27. Comparison of experimental c_k values for contingency Base Case 6 (Graphite-moderated TRISO fuel pins in hexagonal lattice c_k results)

Analysis of enrichment dependence of applicable experiments

For Base Case 6, since so many of the experiments are similar, a deeper analysis was performed on the enrichment distribution of the experiments that are similar to the base case. In particular, as the enrichment of the base case varied from 5% to 10%, did the enrichments of the experiments with high c_k values similarly vary? That is, were the lower enrichment experiments more similar to the 5% case and the high enrichment cases more similar to the 10% case? Figures 28 through 31 show c_k values plotted against the enrichment of the experiment (rather than its number). As can been seen, although there is a preference of high enrichment experiments for the higher enriched base cases, each of the base cases has "similar" experiments from across the range of enrichments. (Note that the highest point represents the base case compared to itself, which results in a c_k of 1.00.)

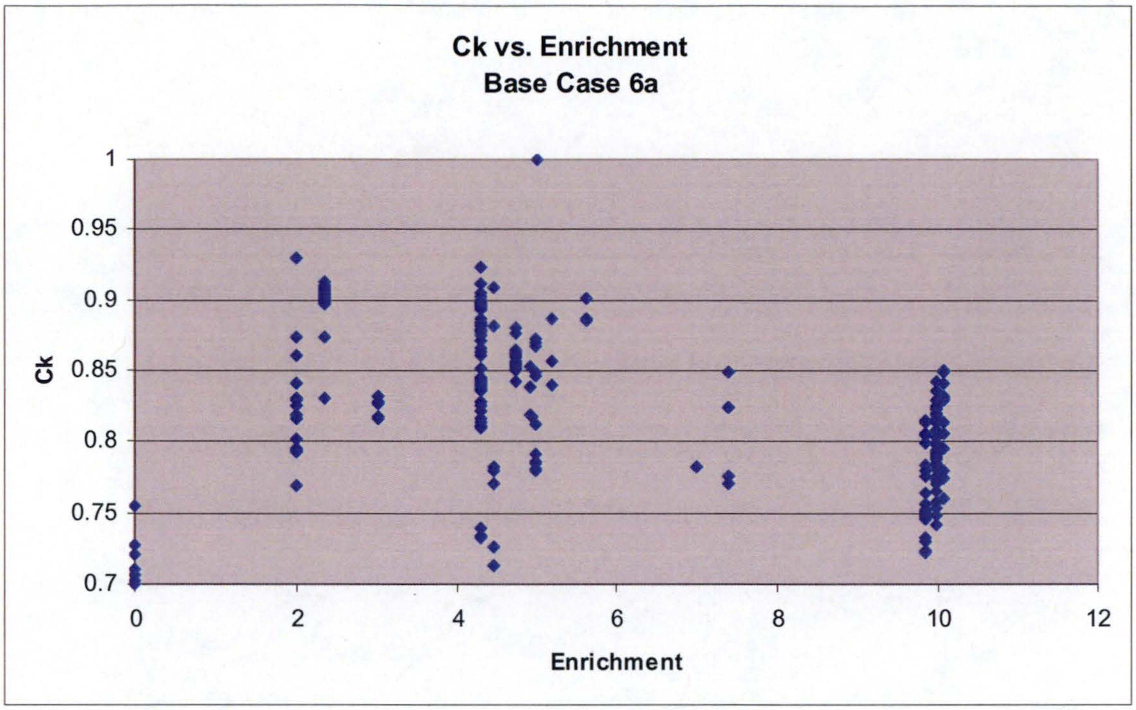

Figure 28. Distribution of c_k values by enrichment for 5% version of Base Case 6.

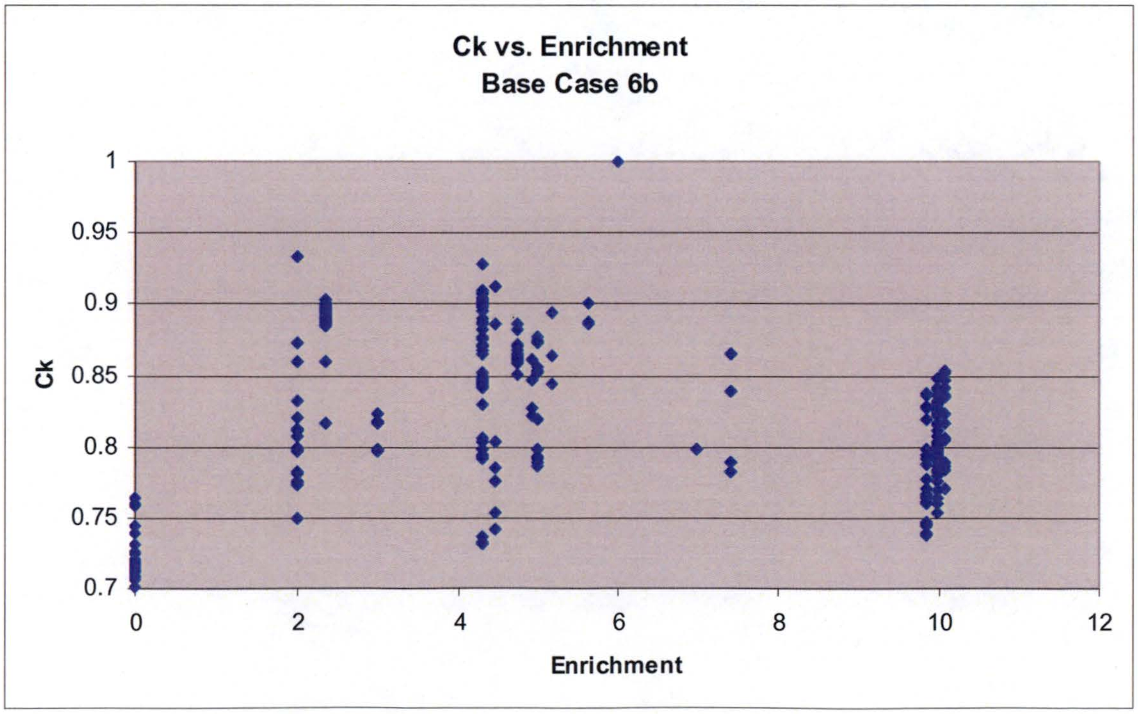

Figure 29. Distribution of c_k values by enrichment for 6% version of Base Case 6.

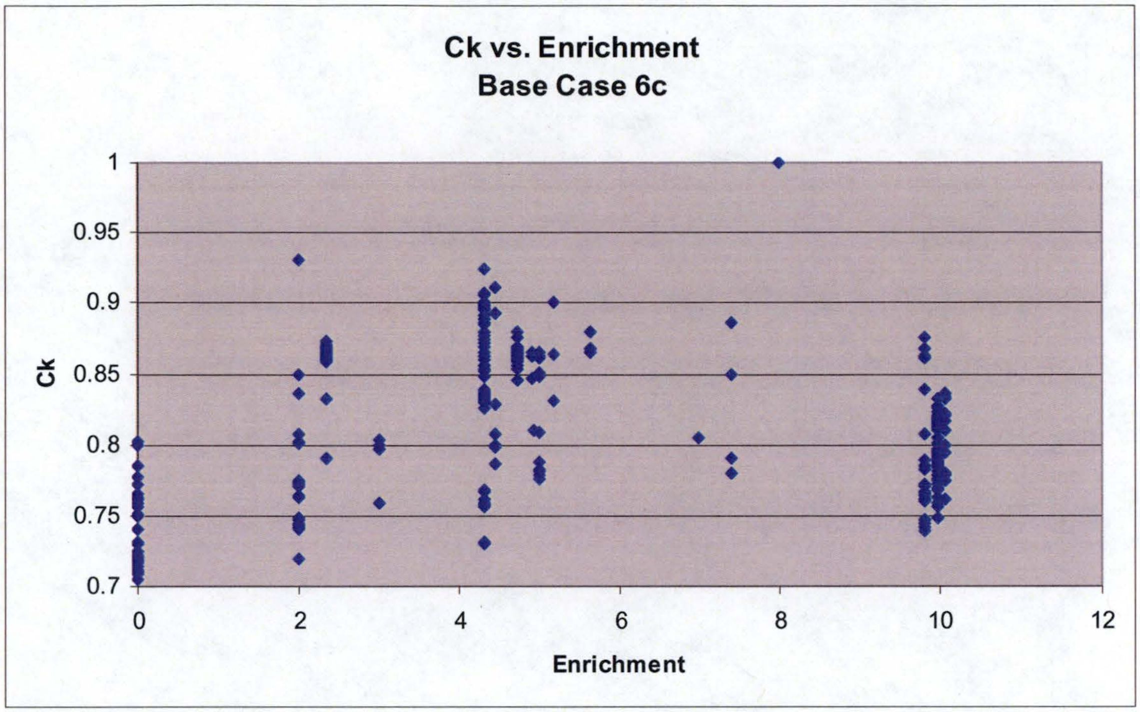

Figure 30. Distribution of c_k values by enrichment for 8% version of Base Case 6.

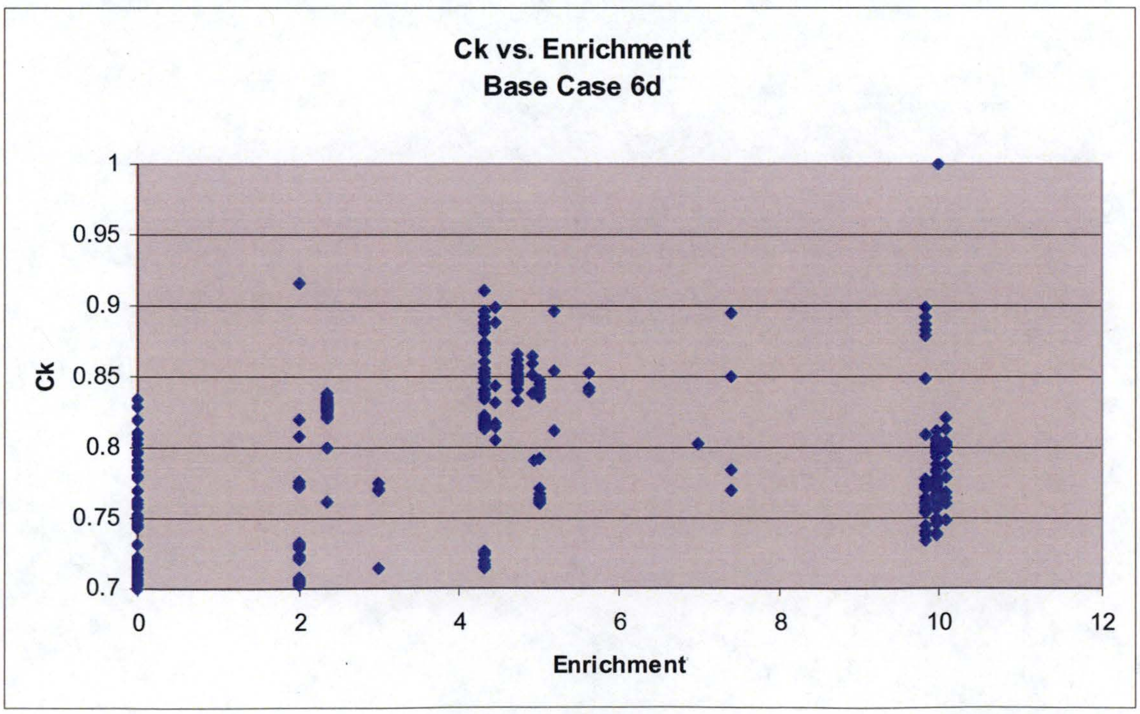

Figure 31. Distribution of c_k values by enrichment for 10% version of Base Case 6.

IV.C. Powdered Case Results

The results for the simplified bulk damp powder case are shown in Table 16 and Figure 32. (Note that an extra 3% enrichment case is included for comparison.) The most noticeable feature is that the sensitivity to enrichment is much more pronounced for these cases; this is most likely due to the large range of EALF between the cases. As shown in Table 15, the coverage according to the criteria for c_k is met for the cases up to 6% enrichment, but fails for the 8% and 10% cases (for which only 14 and 13 cases, respectively, have $c_k > 0.80$, less than the 25 minimum of the criteria.) If allowance is made for the fact that only 40% of the available LEU critical experiments are being used, it seems likely that other applicable critical experiments could be found in a validation effort for a bulk powder case, especially since both of the failing cases fall outside of the EALF range that was used as the search parameter in DICE.

Table 16. Calculational results for the Damp Bulk Powder case

Enrichment	k_{eff}	EALF (eV)
3%	0.8970	1.29
5%	0.8928	4.74
6%	0.8922	8.08
8%	0.8913	20.75
10%	0.8907	47.36

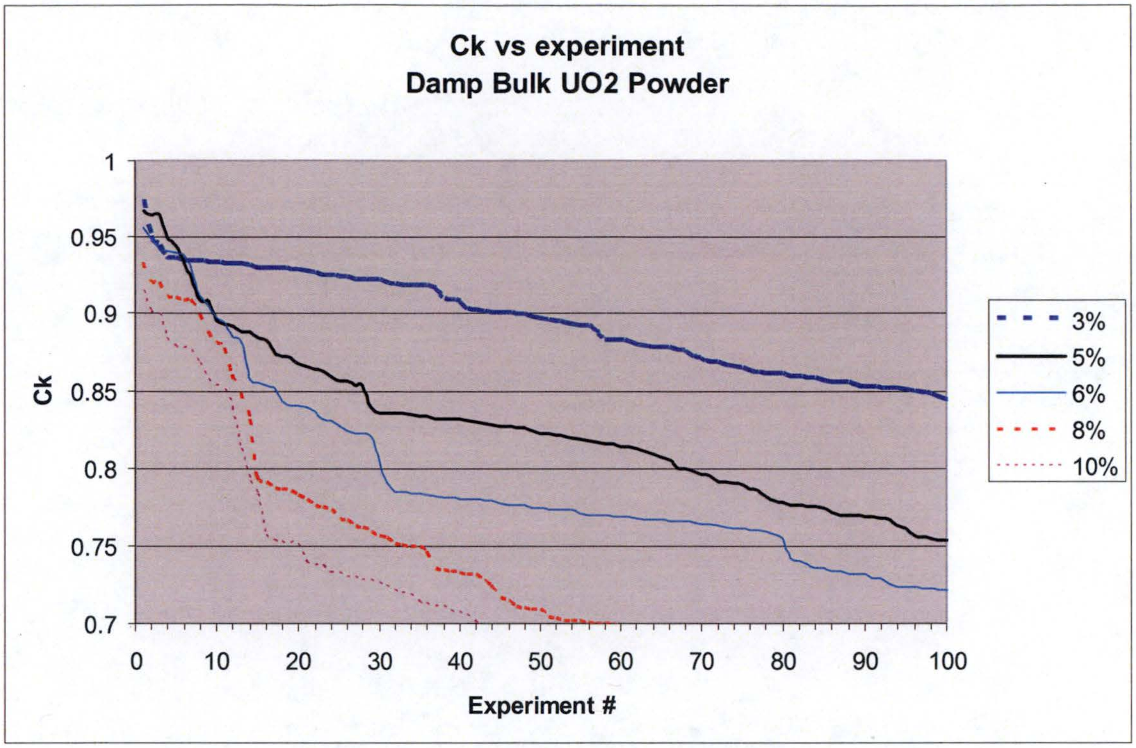

Figure 32. Comparison of experimental c_k values for Damp Powder case

V. CONCLUSIONS

A study has been conducted to evaluate how well existing critical experiments cover the validation needs for seven representative "snapshots" of likely configurations in nuclear fuel processing for uranium enrichments of 5-10% ^{235}U. The criteria of applicability used were based on the c_k values that result from comparisons of the individual bases cases with TSUNAMI-produced SDF files representing an estimated 40% of available experiments from the ICSBEP database. The minimum criteria utilized were for at least 15 critical benchmarks with a c_k value exceeding 0.90 or at least 25 systems with a c_k value exceeding 0.80.

Five out of the seven configurations analyzed were shown to meet at least on of the criteria, leading to an assessment that they are adequately covered by the subset of experiments used. The two remaining cases—representing dry UF_6 canisters at 5-10% ^{235}U enrichment and bulk damp powder cases above about 8% ^{235}U enrichment—are predicted to be adequately covered in true validation cases for which a more extensive subset of the existing critical experiments would be expected to be utilized. This result depends heavily on the second criteria; most of the cases fail to identify enough experiments with $c_k > 0.90$, so if this criterion becomes more important, the results of this project will have to be reevaluated.

Future work could involve assessment of the need for experiments based on other criteria (fuel burnup, UF_6 fuel form, etc.). In addition, if TSUNAMI-3D is to become a standard

tool for studies of this kind, effort should be expended to speed up the Monte Carlo adjoint calculation, which was demonstrated to be up to several hundred times slower than the forward calculations.

REFERENCES

1. International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, Nuclear Energy Agency Nuclear Science Committee of the Organization for Economic Cooperation and Development (2007).

2. Rearden, B. T. "TSUNAMI-3D: Control Module for Three-Dimensional Cross-Section Sensitivity and Uncertainty Analysis for Criticality". Oak Ridge National Laboratory. November 2006.

3. NRC Image: http://www.nrc.gov/materials/fuel-cycle-fac/fuel-fab.html

4. Cochran, Robert G. and Tsoulfanidis, Nicholas. The Nuclear Fuel Cycle: Analysis and Management. American Nuclear Society. 1990.

5. Broadhead, B. L., et al., "Sensitivity- and Uncertainty-Based Criticality Safety Validation Techniques," Nuclear Science and Engineering: 146, 340–366, 2004.

6. "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-1998, American Nuclear Society, 1998.

7. "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing and Evaluations," NUREG/CR-0200, Rev. 6, (ORNL/NUREG/CSD-20R6,) Vols. I, II, and III, CCC-545, Radiation Safety Information Computational Center (May 2000).

8. Elam, K.R. and Rearden, B. T., "Use of Sensitivity and Uncertainty Analysis to Select Benchmark Experiments for the Validation of Computer Codes and Data," Nuclear Science and Engineering: 145, 196–212 (2003).

9. Rearden, B.T., Anderson, W.J., Harms, G.A., "Use of Sensitivity and Uncertainty Analysis in the Design of Reactor Physics and Criticality Benchmark Experiments for Advanced Nuclear Fuel," Nuclear Technology, Vol. 151, (Aug., 2005).

10. Poullot, et al. "Incomplete Arrays of Water-Reflected 4.738%-Enriched Uranium Dioxide Fuel-Rod Arrays." Institut de Radioproection et de Surete Nucleaire,1978.

11. Watanabe, Shouichi, et al. "STACY: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions Reflected with Concrete." Japan Atomic Energy Research Facility (JAERI), 1998.

12. Watanabe, Shouichi, et al. "STACY: 80-cm Diameter Cylindrical Tank of 10%-Enriched Uranyl Nitrate Solutions, Unreflected." Japan Atomic Energy Research Facility (JAERI), 1998.

13. Doucet, M., et al. "FRAMATOME-ANP France UO_2 Fuel Fabrication – Criticality Safety Analysis in the Light of the JCO Accident," ANP Fuel Technology Service, 2003.

APPENDIX A: TSUNAMI Input Decks

For use by future investigators, this Appendix contains the TSUNAMI-3D input decks for each of the base cases. The pattern followed for each of the six base cases and for the additional damp powder cases is to include the normal base case in its entirety, then include the changes for the contingency cases. In addition, a sample of the powder cases and "generic" TSUNAMI-IP input deck are presented.

A.1. Use of the MSDOS "fc" command

In the input decks that follow, space will be conserved by utilizing the "fc" command available in MSDOS command prompts. To illustrate how this command works, assume that one has a file (abe1.txt) including Abraham Lincoln's Gettysburg address, the first few lines of which read:

abe1.txt:

```
Four score and seven years ago our fathers brought forth
on this continent, a new nation, conceived in Liberty,
and dedicated to the proposition that all men are created equal.

Now we are engaged in a great civil war, testing whether that
nation, or any nation so conceived and so dedicated, can long
endure. We are met on a great battle-field of that war. We have
come to dedicate a portion of that field, as a final resting
place for those who here gave their lives that that nation might
live. It is altogether fitting and proper that we should do this.
```

Assume that this is to be modernized in a file abe2.txt, to change "men" to "people" in the third line.

abe2.txt:

```
Four score and seven years ago our fathers brought forth
on this continent, a new nation, conceived in Liberty,
and dedicated to the proposition that all people are created equal.

Now we are engaged in a great civil war, testing whether that
nation, or any nation so conceived and so dedicated, can long
endure. We are met on a great battle-field of that war. We have
come to dedicate a portion of that field, as a final resting
place for those who here gave their lives that that nation might
live. It is altogether fitting and proper that we should do this.
```

An eyesight comparison of the two files would tend to obscure this change, but running the command line entry of:

```
fc abe1.txt abe2.txt
```

would return the output:

```
Comparing files ABE1.txt and ABE2.TXT
***** ABE1.txt
on this continent, a new nation, conceived in Liberty,
and dedicated to the proposition that all men are created equal.

***** ABE2.TXT
on this continent, a new nation, conceived in Liberty,
and dedicated to the proposition that all people are created equal.

*****
```

Note that only changed lines and the lines before and after changed lines are returned. In the rest of this section, this utility is used to minimize both output volume and confusion.

A.2. Normal Base Case Input Decks

Normal Base Case 1: Stored UF_6 cylinders

The input deck for the normal case (CASE1A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
base case 1a:  5% enriched uf6 cylinder - model 12b
238groupndf5
read composition
 uf6         1 den=3.254 1 300
                                 92234 0.005407837
                                 92235 5
                                 92238 94.99459   end
 wtptmonel       2  8.33  7
                                 28000 66.5
                                 26000 2
                                 25055 1.5
                                 14000 0.5
                                 13027 2.7
                                 22000 0.5
                                 29000 26.3
                       1 300   end
 orconcrete  3 1 300   end
 n           4 1.e-10 300   end
end composition
read parameter
 gen=130
 npg=1000
 nsk=30
 htm=yes
 fdn=yes
 apg=10000
 agn=630
end parameter
read geometry
unit 1
com='8a monel container bottom'
```

```
 hemisphe-x 1 1   15.86 chord       0
 hemisphe-x 2 1   16.51 chord       0
 xcylinder 2 1   16.61        0  -20.6375
unit 2
com='8a monel container middle'
 xcylinder 1 1   15.86  70.1675        0
 xcylinder 2 1   16.51  70.1675        0
unit 3
com='8a monel container top'
 hemisphe+x 1 1   15.86 chord       0
 hemisphe+x 2 1   16.51 chord       0
 xcylinder 2 1   16.61    21.59        0
unit 4
com='8a monel container parts together'
 cuboid 4 1    112.5        0    16.61   -16.61    16.61   -16.61
  hole 2 20.6375        0        0
  hole 1 20.6375        0        0
  hole 3  90.855        0        0
unit 5
com='monel 8a bottom y-orientation'
 hemisphe-y 1 1   15.86 chord       0
 hemisphe-y 2 1   16.51 chord       0
 ycylinder 2 1   16.61        0  -20.6375
unit 6
com='monel 8a middle y-orientation'
 ycylinder 1 1   15.86  70.1675        0
 ycylinder 2 1   16.51  70.1675        0
unit 7
com='monel 8a top y-orientation'
 hemisphe+y 1 1   15.86 chord       0
 hemisphe+y 2 1   16.51 chord       0
 ycylinder 2 1   16.61    21.59        0
unit 8
com='monel 8a y-orientation'
 cuboid 4 1    16.61   -16.61    112.5        0    16.61   -16.61
  hole 6        0  20.6375        0
  hole 5        0  20.6375        0
  hole 7        0   90.855        0
global unit 9
com='room of cylinders'
 cuboid 0 1     1700        0     4000        0      500        0
  hole 4        1     16.7     16.7
  hole 4     1565     16.7     16.7
  hole 4        1     50.1     16.7
  hole 4     1565     50.1     16.7
  hole 4        1     83.5     16.7
  hole 4     1565     83.5     16.7
  hole 4        1    116.9     16.7
  hole 4     1565    116.9     16.7
  hole 4        1    150.3     16.7
  hole 4     1565    150.3     16.7
  hole 4        1    183.7     16.7
  hole 4     1565    183.7     16.7
  hole 4        1    217.1     16.7
  hole 4     1565    217.1     16.7
  hole 4        1    250.5     16.7
  hole 4     1565    250.5     16.7
```

hole	4	1	283.9	16.7
hole	4	1565	283.9	16.7
hole	4	1	317.3	16.7
hole	4	1565	317.3	16.7
hole	4	1	350.7	16.7
hole	4	1565	350.7	16.7
hole	4	1	384.1	16.7
hole	4	1565	384.1	16.7
hole	4	1	417.5	16.7
hole	4	1565	417.5	16.7
hole	4	1	450.9	16.7
hole	4	1565	450.9	16.7
hole	4	1	484.3	16.7
hole	4	1565	484.3	16.7
hole	4	1	517.7	16.7
hole	4	1565	517.7	16.7
hole	4	1	551.1	16.7
hole	4	1565	551.1	16.7
hole	4	1	584.5	16.7
hole	4	1565	584.5	16.7
hole	4	1	617.9	16.7
hole	4	1565	617.9	16.7
hole	4	1	651.3	16.7
hole	4	1565	651.3	16.7
hole	4	1	684.7	16.7
hole	4	1565	684.7	16.7
hole	4	1	718.1	16.7
hole	4	1565	718.1	16.7
hole	4	1	751.5	16.7
hole	4	1565	751.5	16.7
hole	4	1	784.9	16.7
hole	4	1565	784.9	16.7
hole	4	1	818.3	16.7
hole	4	1565	818.3	16.7
hole	4	1	851.7	16.7
hole	4	1565	851.7	16.7
hole	4	1	885.1	16.7
hole	4	1565	885.1	16.7
hole	4	1	918.5	16.7
hole	4	1565	918.5	16.7
hole	4	1	951.9	16.7
hole	4	1565	951.9	16.7
hole	4	1	985.3	16.7
hole	4	1565	985.3	16.7
hole	4	1	1018.7	16.7
hole	4	1565	1018.7	16.7
hole	4	1	1052.1	16.7
hole	4	1565	1052.1	16.7
hole	4	1	1085.5	16.7
hole	4	1565	1085.5	16.7
hole	4	1	1118.9	16.7
hole	4	1565	1118.9	16.7
hole	4	1	1152.3	16.7
hole	4	1565	1152.3	16.7
hole	4	1	1185.7	16.7
hole	4	1565	1185.7	16.7
hole	4	1	1219.1	16.7

hole	4	1565	1219.1	16.7
hole	4	1	1252.5	16.7
hole	4	1565	1252.5	16.7
hole	4	1	1285.9	16.7
hole	4	1565	1285.9	16.7
hole	4	1	1319.3	16.7
hole	4	1565	1319.3	16.7
hole	4	1	1352.7	16.7
hole	4	1565	1352.7	16.7
hole	4	1	1386.1	16.7
hole	4	1565	1386.1	16.7
hole	4	1	1419.5	16.7
hole	4	1565	1419.5	16.7
hole	4	1	1452.9	16.7
hole	4	1565	1452.9	16.7
hole	4	1	1486.3	16.7
hole	4	1565	1486.3	16.7
hole	4	1	1519.7	16.7
hole	4	1565	1519.7	16.7
hole	4	1	1553.1	16.7
hole	4	1565	1553.1	16.7
hole	4	1	1586.5	16.7
hole	4	1565	1586.5	16.7
hole	4	1	1619.9	16.7
hole	4	1565	1619.9	16.7
hole	4	1	1653.3	16.7
hole	4	1565	1653.3	16.7
hole	4	1	1686.7	16.7
hole	4	1565	1686.7	16.7
hole	4	1	1720.1	16.7
hole	4	1565	1720.1	16.7
hole	4	1	1753.5	16.7
hole	4	1565	1753.5	16.7
hole	4	1	1786.9	16.7
hole	4	1565	1786.9	16.7
hole	4	1	1820.3	16.7
hole	4	1565	1820.3	16.7
hole	4	1	1853.7	16.7
hole	4	1565	1853.7	16.7
hole	4	1	1887.1	16.7
hole	4	1565	1887.1	16.7
hole	4	1	1920.5	16.7
hole	4	1565	1920.5	16.7
hole	4	1	1953.9	16.7
hole	4	1565	1953.9	16.7
hole	4	1	1987.3	16.7
hole	4	1565	1987.3	16.7
hole	4	1	2020.7	16.7
hole	4	1565	2020.7	16.7
hole	4	1	2054.1	16.7
hole	4	1565	2054.1	16.7
hole	4	1	2087.5	16.7
hole	4	1565	2087.5	16.7
hole	4	1	2120.9	16.7
hole	4	1565	2120.9	16.7
hole	4	1	2154.3	16.7
hole	4	1565	2154.3	16.7

hole	4	1	2187.7	16.7
hole	4	1565	2187.7	16.7
hole	4	1	2221.1	16.7
hole	4	1565	2221.1	16.7
hole	4	1	2254.5	16.7
hole	4	1565	2254.5	16.7
hole	4	1	2287.9	16.7
hole	4	1565	2287.9	16.7
hole	4	1	2321.3	16.7
hole	4	1565	2321.3	16.7
hole	4	1	2354.7	16.7
hole	4	1565	2354.7	16.7
hole	4	1	2388.1	16.7
hole	4	1565	2388.1	16.7
hole	4	1	2421.5	16.7
hole	4	1565	2421.5	16.7
hole	4	1	2454.9	16.7
hole	4	1565	2454.9	16.7
hole	4	1	2488.3	16.7
hole	4	1565	2488.3	16.7
hole	4	1	2521.7	16.7
hole	4	1565	2521.7	16.7
hole	4	1	2555.1	16.7
hole	4	1565	2555.1	16.7
hole	4	1	2588.5	16.7
hole	4	1565	2588.5	16.7
hole	4	1	2621.9	16.7
hole	4	1565	2621.9	16.7
hole	4	1	2655.3	16.7
hole	4	1565	2655.3	16.7
hole	4	1	2688.7	16.7
hole	4	1565	2688.7	16.7
hole	4	1	2722.1	16.7
hole	4	1565	2722.1	16.7
hole	4	1	2755.5	16.7
hole	4	1565	2755.5	16.7
hole	4	1	2788.9	16.7
hole	4	1565	2788.9	16.7
hole	4	1	2822.3	16.7
hole	4	1565	2822.3	16.7
hole	4	1	2855.7	16.7
hole	4	1565	2855.7	16.7
hole	4	1	2889.1	16.7
hole	4	1565	2889.1	16.7
hole	4	1	2922.5	16.7
hole	4	1565	2922.5	16.7
hole	4	1	2955.9	16.7
hole	4	1565	2955.9	16.7
hole	4	1	2989.3	16.7
hole	4	1565	2989.3	16.7
hole	4	1	3022.7	16.7
hole	4	1565	3022.7	16.7
hole	4	1	3056.1	16.7
hole	4	1565	3056.1	16.7
hole	4	1	3089.5	16.7
hole	4	1565	3089.5	16.7
hole	4	1	3122.9	16.7

hole	4	1565	3122.9	16.7
hole	4	1	3156.3	16.7
hole	4	1565	3156.3	16.7
hole	4	1	3189.7	16.7
hole	4	1565	3189.7	16.7
hole	4	1	3223.1	16.7
hole	4	1565	3223.1	16.7
hole	4	1	3256.5	16.7
hole	4	1565	3256.5	16.7
hole	4	1	3289.9	16.7
hole	4	1565	3289.9	16.7
hole	4	1	3323.3	16.7
hole	4	1565	3323.3	16.7
hole	4	1	3356.7	16.7
hole	4	1565	3356.7	16.7
hole	4	1	3390.1	16.7
hole	4	1565	3390.1	16.7
hole	4	1	3423.5	16.7
hole	4	1565	3423.5	16.7
hole	4	1	3456.9	16.7
hole	4	1565	3456.9	16.7
hole	4	1	3490.3	16.7
hole	4	1565	3490.3	16.7
hole	4	1	3523.7	16.7
hole	4	1565	3523.7	16.7
hole	4	1	3557.1	16.7
hole	4	1565	3557.1	16.7
hole	4	1	3590.5	16.7
hole	4	1565	3590.5	16.7
hole	4	1	3623.9	16.7
hole	4	1565	3623.9	16.7
hole	4	1	3657.3	16.7
hole	4	1565	3657.3	16.7
hole	4	1	3690.7	16.7
hole	4	1565	3690.7	16.7
hole	4	1	3724.1	16.7
hole	4	1565	3724.1	16.7
hole	4	1	3757.5	16.7
hole	4	1565	3757.5	16.7
hole	4	1	3790.9	16.7
hole	4	1565	3790.9	16.7
hole	4	1	3824.3	16.7
hole	4	1565	3824.3	16.7
hole	4	1	3857.7	16.7
hole	4	1565	3857.7	16.7
hole	4	1	3891.1	16.7
hole	4	1565	3891.1	16.7
hole	4	1	3924.5	16.7
hole	4	1565	3924.5	16.7
hole	4	1	3957.9	16.7
hole	4	1565	3957.9	16.7
hole	4	433	429.2	16.7
hole	4	566	429.2	16.7
hole	4	999	429.2	16.7
hole	4	1132	429.2	16.7
hole	4	433	462.6	16.7
hole	4	566	462.6	16.7

hole	4	999	462.6	16.7
hole	4	1132	462.6	16.7
hole	4	433	496	16.7
hole	4	566	496	16.7
hole	4	999	496	16.7
hole	4	1132	496	16.7
hole	4	433	529.4	16.7
hole	4	566	529.4	16.7
hole	4	999	529.4	16.7
hole	4	1132	529.4	16.7
hole	4	433	562.8	16.7
hole	4	566	562.8	16.7
hole	4	999	562.8	16.7
hole	4	1132	562.8	16.7
hole	4	433	596.2	16.7
hole	4	566	596.2	16.7
hole	4	999	596.2	16.7
hole	4	1132	596.2	16.7
hole	4	433	629.6	16.7
hole	4	566	629.6	16.7
hole	4	999	629.6	16.7
hole	4	1132	629.6	16.7
hole	4	433	663	16.7
hole	4	566	663	16.7
hole	4	999	663	16.7
hole	4	1132	663	16.7
hole	4	433	696.4	16.7
hole	4	566	696.4	16.7
hole	4	999	696.4	16.7
hole	4	1132	696.4	16.7
hole	4	433	729.8	16.7
hole	4	566	729.8	16.7
hole	4	999	729.8	16.7
hole	4	1132	729.8	16.7
hole	4	433	763.2	16.7
hole	4	566	763.2	16.7
hole	4	999	763.2	16.7
hole	4	1132	763.2	16.7
hole	4	433	796.6	16.7
hole	4	566	796.6	16.7
hole	4	999	796.6	16.7
hole	4	1132	796.6	16.7
hole	4	433	830	16.7
hole	4	566	830	16.7
hole	4	999	830	16.7
hole	4	1132	830	16.7
hole	4	433	863.4	16.7
hole	4	566	863.4	16.7
hole	4	999	863.4	16.7
hole	4	1132	863.4	16.7
hole	4	433	896.8	16.7
hole	4	566	896.8	16.7
hole	4	999	896.8	16.7
hole	4	1132	896.8	16.7
hole	4	433	930.2	16.7
hole	4	566	930.2	16.7
hole	4	999	930.2	16.7

hole	4	1132	930.2	16.7
hole	4	433	963.6	16.7
hole	4	566	963.6	16.7
hole	4	999	963.6	16.7
hole	4	1132	963.6	16.7
hole	4	433	997	16.7
hole	4	566	997	16.7
hole	4	999	997	16.7
hole	4	1132	997	16.7
hole	4	433	1030.4	16.7
hole	4	566	1030.4	16.7
hole	4	999	1030.4	16.7
hole	4	1132	1030.4	16.7
hole	4	433	1063.8	16.7
hole	4	566	1063.8	16.7
hole	4	999	1063.8	16.7
hole	4	1132	1063.8	16.7
hole	4	433	1097.2	16.7
hole	4	566	1097.2	16.7
hole	4	999	1097.2	16.7
hole	4	1132	1097.2	16.7
hole	4	433	1130.6	16.7
hole	4	566	1130.6	16.7
hole	4	999	1130.6	16.7
hole	4	1132	1130.6	16.7
hole	4	433	1164	16.7
hole	4	566	1164	16.7
hole	4	999	1164	16.7
hole	4	1132	1164	16.7
hole	4	433	1197.4	16.7
hole	4	566	1197.4	16.7
hole	4	999	1197.4	16.7
hole	4	1132	1197.4	16.7
hole	4	433	1230.8	16.7
hole	4	566	1230.8	16.7
hole	4	999	1230.8	16.7
hole	4	1132	1230.8	16.7
hole	4	433	1264.2	16.7
hole	4	566	1264.2	16.7
hole	4	999	1264.2	16.7
hole	4	1132	1264.2	16.7
hole	4	433	1297.6	16.7
hole	4	566	1297.6	16.7
hole	4	999	1297.6	16.7
hole	4	1132	1297.6	16.7
hole	4	433	1331	16.7
hole	4	566	1331	16.7
hole	4	999	1331	16.7
hole	4	1132	1331	16.7
hole	4	433	1364.4	16.7
hole	4	566	1364.4	16.7
hole	4	999	1364.4	16.7
hole	4	1132	1364.4	16.7
hole	4	433	1397.8	16.7
hole	4	566	1397.8	16.7
hole	4	999	1397.8	16.7
hole	4	1132	1397.8	16.7

hole	4	433	1431.2	16.7
hole	4	566	1431.2	16.7
hole	4	999	1431.2	16.7
hole	4	1132	1431.2	16.7
hole	4	433	1464.6	16.7
hole	4	566	1464.6	16.7
hole	4	999	1464.6	16.7
hole	4	1132	1464.6	16.7
hole	4	433	1498	16.7
hole	4	566	1498	16.7
hole	4	999	1498	16.7
hole	4	1132	1498	16.7
hole	4	433	1531.4	16.7
hole	4	566	1531.4	16.7
hole	4	999	1531.4	16.7
hole	4	1132	1531.4	16.7
hole	4	433	1564.8	16.7
hole	4	566	1564.8	16.7
hole	4	999	1564.8	16.7
hole	4	1132	1564.8	16.7
hole	4	433	1598.2	16.7
hole	4	566	1598.2	16.7
hole	4	999	1598.2	16.7
hole	4	1132	1598.2	16.7
hole	4	433	1631.6	16.7
hole	4	566	1631.6	16.7
hole	4	999	1631.6	16.7
hole	4	1132	1631.6	16.7
hole	4	433	1665	16.7
hole	4	566	1665	16.7
hole	4	999	1665	16.7
hole	4	1132	1665	16.7
hole	4	433	1698.4	16.7
hole	4	566	1698.4	16.7
hole	4	999	1698.4	16.7
hole	4	1132	1698.4	16.7
hole	4	433	1731.8	16.7
hole	4	566	1731.8	16.7
hole	4	999	1731.8	16.7
hole	4	1132	1731.8	16.7
hole	4	433	1765.2	16.7
hole	4	566	1765.2	16.7
hole	4	999	1765.2	16.7
hole	4	1132	1765.2	16.7
hole	4	433	1798.6	16.7
hole	4	566	1798.6	16.7
hole	4	999	1798.6	16.7
hole	4	1132	1798.6	16.7
hole	4	433	1832	16.7
hole	4	566	1832	16.7
hole	4	999	1832	16.7
hole	4	1132	1832	16.7
hole	4	433	1865.4	16.7
hole	4	566	1865.4	16.7
hole	4	999	1865.4	16.7
hole	4	1132	1865.4	16.7
hole	4	433	1898.8	16.7

hole	4	566	1898.8	16.7
hole	4	999	1898.8	16.7
hole	4	1132	1898.8	16.7
hole	4	433	1932.2	16.7
hole	4	566	1932.2	16.7
hole	4	999	1932.2	16.7
hole	4	1132	1932.2	16.7
hole	4	433	1965.6	16.7
hole	4	566	1965.6	16.7
hole	4	999	1965.6	16.7
hole	4	1132	1965.6	16.7
hole	4	433	1999	16.7
hole	4	566	1999	16.7
hole	4	999	1999	16.7
hole	4	1132	1999	16.7
hole	4	433	2032.4	16.7
hole	4	566	2032.4	16.7
hole	4	999	2032.4	16.7
hole	4	1132	2032.4	16.7
hole	4	433	2065.8	16.7
hole	4	566	2065.8	16.7
hole	4	999	2065.8	16.7
hole	4	1132	2065.8	16.7
hole	4	433	2099.2	16.7
hole	4	566	2099.2	16.7
hole	4	999	2099.2	16.7
hole	4	1132	2099.2	16.7
hole	4	433	2132.6	16.7
hole	4	566	2132.6	16.7
hole	4	999	2132.6	16.7
hole	4	1132	2132.6	16.7
hole	4	433	2166	16.7
hole	4	566	2166	16.7
hole	4	999	2166	16.7
hole	4	1132	2166	16.7
hole	4	433	2199.4	16.7
hole	4	566	2199.4	16.7
hole	4	999	2199.4	16.7
hole	4	1132	2199.4	16.7
hole	4	433	2232.8	16.7
hole	4	566	2232.8	16.7
hole	4	999	2232.8	16.7
hole	4	1132	2232.8	16.7
hole	4	433	2266.2	16.7
hole	4	566	2266.2	16.7
hole	4	999	2266.2	16.7
hole	4	1132	2266.2	16.7
hole	4	433	2299.6	16.7
hole	4	566	2299.6	16.7
hole	4	999	2299.6	16.7
hole	4	1132	2299.6	16.7
hole	4	433	2333	16.7
hole	4	566	2333	16.7
hole	4	999	2333	16.7
hole	4	1132	2333	16.7
hole	4	433	2366.4	16.7
hole	4	566	2366.4	16.7

hole	4	999	2366.4	16.7
hole	4	1132	2366.4	16.7
hole	4	433	2399.8	16.7
hole	4	566	2399.8	16.7
hole	4	999	2399.8	16.7
hole	4	1132	2399.8	16.7
hole	4	433	2433.2	16.7
hole	4	566	2433.2	16.7
hole	4	999	2433.2	16.7
hole	4	1132	2433.2	16.7
hole	4	433	2466.6	16.7
hole	4	566	2466.6	16.7
hole	4	999	2466.6	16.7
hole	4	1132	2466.6	16.7
hole	4	433	2500	16.7
hole	4	566	2500	16.7
hole	4	999	2500	16.7
hole	4	1132	2500	16.7
hole	4	433	2533.4	16.7
hole	4	566	2533.4	16.7
hole	4	999	2533.4	16.7
hole	4	1132	2533.4	16.7
hole	4	433	2566.8	16.7
hole	4	566	2566.8	16.7
hole	4	999	2566.8	16.7
hole	4	1132	2566.8	16.7
hole	4	433	2600.2	16.7
hole	4	566	2600.2	16.7
hole	4	999	2600.2	16.7
hole	4	1132	2600.2	16.7
hole	4	433	2633.6	16.7
hole	4	566	2633.6	16.7
hole	4	999	2633.6	16.7
hole	4	1132	2633.6	16.7
hole	4	433	2667	16.7
hole	4	566	2667	16.7
hole	4	999	2667	16.7
hole	4	1132	2667	16.7
hole	4	433	2700.4	16.7
hole	4	566	2700.4	16.7
hole	4	999	2700.4	16.7
hole	4	1132	2700.4	16.7
hole	4	433	2733.8	16.7
hole	4	566	2733.8	16.7
hole	4	999	2733.8	16.7
hole	4	1132	2733.8	16.7
hole	4	433	2767.2	16.7
hole	4	566	2767.2	16.7
hole	4	999	2767.2	16.7
hole	4	1132	2767.2	16.7
hole	4	433	2800.6	16.7
hole	4	566	2800.6	16.7
hole	4	999	2800.6	16.7
hole	4	1132	2800.6	16.7
hole	4	433	2834	16.7
hole	4	566	2834	16.7
hole	4	999	2834	16.7

hole	4	1132	2834	16.7
hole	4	433	2867.4	16.7
hole	4	566	2867.4	16.7
hole	4	999	2867.4	16.7
hole	4	1132	2867.4	16.7
hole	4	433	2900.8	16.7
hole	4	566	2900.8	16.7
hole	4	999	2900.8	16.7
hole	4	1132	2900.8	16.7
hole	4	433	2934.2	16.7
hole	4	566	2934.2	16.7
hole	4	999	2934.2	16.7
hole	4	1132	2934.2	16.7
hole	4	433	2967.6	16.7
hole	4	566	2967.6	16.7
hole	4	999	2967.6	16.7
hole	4	1132	2967.6	16.7
hole	4	433	3001	16.7
hole	4	566	3001	16.7
hole	4	999	3001	16.7
hole	4	1132	3001	16.7
hole	4	433	3034.4	16.7
hole	4	566	3034.4	16.7
hole	4	999	3034.4	16.7
hole	4	1132	3034.4	16.7
hole	4	433	3067.8	16.7
hole	4	566	3067.8	16.7
hole	4	999	3067.8	16.7
hole	4	1132	3067.8	16.7
hole	4	433	3101.2	16.7
hole	4	566	3101.2	16.7
hole	4	999	3101.2	16.7
hole	4	1132	3101.2	16.7
hole	4	433	3134.6	16.7
hole	4	566	3134.6	16.7
hole	4	999	3134.6	16.7
hole	4	1132	3134.6	16.7
hole	4	433	3168	16.7
hole	4	566	3168	16.7
hole	4	999	3168	16.7
hole	4	1132	3168	16.7
hole	4	433	3201.4	16.7
hole	4	566	3201.4	16.7
hole	4	999	3201.4	16.7
hole	4	1132	3201.4	16.7
hole	4	433	3234.8	16.7
hole	4	566	3234.8	16.7
hole	4	999	3234.8	16.7
hole	4	1132	3234.8	16.7
hole	4	433	3268.2	16.7
hole	4	566	3268.2	16.7
hole	4	999	3268.2	16.7
hole	4	1132	3268.2	16.7
hole	4	433	3301.6	16.7
hole	4	566	3301.6	16.7
hole	4	999	3301.6	16.7
hole	4	1132	3301.6	16.7

hole	4	433	3335	16.7
hole	4	566	3335	16.7
hole	4	999	3335	16.7
hole	4	1132	3335	16.7
hole	4	433	3368.4	16.7
hole	4	566	3368.4	16.7
hole	4	999	3368.4	16.7
hole	4	1132	3368.4	16.7
hole	4	433	3401.8	16.7
hole	4	566	3401.8	16.7
hole	4	999	3401.8	16.7
hole	4	1132	3401.8	16.7
hole	4	433	3435.2	16.7
hole	4	566	3435.2	16.7
hole	4	999	3435.2	16.7
hole	4	1132	3435.2	16.7
hole	4	433	3468.6	16.7
hole	4	566	3468.6	16.7
hole	4	999	3468.6	16.7
hole	4	1132	3468.6	16.7
hole	4	433	3502	16.7
hole	4	566	3502	16.7
hole	4	999	3502	16.7
hole	4	1132	3502	16.7
hole	4	433	3535.4	16.7
hole	4	566	3535.4	16.7
hole	4	999	3535.4	16.7
hole	4	1132	3535.4	16.7
hole	8	433	1	16.7
hole	8	433	3867	16.7
hole	8	466.4	1	16.7
hole	8	466.4	3867	16.7
hole	8	499.8	1	16.7
hole	8	499.8	3867	16.7
hole	8	533.2	1	16.7
hole	8	533.2	3867	16.7
hole	8	566.6	1	16.7
hole	8	566.6	3867	16.7
hole	8	600	1	16.7
hole	8	600	3867	16.7
hole	8	633.4	1	16.7
hole	8	633.4	3867	16.7
hole	8	666.8	1	16.7
hole	8	666.8	3867	16.7
hole	8	700.2	1	16.7
hole	8	700.2	3867	16.7
hole	8	733.6	1	16.7
hole	8	733.6	3867	16.7
hole	8	767	1	16.7
hole	8	767	3867	16.7
hole	8	800.4	1	16.7
hole	8	800.4	3867	16.7
hole	8	833.8	1	16.7
hole	8	833.8	3867	16.7
hole	8	867.2	1	16.7
hole	8	867.2	3867	16.7
hole	8	900.6	1	16.7

```
   hole 8   900.6      3867      16.7
   hole 8     934         1      16.7
   hole 8     934      3867      16.7
   hole 8   967.4         1      16.7
   hole 8   967.4      3867      16.7
   hole 8  1000.8         1      16.7
   hole 8  1000.8      3867      16.7
   hole 8  1034.2         1      16.7
   hole 8  1034.2      3867      16.7
   hole 8  1067.6         1      16.7
   hole 8  1067.6      3867      16.7
   hole 8    1101         1      16.7
   hole 8    1101      3867      16.7
   hole 8  1134.4         1      16.7
   hole 8  1134.4      3867      16.7
   hole 8  1167.8         1      16.7
   hole 8  1167.8      3867      16.7
   hole 8  1201.2         1      16.7
   hole 8  1201.2      3867      16.7
  cuboid 3 1      1800      -100      4100      -100        600      -100
 end geometry
 read plot
  scr=yes
  ttl='room cross section xy view'
  pic=mixtures
  xul=-100
  yul=4100
  zul=16.61
  xlr=4100
  ylr=-100
  zlr=16.61
  nax=3000
  clr=1 225 104 23
      2 0 0 205
      3 0 229 238
      4 0 238 0
  end color
  uax=1 vdn=-1
   end
 end plot
 read bnds
  +xb=vacuum
  -xb=vacuum
  +yb=vacuum
  -yb=vacuum
  +zb=vacuum
  -zb=vacuum
   end bnds
 end data
 read sams
   prtgeom
 end sams
 end
```

A file comparison with CASE1B.inp returns:

```
Comparing files casela.inp and CASE1B.INP
```

```
***** casela.inp
=tsunami-3d-k5 parm=(nitawlst)
base case 1a:  5% enriched uf6 cylinder - model 12b
238groupndf5
***** CASE1B.INP
=tsunami-3d-k5 parm=(nitawlst)
base case 1b:  6% enriched uf6 cylinder - model 12b
238groupndf5
*****

***** casela.inp
                                    92234 0.005407837
                                    92235 5
                                    92238 94.99459   end
 wtptmonel       2   8.33   7
***** CASE1B.INP
                                    92234 0.005407837
                                    92235 6
                                    92238 93.99459   end
 wtptmonel       2   8.33   7
*****
```

A file comparison with CASE1C.inp returns:

```
Comparing files casela.inp and CASE1C.INP
***** casela.inp
=tsunami-3d-k5 parm=(nitawlst)
base case 1a:  5% enriched uf6 cylinder - model 12b
238groupndf5
***** CASE1C.INP
=tsunami-3d-k5 parm=(nitawlst)
base case 1c:  8% enriched uf6 cylinder - model 12b
238groupndf5
*****

***** casela.inp
                                    92234 0.005407837
                                    92235 5
                                    92238 94.99459   end
 wtptmonel       2   8.33   7
***** CASE1C.INP
                                    92234 0.005407837
                                    92235 8
                                    92238 91.99459   end
 wtptmonel       2   8.33   7
*****
```

A file comparison with CASE1D.inp returns:

```
Comparing files casela.inp and CASE1D.INP
***** casela.inp
=tsunami-3d-k5 parm=(nitawlst)
base case 1a:  5% enriched uf6 cylinder - model 12b
238groupndf5
```

```
***** CASE1D.INP
=tsunami-3d-k5 parm=(nitawlst)
base case 1d:  5% enriched uf6 cylinder - model 12b
238groupndf5
*****

***** case1a.inp
                                    92234 0.005407837
                                    92235 5
                                    92238 94.99459   end
 wtptmonel       2  8.33  7
***** CASE1D.INP
                                    92234 0.005407837
                                    92235 10
                                    92238 89.99459   end
 wtptmonel       2  8.33  7
*****
```

Normal Base Case 2: UO_2 powder in storage rack arrays

The input deck for the normal case (CASE2A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 powder in storage rack arrays
238groupndf5
read composition
 uo2          1 1 300
                                    92234 0.005407837
                                    92235 5
                                    92238 94.99459   end
 ss316        2 1 300   end
 aluminum     3 1 300   end
 h2o          4 0.06 300   end
 orconcrete   5 1 300   end
 h2o          6 1 300   end
end composition
read parameter
 gen=130
 npg=1000
 nsk=30
 htm=yes
 fdn=yes
 apg=10000
 agn=630
end parameter
read geometry
unit 1
com='single can on shelf'
 zcylinder 1 1     7.5      13.5       0.8
 zcylinder 2 1     7.8      13.8       0.3
 cuboid 0 1        8        -8         8        -8        16       0.3
 cuboid 3 1        8        -8         8        -8        16         0
unit 2
com='single rack'
 cuboid 0 1      240         0        16         0       150         0
  hole 1       8         8        0
```

hole	1	24	8	0
hole	1	40	8	0
hole	1	56	8	0
hole	1	72	8	0
hole	1	88	8	0
hole	1	104	8	0
hole	1	120	8	0
hole	1	136	8	0
hole	1	152	8	0
hole	1	168	8	0
hole	1	184	8	0
hole	1	200	8	0
hole	1	216	8	0
hole	1	232	8	0
hole	1	8	8	16
hole	1	24	8	16
hole	1	40	8	16
hole	1	56	8	16
hole	1	72	8	16
hole	1	88	8	16
hole	1	104	8	16
hole	1	120	8	16
hole	1	136	8	16
hole	1	152	8	16
hole	1	168	8	16
hole	1	184	8	16
hole	1	200	8	16
hole	1	216	8	16
hole	1	232	8	16
hole	1	8	8	32
hole	1	24	8	32
hole	1	40	8	32
hole	1	56	8	32
hole	1	72	8	32
hole	1	88	8	32
hole	1	104	8	32
hole	1	120	8	32
hole	1	136	8	32
hole	1	152	8	32
hole	1	168	8	32
hole	1	184	8	32
hole	1	200	8	32
hole	1	216	8	32
hole	1	232	8	32
hole	1	8	8	48
hole	1	24	8	48
hole	1	40	8	48
hole	1	56	8	48
hole	1	72	8	48
hole	1	88	8	48
hole	1	104	8	48
hole	1	120	8	48
hole	1	136	8	48
hole	1	152	8	48
hole	1	168	8	48
hole	1	184	8	48
hole	1	200	8	48

hole	1	216	8	48
hole	1	232	8	48
hole	1	8	8	64
hole	1	24	8	64
hole	1	40	8	64
hole	1	56	8	64
hole	1	72	8	64
hole	1	88	8	64
hole	1	104	8	64
hole	1	120	8	64
hole	1	136	8	64
hole	1	152	8	64
hole	1	168	8	64
hole	1	184	8	64
hole	1	200	8	64
hole	1	216	8	64
hole	1	232	8	64
hole	1	8	8	80
hole	1	24	8	80
hole	1	40	8	80
hole	1	56	8	80
hole	1	72	8	80
hole	1	88	8	80
hole	1	104	8	80
hole	1	120	8	80
hole	1	136	8	80
hole	1	152	8	80
hole	1	168	8	80
hole	1	184	8	80
hole	1	200	8	80
hole	1	216	8	80
hole	1	232	8	80
hole	1	8	8	96
hole	1	24	8	96
hole	1	40	8	96
hole	1	56	8	96
hole	1	72	8	96
hole	1	88	8	96
hole	1	104	8	96
hole	1	120	8	96
hole	1	136	8	96
hole	1	152	8	96
hole	1	168	8	96
hole	1	184	8	96
hole	1	200	8	96
hole	1	216	8	96
hole	1	232	8	96
hole	1	8	8	112
hole	1	24	8	112
hole	1	40	8	112
hole	1	56	8	112
hole	1	72	8	112
hole	1	88	8	112
hole	1	104	8	112
hole	1	120	8	112
hole	1	136	8	112
hole	1	152	8	112

```
   hole 1     168          8       112
   hole 1     184          8       112
   hole 1     200          8       112
   hole 1     216          8       112
   hole 1     232          8       112
unit 3
com='y orientation'
 cuboid 0 1        16        0       240          0       150          0
   hole 1       8          8         0
   hole 1       8         24         0
   hole 1       8         40         0
   hole 1       8         56         0
   hole 1       8         72         0
   hole 1       8         88         0
   hole 1       8        104         0
   hole 1       8        120         0
   hole 1       8        136         0
   hole 1       8        152         0
   hole 1       8        168         0
   hole 1       8        184         0
   hole 1       8        200         0
   hole 1       8        216         0
   hole 1       8        232         0
   hole 1       8          8        16
   hole 1       8         24        16
   hole 1       8         40        16
   hole 1       8         56        16
   hole 1       8         72        16
   hole 1       8         88        16
   hole 1       8        104        16
   hole 1       8        120        16
   hole 1       8        136        16
   hole 1       8        152        16
   hole 1       8        168        16
   hole 1       8        184        16
   hole 1       8        200        16
   hole 1       8        216        16
   hole 1       8        232        16
   hole 1       8          8        32
   hole 1       8         24        32
   hole 1       8         40        32
   hole 1       8         56        32
   hole 1       8         72        32
   hole 1       8         88        32
   hole 1       8        104        32
   hole 1       8        120        32
   hole 1       8        136        32
   hole 1       8        152        32
   hole 1       8        168        32
   hole 1       8        184        32
   hole 1       8        200        32
   hole 1       8        216        32
   hole 1       8        232        32
   hole 1       8          8        48
   hole 1       8         24        48
   hole 1       8         40        48
   hole 1       8         56        48
```

hole	1	8	72	48
hole	1	8	88	48
hole	1	8	104	48
hole	1	8	120	48
hole	1	8	136	48
hole	1	8	152	48
hole	1	8	168	48
hole	1	8	184	48
hole	1	8	200	48
hole	1	8	216	48
hole	1	8	232	48
hole	1	8	8	64
hole	1	8	24	64
hole	1	8	40	64
hole	1	8	56	64
hole	1	8	72	64
hole	1	8	88	64
hole	1	8	104	64
hole	1	8	120	64
hole	1	8	136	64
hole	1	8	152	64
hole	1	8	168	64
hole	1	8	184	64
hole	1	8	200	64
hole	1	8	216	64
hole	1	8	232	64
hole	1	8	8	80
hole	1	8	24	80
hole	1	8	40	80
hole	1	8	56	80
hole	1	8	72	80
hole	1	8	88	80
hole	1	8	104	80
hole	1	8	120	80
hole	1	8	136	80
hole	1	8	152	80
hole	1	8	168	80
hole	1	8	184	80
hole	1	8	200	80
hole	1	8	216	80
hole	1	8	232	80
hole	1	8	8	96
hole	1	8	24	96
hole	1	8	40	96
hole	1	8	56	96
hole	1	8	72	96
hole	1	8	88	96
hole	1	8	104	96
hole	1	8	120	96
hole	1	8	136	96
hole	1	8	152	96
hole	1	8	168	96
hole	1	8	184	96
hole	1	8	200	96
hole	1	8	216	96
hole	1	8	232	96
hole	1	8	8	112

```
    hole 1       8       24       112
    hole 1       8       40       112
    hole 1       8       56       112
    hole 1       8       72       112
    hole 1       8       88       112
    hole 1       8      104       112
    hole 1       8      120       112
    hole 1       8      136       112
    hole 1       8      152       112
    hole 1       8      168       112
    hole 1       8      184       112
    hole 1       8      200       112
    hole 1       8      216       112
    hole 1       8      232       112
global unit 4
com='rack room'
  cuboid 0 1    1232        0     1712        0      300        30
    hole 2      16        0        30
    hole 2     496        0        30
    hole 2     736        0        30
    hole 2     976        0        30
    hole 2      16     1696        30
    hole 2     256     1696        30
    hole 2     496     1696        30
    hole 2     976     1696        30
    hole 3       0       16        30
    hole 3       0      256        30
    hole 3       0      496        30
    hole 3       0      736        30
    hole 3       0      976        30
    hole 3       0     1216        30
    hole 3       0     1456        30
    hole 3    1216       16        30
    hole 3    1216      256        30
    hole 3    1216      496        30
    hole 3    1216      736        30
    hole 3    1216      976        30
    hole 3    1216     1216        30
    hole 3    1216     1456        30
    hole 3     300      256        30
    hole 3     300      496        30
    hole 3     300      736        30
    hole 3     300      976        30
    hole 3     300     1216        30
    hole 3     600      256        30
    hole 3     600      496        30
    hole 3     600      736        30
    hole 3     600      976        30
    hole 3     600     1216        30
    hole 3     900      256        30
    hole 3     900      496        30
    hole 3     900      736        30
    hole 3     900      976        30
    hole 3     900     1216        30
  cuboid 0 1    1232        0     1712        0      300         0
  cuboid 5 1    1332     -100     1812     -100      400      -100
end geometry
```

```
read plot
 scr=yes
 ttl='storage room cross section at z = 34 cm'
 pic=mixtures
 xul=-20
 yul=1730
 zul=34
 xlr=1240
 ylr=-20
 zlr=34
 nax=1200
 clr=1 224 104 52
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 vdn=-1
  end
 scr=yes
 ttl='cross section of storage rack'
 pic=mixtures
 xul=15
 yul=8
 zul=310
 xlr=257
 ylr=8
 zlr=15
 nax=1200
 clr=1 200 200 200
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 wdn=-1
  end
end plot
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=mirror
 -zb=mirror
  end bnds
end data
read sams
  prtgeom
end sams
end
```

A file comparison with CASE2B.inp returns:

```
Comparing files case2a.inp and CASE2B.INP
***** case2a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 powder in storage rack arrays
238groupndf5
***** CASE2B.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 6% enriched uo2 powder in storage rack arrays
238groupndf5
*****

***** case2a.inp
                                92234 0.005407837
                                92235 5
                                92238 94.99459   end
 ss316       2 1 300   end
***** CASE2B.INP
                                92234 0.005407837
                                92235 6
                                92238 93.99459   end
 ss316       2 1 300   end
*****
```

A file comparison with CASE2C.inp returns:

```
Comparing files case2a.inp and CASE2C.INP
***** case2a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 powder in storage rack arrays
238groupndf5
***** CASE2C.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 8% enriched uo2 powder in storage rack arrays
238groupndf5
*****

***** case2a.inp
                                92234 0.005407837
                                92235 5
                                92238 94.99459   end
 ss316       2 1 300   end
***** CASE2C.INP
                                92234 0.005407837
                                92235 8
                                92238 91.99459   end
 ss316       2 1 300   end
*****
```

A file comparison with CASE2D.inp returns:

```
Comparing files case2a.inp and CASE2D.INP
***** case2a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 powder in storage rack arrays
238groupndf5
```

```
***** CASE2D.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 10% enriched uo2 powder in storage rack arrays
238groupndf5
*****

***** case2a.inp
                                92234 0.005407837
                                92235 5
                                92238 94.99459    end
 ss316       2 1 300    end
***** CASE2D.INP
                                92234 0.005407837
                                92235 10
                                92238 89.99459    end
 ss316       2 1 300    end
*****
```

Normal Base Case 3: Pressed ceramic UO_2 fuel pellets in boxes

The input deck for the normal case (CASE3A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 pellets in boxes
238groupndf5
read composition
 uo2         1 1.0000 300
                                92234 0.005407837
                                92235 5
                                92238 94.99459    end
 ss316       2 1 300    end
 aluminum    3 1 300    end
 h2o         4 0.06 300    end
 orconcrete  5 1 300    end
 h2o         6 1 300    end
end composition
read parameter
 gen=130
 npg=1000
 nsk=30
 htm=yes
 fdn=yes
 apg=10000
 agn=630
end parameter
read geometry
unit 1
com='fuel pin'
 zcylinder 1 1    0.55        7        0
unit 2
com='pins in box'
 cuboid 0 1      7.5     -7.5      7.5     -7.5      7.5      0.2
  hole 1      6.9      6.9      0.2
  hole 1      5.7      6.9      0.2
  hole 1      4.5      6.9      0.2
```

hole	1	3.3	6.9	0.2
hole	1	2.1	6.9	0.2
hole	1	0.9	6.9	0.2
hole	1	-6.9	6.9	0.2
hole	1	-5.7	6.9	0.2
hole	1	-4.5	6.9	0.2
hole	1	-3.3	6.9	0.2
hole	1	-2.1	6.9	0.2
hole	1	-0.9	6.9	0.2
hole	1	6.9	-6.9	0.2
hole	1	5.7	-6.9	0.2
hole	1	4.5	-6.9	0.2
hole	1	3.3	-6.9	0.2
hole	1	2.1	-6.9	0.2
hole	1	0.9	-6.9	0.2
hole	1	-6.9	-6.9	0.2
hole	1	-5.7	-6.9	0.2
hole	1	-4.5	-6.9	0.2
hole	1	-3.3	-6.9	0.2
hole	1	-2.1	-6.9	0.2
hole	1	-0.9	-6.9	0.2
hole	1	6.9	5.7	0.2
hole	1	5.7	5.7	0.2
hole	1	4.5	5.7	0.2
hole	1	3.3	5.7	0.2
hole	1	2.1	5.7	0.2
hole	1	0.9	5.7	0.2
hole	1	-6.9	5.7	0.2
hole	1	-5.7	5.7	0.2
hole	1	-4.5	5.7	0.2
hole	1	-3.3	5.7	0.2
hole	1	-2.1	5.7	0.2
hole	1	-0.9	5.7	0.2
hole	1	6.9	-5.7	0.2
hole	1	5.7	-5.7	0.2
hole	1	4.5	-5.7	0.2
hole	1	3.3	-5.7	0.2
hole	1	2.1	-5.7	0.2
hole	1	0.9	-5.7	0.2
hole	1	-6.9	-5.7	0.2
hole	1	-5.7	-5.7	0.2
hole	1	-4.5	-5.7	0.2
hole	1	-3.3	-5.7	0.2
hole	1	-2.1	-5.7	0.2
hole	1	-0.9	-5.7	0.2
hole	1	6.9	4.5	0.2
hole	1	5.7	4.5	0.2
hole	1	4.5	4.5	0.2
hole	1	3.3	4.5	0.2
hole	1	2.1	4.5	0.2
hole	1	0.9	4.5	0.2
hole	1	-6.9	4.5	0.2
hole	1	-5.7	4.5	0.2
hole	1	-4.5	4.5	0.2
hole	1	-3.3	4.5	0.2
hole	1	-2.1	4.5	0.2
hole	1	-0.9	4.5	0.2

hole	1	6.9	-4.5	0.2
hole	1	5.7	-4.5	0.2
hole	1	4.5	-4.5	0.2
hole	1	3.3	-4.5	0.2
hole	1	2.1	-4.5	0.2
hole	1	0.9	-4.5	0.2
hole	1	-6.9	-4.5	0.2
hole	1	-5.7	-4.5	0.2
hole	1	-4.5	-4.5	0.2
hole	1	-3.3	-4.5	0.2
hole	1	-2.1	-4.5	0.2
hole	1	-0.9	-4.5	0.2
hole	1	6.9	3.3	0.2
hole	1	5.7	3.3	0.2
hole	1	4.5	3.3	0.2
hole	1	3.3	3.3	0.2
hole	1	2.1	3.3	0.2
hole	1	0.9	3.3	0.2
hole	1	-6.9	3.3	0.2
hole	1	-5.7	3.3	0.2
hole	1	-4.5	3.3	0.2
hole	1	-3.3	3.3	0.2
hole	1	-2.1	3.3	0.2
hole	1	-0.9	3.3	0.2
hole	1	6.9	-3.3	0.2
hole	1	5.7	-3.3	0.2
hole	1	4.5	-3.3	0.2
hole	1	3.3	-3.3	0.2
hole	1	2.1	-3.3	0.2
hole	1	0.9	-3.3	0.2
hole	1	-6.9	-3.3	0.2
hole	1	-5.7	-3.3	0.2
hole	1	-4.5	-3.3	0.2
hole	1	-3.3	-3.3	0.2
hole	1	-2.1	-3.3	0.2
hole	1	-0.9	-3.3	0.2
hole	1	6.9	2.1	0.2
hole	1	5.7	2.1	0.2
hole	1	4.5	2.1	0.2
hole	1	3.3	2.1	0.2
hole	1	2.1	2.1	0.2
hole	1	0.9	2.1	0.2
hole	1	-6.9	2.1	0.2
hole	1	-5.7	2.1	0.2
hole	1	-4.5	2.1	0.2
hole	1	-3.3	2.1	0.2
hole	1	-2.1	2.1	0.2
hole	1	-0.9	2.1	0.2
hole	1	6.9	-2.1	0.2
hole	1	5.7	-2.1	0.2
hole	1	4.5	-2.1	0.2
hole	1	3.3	-2.1	0.2
hole	1	2.1	-2.1	0.2
hole	1	0.9	-2.1	0.2
hole	1	-6.9	-2.1	0.2
hole	1	-5.7	-2.1	0.2
hole	1	-4.5	-2.1	0.2

```
  hole 1     -3.3      -2.1       0.2
  hole 1     -2.1      -2.1       0.2
  hole 1     -0.9      -2.1       0.2
  hole 1      6.9       0.9       0.2
  hole 1      5.7       0.9       0.2
  hole 1      4.5       0.9       0.2
  hole 1      3.3       0.9       0.2
  hole 1      2.1       0.9       0.2
  hole 1      0.9       0.9       0.2
  hole 1     -6.9       0.9       0.2
  hole 1     -5.7       0.9       0.2
  hole 1     -4.5       0.9       0.2
  hole 1     -3.3       0.9       0.2
  hole 1     -2.1       0.9       0.2
  hole 1     -0.9       0.9       0.2
  hole 1      6.9      -0.9       0.2
  hole 1      5.7      -0.9       0.2
  hole 1      4.5      -0.9       0.2
  hole 1      3.3      -0.9       0.2
  hole 1      2.1      -0.9       0.2
  hole 1      0.9      -0.9       0.2
  hole 1     -6.9      -0.9       0.2
  hole 1     -5.7      -0.9       0.2
  hole 1     -4.5      -0.9       0.2
  hole 1     -3.3      -0.9       0.2
  hole 1     -2.1      -0.9       0.2
  hole 1     -0.9      -0.9       0.2
 cuboid 3 1       7.6      -7.6       7.6      -7.6       7.7        0
unit 3
com='single rack of boxes'
 cuboid 0 1       240         0        16         0       150        0
  hole 2        8         8        0
  hole 2       24         8        0
  hole 2       40         8        0
  hole 2       56         8        0
  hole 2       72         8        0
  hole 2       88         8        0
  hole 2      104         8        0
  hole 2      120         8        0
  hole 2      136         8        0
  hole 2      152         8        0
  hole 2      168         8        0
  hole 2      184         8        0
  hole 2      200         8        0
  hole 2      216         8        0
  hole 2      232         8        0
  hole 2        8         8       16
  hole 2       24         8       16
  hole 2       40         8       16
  hole 2       56         8       16
  hole 2       72         8       16
  hole 2       88         8       16
  hole 2      104         8       16
  hole 2      120         8       16
  hole 2      136         8       16
  hole 2      152         8       16
  hole 2      168         8       16
```

hole	2	184	8	16
hole	2	200	8	16
hole	2	216	8	16
hole	2	232	8	16
hole	2	8	8	32
hole	2	24	8	32
hole	2	40	8	32
hole	2	56	8	32
hole	2	72	8	32
hole	2	88	8	32
hole	2	104	8	32
hole	2	120	8	32
hole	2	136	8	32
hole	2	152	8	32
hole	2	168	8	32
hole	2	184	8	32
hole	2	200	8	32
hole	2	216	8	32
hole	2	232	8	32
hole	2	8	8	48
hole	2	24	8	48
hole	2	40	8	48
hole	2	56	8	48
hole	2	72	8	48
hole	2	88	8	48
hole	2	104	8	48
hole	2	120	8	48
hole	2	136	8	48
hole	2	152	8	48
hole	2	168	8	48
hole	2	184	8	48
hole	2	200	8	48
hole	2	216	8	48
hole	2	232	8	48
hole	2	8	8	64
hole	2	24	8	64
hole	2	40	8	64
hole	2	56	8	64
hole	2	72	8	64
hole	2	88	8	64
hole	2	104	8	64
hole	2	120	8	64
hole	2	136	8	64
hole	2	152	8	64
hole	2	168	8	64
hole	2	184	8	64
hole	2	200	8	64
hole	2	216	8	64
hole	2	232	8	64
hole	2	8	8	80
hole	2	24	8	80
hole	2	40	8	80
hole	2	56	8	80
hole	2	72	8	80
hole	2	88	8	80
hole	2	104	8	80
hole	2	120	8	80

```
  hole 2      136          8        80
  hole 2      152          8        80
  hole 2      168          8        80
  hole 2      184          8        80
  hole 2      200          8        80
  hole 2      216          8        80
  hole 2      232          8        80
  hole 2        8          8        96
  hole 2       24          8        96
  hole 2       40          8        96
  hole 2       56          8        96
  hole 2       72          8        96
  hole 2       88          8        96
  hole 2      104          8        96
  hole 2      120          8        96
  hole 2      136          8        96
  hole 2      152          8        96
  hole 2      168          8        96
  hole 2      184          8        96
  hole 2      200          8        96
  hole 2      216          8        96
  hole 2      232          8        96
  hole 2        8          8       112
  hole 2       24          8       112
  hole 2       40          8       112
  hole 2       56          8       112
  hole 2       72          8       112
  hole 2       88          8       112
  hole 2      104          8       112
  hole 2      120          8       112
  hole 2      136          8       112
  hole 2      152          8       112
  hole 2      168          8       112
  hole 2      184          8       112
  hole 2      200          8       112
  hole 2      216          8       112
  hole 2      232          8       112
unit 4
com='y orientation'
 cuboid 0 1        16         0       240         0       150         0
  hole 2        8          8         0
  hole 2        8         24         0
  hole 2        8         40         0
  hole 2        8         56         0
  hole 2        8         72         0
  hole 2        8         88         0
  hole 2        8        104         0
  hole 2        8        120         0
  hole 2        8        136         0
  hole 2        8        152         0
  hole 2        8        168         0
  hole 2        8        184         0
  hole 2        8        200         0
  hole 2        8        216         0
  hole 2        8        232         0
  hole 2        8          8        16
  hole 2        8         24        16
```

hole 2	8	40	16
hole 2	8	56	16
hole 2	8	72	16
hole 2	8	88	16
hole 2	8	104	16
hole 2	8	120	16
hole 2	8	136	16
hole 2	8	152	16
hole 2	8	168	16
hole 2	8	184	16
hole 2	8	200	16
hole 2	8	216	16
hole 2	8	232	16
hole 2	8	8	32
hole 2	8	24	32
hole 2	8	40	32
hole 2	8	56	32
hole 2	8	72	32
hole 2	8	88	32
hole 2	8	104	32
hole 2	8	120	32
hole 2	8	136	32
hole 2	8	152	32
hole 2	8	168	32
hole 2	8	184	32
hole 2	8	200	32
hole 2	8	216	32
hole 2	8	232	32
hole 2	8	8	48
hole 2	8	24	48
hole 2	8	40	48
hole 2	8	56	48
hole 2	8	72	48
hole 2	8	88	48
hole 2	8	104	48
hole 2	8	120	48
hole 2	8	136	48
hole 2	8	152	48
hole 2	8	168	48
hole 2	8	184	48
hole 2	8	200	48
hole 2	8	216	48
hole 2	8	232	48
hole 2	8	8	64
hole 2	8	24	64
hole 2	8	40	64
hole 2	8	56	64
hole 2	8	72	64
hole 2	8	88	64
hole 2	8	104	64
hole 2	8	120	64
hole 2	8	136	64
hole 2	8	152	64
hole 2	8	168	64
hole 2	8	184	64
hole 2	8	200	64
hole 2	8	216	64

```
   hole 2       8      232       64
   hole 2       8        8       80
   hole 2       8       24       80
   hole 2       8       40       80
   hole 2       8       56       80
   hole 2       8       72       80
   hole 2       8       88       80
   hole 2       8      104       80
   hole 2       8      120       80
   hole 2       8      136       80
   hole 2       8      152       80
   hole 2       8      168       80
   hole 2       8      184       80
   hole 2       8      200       80
   hole 2       8      216       80
   hole 2       8      232       80
   hole 2       8        8       96
   hole 2       8       24       96
   hole 2       8       40       96
   hole 2       8       56       96
   hole 2       8       72       96
   hole 2       8       88       96
   hole 2       8      104       96
   hole 2       8      120       96
   hole 2       8      136       96
   hole 2       8      152       96
   hole 2       8      168       96
   hole 2       8      184       96
   hole 2       8      200       96
   hole 2       8      216       96
   hole 2       8      232       96
   hole 2       8        8      112
   hole 2       8       24      112
   hole 2       8       40      112
   hole 2       8       56      112
   hole 2       8       72      112
   hole 2       8       88      112
   hole 2       8      104      112
   hole 2       8      120      112
   hole 2       8      136      112
   hole 2       8      152      112
   hole 2       8      168      112
   hole 2       8      184      112
   hole 2       8      200      112
   hole 2       8      216      112
   hole 2       8      232      112
global unit 5
com='rack room'
  cuboid 0 1     1232         0      1712         0       300        30
   hole 3      16        0       30
   hole 3     496        0       30
   hole 3     736        0       30
   hole 3     976        0       30
   hole 3      16     1696       30
   hole 3     256     1696       30
   hole 3     496     1696       30
   hole 3     976     1696       30
```

```
 hole 4        0       16       30
 hole 4        0      256       30
 hole 4        0      496       30
 hole 4        0      736       30
 hole 4        0      976       30
 hole 4        0     1216       30
 hole 4        0     1456       30
 hole 4     1216       16       30
 hole 4     1216      256       30
 hole 4     1216      496       30
 hole 4     1216      736       30
 hole 4     1216      976       30
 hole 4     1216     1216       30
 hole 4     1216     1456       30
 hole 4      300      256       30
 hole 4      300      496       30
 hole 4      300      736       30
 hole 4      300      976       30
 hole 4      300     1216       30
 hole 4      600      256       30
 hole 4      600      496       30
 hole 4      600      736       30
 hole 4      600      976       30
 hole 4      600     1216       30
 hole 4      900      256       30
 hole 4      900      496       30
 hole 4      900      736       30
 hole 4      900      976       30
 hole 4      900     1216       30
cuboid 0 1      1232        0      1712        0       300        0
cuboid 5 1      1332     -100      1812     -100       400     -100
end geometry
read plot
 scr=yes
 ttl='storage room cross section at z = 34 cm'
 pic=mixtures
 xul=-20
 yul=1730
 zul=34
 xlr=1240
 ylr=-20
 zlr=34
 nax=1200
 clr=1 224 104 52
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 vdn=-1
  end
 scr=yes
 ttl='cross section of storage rack'
 pic=mixtures
 xul=15
 yul=8
```

```
 zul=310
 xlr=257
 ylr=8
 zlr=15
 nax=1200
 clr=1 200 200 200
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 wdn=-1
  end
 scr=yes
 ttl='cross section of storage rack'
 pic=mixtures
 xul=14
 yul=20
 zul=35
 xlr=30
 ylr=-2
 zlr=35
 nax=1200
 clr=1 228 5 67
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 vdn=-1
  end
end plot
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=mirror
 -zb=mirror
  end bnds
end data
read sams
  prtgeom
end sams
end
```

A file comparison with CASE3B.inp returns:

```
Comparing files case3a.inp and CASE3B.INP
***** case3a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 pellets in boxes
238groupndf5
***** CASE3B.INP
```

```
=tsunami-3d-k5 parm=(nitawlst)
storage of 6% enriched uo2 pellets in boxes
238groupndf5
*****

***** case3a.inp
                                92234 0.005407837
                                92235 5
                                92238 94.99459   end
 ss316       2 1 300   end
***** CASE3B.INP
                                92234 0.005407837
                                92235 6
                                92238 93.99459   end
 ss316       2 1 300   end
*****
```

A file comparison with CASE3C.inp returns:

```
Comparing files case3a.inp and CASE3C.INP
***** case3a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 pellets in boxes
238groupndf5
***** CASE3C.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 8% enriched uo2 pellets in boxes
238groupndf5
*****

***** case3a.inp
                                92234 0.005407837
                                92235 5
                                92238 94.99459   end
 ss316       2 1 300   end
***** CASE3C.INP
                                92234 0.005407837
                                92235 8
                                92238 91.99459   end
 ss316       2 1 300   end
*****
```

A file comparison with CASE3D.inp returns:

```
Comparing files case3a.inp and CASE3D.INP
***** case3a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 pellets in boxes
238groupndf5
***** CASE3D.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 10% enriched uo2 pellets in boxes
238groupndf5
*****
```

```
***** case3a.inp
                                      92234 0.005407837
                                      92235 5
                                      92238 94.99459   end
 ss316       2 1 300   end
***** CASE3D.INP
                                      92234 0.005407837
                                      92235 10
                                      92238 89.99459   end
 ss316       2 1 300   end
*****
```

Normal Base Case 4: TRISO pellets in boxes

The input deck for the normal case (CASE4A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched TRISO powder in storage rack arrays
238groupndf5
read composition
 uo2         1 0.1605 300
                                      92235 5
                                      92238 95   end
 c           1 0.6698 300    end
 si          1 0.0874 300    end
 gd          1 2e-05 300    end
 ss316       2 1 300   end
 aluminum    3 1 300   end
 h2o         4 0.06 300   end
 orconcrete  5 1 300   end
 h2o         6 1 300   end
end composition
read parameter
 gen=130
 npg=1000
 nsk=30
 htm=yes
 fdn=yes
 apg=10000
 agn=630
end parameter
read geometry
unit 1
com='fuel pin'
 zcylinder 1 1    0.75        7        0
unit 2
com='pins in box'
 cuboid 0 1    7.5     -7.5       7.5     -7.5       7.5       0.2
 hole 1 6.75 6.75 0.2
 hole 1 5.25 6.75 0.2
 hole 1 3.75 6.75 0.2
 hole 1 2.25 6.75 0.2
 hole 1 0.75 6.75 0.2
```

```
hole 1 6.75 -6.75 0.2
hole 1 5.25 -6.75 0.2
hole 1 3.75 -6.75 0.2
hole 1 2.25 -6.75 0.2
hole 1 0.75 -6.75 0.2
hole 1 -6.75 6.75 0.2
hole 1 -5.25 6.75 0.2
hole 1 -3.75 6.75 0.2
hole 1 -2.25 6.75 0.2
hole 1 -0.75 6.75 0.2
hole 1 -6.75 -6.75 0.2
hole 1 -5.25 -6.75 0.2
hole 1 -3.75 -6.75 0.2
hole 1 -2.25 -6.75 0.2
hole 1 -0.75 -6.75 0.2
hole 1 6.75 5.25 0.2
hole 1 5.25 5.25 0.2
hole 1 3.75 5.25 0.2
hole 1 2.25 5.25 0.2
hole 1 0.75 5.25 0.2
hole 1 6.75 -5.25 0.2
hole 1 5.25 -5.25 0.2
hole 1 3.75 -5.25 0.2
hole 1 2.25 -5.25 0.2
hole 1 0.75 -5.25 0.2
hole 1 -6.75 5.25 0.2
hole 1 -5.25 5.25 0.2
hole 1 -3.75 5.25 0.2
hole 1 -2.25 5.25 0.2
hole 1 -0.75 5.25 0.2
hole 1 -6.75 -5.25 0.2
hole 1 -5.25 -5.25 0.2
hole 1 -3.75 -5.25 0.2
hole 1 -2.25 -5.25 0.2
hole 1 -0.75 -5.25 0.2
hole 1 6.75 3.75 0.2
hole 1 5.25 3.75 0.2
hole 1 3.75 3.75 0.2
hole 1 2.25 3.75 0.2
hole 1 0.75 3.75 0.2
hole 1 6.75 -3.75 0.2
hole 1 5.25 -3.75 0.2
hole 1 3.75 -3.75 0.2
hole 1 2.25 -3.75 0.2
hole 1 0.75 -3.75 0.2
hole 1 -6.75 3.75 0.2
hole 1 -5.25 3.75 0.2
hole 1 -3.75 3.75 0.2
hole 1 -2.25 3.75 0.2
hole 1 -0.75 3.75 0.2
hole 1 -6.75 -3.75 0.2
hole 1 -5.25 -3.75 0.2
hole 1 -3.75 -3.75 0.2
hole 1 -2.25 -3.75 0.2
hole 1 -0.75 -3.75 0.2
hole 1 6.75 2.25 0.2
hole 1 5.25 2.25 0.2
```

```
 hole 1 3.75 2.25 0.2
 hole 1 2.25 2.25 0.2
 hole 1 0.75 2.25 0.2
 hole 1 6.75 -2.25 0.2
 hole 1 5.25 -2.25 0.2
 hole 1 3.75 -2.25 0.2
 hole 1 2.25 -2.25 0.2
 hole 1 0.75 -2.25 0.2
 hole 1 -6.75 2.25 0.2
 hole 1 -5.25 2.25 0.2
 hole 1 -3.75 2.25 0.2
 hole 1 -2.25 2.25 0.2
 hole 1 -0.75 2.25 0.2
 hole 1 -6.75 -2.25 0.2
 hole 1 -5.25 -2.25 0.2
 hole 1 -3.75 -2.25 0.2
 hole 1 -2.25 -2.25 0.2
 hole 1 -0.75 -2.25 0.2
 hole 1 6.75 0.75 0.2
 hole 1 5.25 0.75 0.2
 hole 1 3.75 0.75 0.2
 hole 1 2.25 0.75 0.2
 hole 1 0.75 0.75 0.2
 hole 1 6.75 -0.75 0.2
 hole 1 5.25 -0.75 0.2
 hole 1 3.75 -0.75 0.2
 hole 1 2.25 -0.75 0.2
 hole 1 0.75 -0.75 0.2
 hole 1 -6.75 0.75 0.2
 hole 1 -5.25 0.75 0.2
 hole 1 -3.75 0.75 0.2
 hole 1 -2.25 0.75 0.2
 hole 1 -0.75 0.75 0.2
 hole 1 -6.75 -0.75 0.2
 hole 1 -5.25 -0.75 0.2
 hole 1 -3.75 -0.75 0.2
 hole 1 -2.25 -0.75 0.2
 hole 1 -0.75 -0.75 0.2
 cuboid 3 1      7.6     -7.6       7.6     -7.6       7.7        0
unit 3
com='single rack of boxes'
 cuboid 0 1      240        0        16        0       150        0
  hole 2      8        8        0
  hole 2     24        8        0
  hole 2     40        8        0
  hole 2     56        8        0
  hole 2     72        8        0
  hole 2     88        8        0
  hole 2    104        8        0
  hole 2    120        8        0
  hole 2    136        8        0
  hole 2    152        8        0
  hole 2    168        8        0
  hole 2    184        8        0
  hole 2    200        8        0
  hole 2    216        8        0
  hole 2    232        8        0
```

hole 2	8	8	16
hole 2	24	8	16
hole 2	40	8	16
hole 2	56	8	16
hole 2	72	8	16
hole 2	88	8	16
hole 2	104	8	16
hole 2	120	8	16
hole 2	136	8	16
hole 2	152	8	16
hole 2	168	8	16
hole 2	184	8	16
hole 2	200	8	16
hole 2	216	8	16
hole 2	232	8	16
hole 2	8	8	32
hole 2	24	8	32
hole 2	40	8	32
hole 2	56	8	32
hole 2	72	8	32
hole 2	88	8	32
hole 2	104	8	32
hole 2	120	8	32
hole 2	136	8	32
hole 2	152	8	32
hole 2	168	8	32
hole 2	184	8	32
hole 2	200	8	32
hole 2	216	8	32
hole 2	232	8	32
hole 2	8	8	48
hole 2	24	8	48
hole 2	40	8	48
hole 2	56	8	48
hole 2	72	8	48
hole 2	88	8	48
hole 2	104	8	48
hole 2	120	8	48
hole 2	136	8	48
hole 2	152	8	48
hole 2	168	8	48
hole 2	184	8	48
hole 2	200	8	48
hole 2	216	8	48
hole 2	232	8	48
hole 2	8	8	64
hole 2	24	8	64
hole 2	40	8	64
hole 2	56	8	64
hole 2	72	8	64
hole 2	88	8	64
hole 2	104	8	64
hole 2	120	8	64
hole 2	136	8	64
hole 2	152	8	64
hole 2	168	8	64
hole 2	184	8	64

```
  hole 2     200        8        64
  hole 2     216        8        64
  hole 2     232        8        64
  hole 2       8        8        80
  hole 2      24        8        80
  hole 2      40        8        80
  hole 2      56        8        80
  hole 2      72        8        80
  hole 2      88        8        80
  hole 2     104        8        80
  hole 2     120        8        80
  hole 2     136        8        80
  hole 2     152        8        80
  hole 2     168        8        80
  hole 2     184        8        80
  hole 2     200        8        80
  hole 2     216        8        80
  hole 2     232        8        80
  hole 2       8        8        96
  hole 2      24        8        96
  hole 2      40        8        96
  hole 2      56        8        96
  hole 2      72        8        96
  hole 2      88        8        96
  hole 2     104        8        96
  hole 2     120        8        96
  hole 2     136        8        96
  hole 2     152        8        96
  hole 2     168        8        96
  hole 2     184        8        96
  hole 2     200        8        96
  hole 2     216        8        96
  hole 2     232        8        96
  hole 2       8        8       112
  hole 2      24        8       112
  hole 2      40        8       112
  hole 2      56        8       112
  hole 2      72        8       112
  hole 2      88        8       112
  hole 2     104        8       112
  hole 2     120        8       112
  hole 2     136        8       112
  hole 2     152        8       112
  hole 2     168        8       112
  hole 2     184        8       112
  hole 2     200        8       112
  hole 2     216        8       112
  hole 2     232        8       112
unit 4
com='y orientation'
 cuboid 0 1        16        0        240        0        150        0
  hole 2       8        8        0
  hole 2       8       24        0
  hole 2       8       40        0
  hole 2       8       56        0
  hole 2       8       72        0
  hole 2       8       88        0
```

hole 2	8	104	0
hole 2	8	120	0
hole 2	8	136	0
hole 2	8	152	0
hole 2	8	168	0
hole 2	8	184	0
hole 2	8	200	0
hole 2	8	216	0
hole 2	8	232	0
hole 2	8	8	16
hole 2	8	24	16
hole 2	8	40	16
hole 2	8	56	16
hole 2	8	72	16
hole 2	8	88	16
hole 2	8	104	16
hole 2	8	120	16
hole 2	8	136	16
hole 2	8	152	16
hole 2	8	168	16
hole 2	8	184	16
hole 2	8	200	16
hole 2	8	216	16
hole 2	8	232	16
hole 2	8	8	32
hole 2	8	24	32
hole 2	8	40	32
hole 2	8	56	32
hole 2	8	72	32
hole 2	8	88	32
hole 2	8	104	32
hole 2	8	120	32
hole 2	8	136	32
hole 2	8	152	32
hole 2	8	168	32
hole 2	8	184	32
hole 2	8	200	32
hole 2	8	216	32
hole 2	8	232	32
hole 2	8	8	48
hole 2	8	24	48
hole 2	8	40	48
hole 2	8	56	48
hole 2	8	72	48
hole 2	8	88	48
hole 2	8	104	48
hole 2	8	120	48
hole 2	8	136	48
hole 2	8	152	48
hole 2	8	168	48
hole 2	8	184	48
hole 2	8	200	48
hole 2	8	216	48
hole 2	8	232	48
hole 2	8	8	64
hole 2	8	24	64
hole 2	8	40	64

hole 2	8	56	64
hole 2	8	72	64
hole 2	8	88	64
hole 2	8	104	64
hole 2	8	120	64
hole 2	8	136	64
hole 2	8	152	64
hole 2	8	168	64
hole 2	8	184	64
hole 2	8	200	64
hole 2	8	216	64
hole 2	8	232	64
hole 2	8	8	80
hole 2	8	24	80
hole 2	8	40	80
hole 2	8	56	80
hole 2	8	72	80
hole 2	8	88	80
hole 2	8	104	80
hole 2	8	120	80
hole 2	8	136	80
hole 2	8	152	80
hole 2	8	168	80
hole 2	8	184	80
hole 2	8	200	80
hole 2	8	216	80
hole 2	8	232	80
hole 2	8	8	96
hole 2	8	24	96
hole 2	8	40	96
hole 2	8	56	96
hole 2	8	72	96
hole 2	8	88	96
hole 2	8	104	96
hole 2	8	120	96
hole 2	8	136	96
hole 2	8	152	96
hole 2	8	168	96
hole 2	8	184	96
hole 2	8	200	96
hole 2	8	216	96
hole 2	8	232	96
hole 2	8	8	112
hole 2	8	24	112
hole 2	8	40	112
hole 2	8	56	112
hole 2	8	72	112
hole 2	8	88	112
hole 2	8	104	112
hole 2	8	120	112
hole 2	8	136	112
hole 2	8	152	112
hole 2	8	168	112
hole 2	8	184	112
hole 2	8	200	112
hole 2	8	216	112
hole 2	8	232	112

```
global unit 5
com='rack room'
 cuboid 0 1      1232         0      1712         0       300        30
  hole 3       16        0       30
  hole 3      496        0       30
  hole 3      736        0       30
  hole 3      976        0       30
  hole 3       16     1696       30
  hole 3      256     1696       30
  hole 3      496     1696       30
  hole 3      976     1696       30
  hole 4        0       16       30
  hole 4        0      256       30
  hole 4        0      496       30
  hole 4        0      736       30
  hole 4        0      976       30
  hole 4        0     1216       30
  hole 4        0     1456       30
  hole 4     1216       16       30
  hole 4     1216      256       30
  hole 4     1216      496       30
  hole 4     1216      736       30
  hole 4     1216      976       30
  hole 4     1216     1216       30
  hole 4     1216     1456       30
  hole 4      300      256       30
  hole 4      300      496       30
  hole 4      300      736       30
  hole 4      300      976       30
  hole 4      300     1216       30
  hole 4      600      256       30
  hole 4      600      496       30
  hole 4      600      736       30
  hole 4      600      976       30
  hole 4      600     1216       30
  hole 4      900      256       30
  hole 4      900      496       30
  hole 4      900      736       30
  hole 4      900      976       30
  hole 4      900     1216       30
 cuboid 0 1      1232         0      1712         0       300         0
 cuboid 5 1      1332      -100      1812      -100       400      -100
end geometry
read plot
 scr=yes
 ttl='storage room cross section at z = 34 cm'
 pic=mixtures
 xul=-20
 yul=1730
 zul=34
 xlr=1240
 ylr=-20
 zlr=34
 nax=1200
 clr=1 224 104 52
     2 0 0 205
     3 0 229 238
```

```
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 vdn=-1
  end
 scr=yes
 ttl='cross section of storage rack'
 pic=mixtures
 xul=15
 yul=8
 zul=310
 xlr=257
 ylr=8
 zlr=15
 nax=1200
 clr=1 200 200 200
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 wdn=-1
  end
 scr=yes
 ttl='cross section of storage rack'
 pic=mixtures
 xul=14
 yul=20
 zul=35
 xlr=30
 ylr=-2
 zlr=35
 nax=1200
 clr=1 228 5 67
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
 end color
 uax=1 vdn=-1
  end
end plot
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=mirror
 -zb=mirror
  end bnds
end data
read sams
  prtgeom
end sams
```

```
end
```

A file comparison with CASE4B.inp returns:

```
Comparing files case4a.inp and CASE4B.INP
***** case4a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched TRISO powder in storage rack arrays
238groupndf5
***** CASE4B.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 6% enriched TRISO powder in storage rack arrays
238groupndf5
*****

***** case4a.inp
 uo2          1 0.1605 300
                                 92235 5
                                 92238 95   end
 c            1 0.6698 300    end
***** CASE4B.INP
 uo2          1 0.1605 300
                                 92235 6
                                 92238 94   end
 c            1 0.6698 300    end
*****
```

A file comparison with CASE4C.inp returns:

```
Comparing files case4a.inp and CASE4C.INP
***** case4a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched TRISO powder in storage rack arrays
238groupndf5
***** CASE4C.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 8% enriched TRISO powder in storage rack arrays
238groupndf5
*****

***** case4a.inp
 uo2          1 0.1605 300
                                 92235 5
                                 92238 95   end
 c            1 0.6698 300    end
***** CASE4C.INP
 uo2          1 0.1605 300
                                 92235 8
                                 92238 92   end
 c            1 0.6698 300    end
*****
```

A file comparison with CASE4D.inp returns:

```
Comparing files case4a.inp and CASE4D.INP
```

```
***** case4a.inp
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched TRISO powder in storage rack arrays
238groupndf5
***** CASE4D.INP
=tsunami-3d-k5 parm=(nitawlst)
storage of 10% enriched TRISO powder in storage rack arrays
238groupndf5
*****

***** case4a.inp
 uo2          1 0.1605 300
                                  92235 5
                                  92238 95    end
 c            1 0.6698 300    end
***** CASE4D.INP
 uo2          1 0.1605 300
                                  92235 10
                                  92238 90    end
 c            1 0.6698 300    end
*****
```

Normal Base Case 5: UO_2, zircaloy clad fuel pin array in shipping cask

The input deck for the normal case (CASE5A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
base case 5a:  17x17 array of 5.0% enriched pwr fuel pins
238groupndf5
read composition
 uo2          1 1.0000 300
                                  92234 0.005407837
                                  92235 5
                                  92238 94.99459    end
 helium       2 1.e-10 300    end
 wtptzircaloy-4   3  6.501  5
                                  40000 98.24
                                  50000 1.45
                                  24000 0.1
                                  26000 0.2
                                  72000 0.01
                          1 300   end
 h2o          4 1 300    end
 pyrex        5 1 300
                                  5010 18.4309
                                  5011 81.5691    end
 orconcrete   6 1 300    end
 ss304        7 1 300    end
 aluminum     8 1 300    end
end composition
read celldata
  latticecell squarepitch fuelr=0.55 1 gapr=0.62 2 cladr=0.647 3
hpitch=0.7 4 end
end celldata
```

```
read parameter
 gen=130
 npg=1000
 nsk=30
 htm=yes
 fdn=yes
 apg=10000
 agn=630
end parameter
read geometry
unit 1
com='fuel pin'
 zcylinder 1 1     0.55       366         0
 zcylinder 2 1     0.62       366         0
 zcylinder 3 1    0.647       366         0
unit 2
com='control rod'
 zcylinder 2 1     0.09       120         0
 zcylinder 5 1     0.18       120         0
 zcylinder 2 1      0.2       120         0
 zcylinder 4 1     0.23       120         0
unit 3
com='array of pins'
 cuboid 4 1      24.5      -0.7      24.5      -0.7      366         0
  hole 1        0         0         0
  hole 1        0       1.4         0
  hole 1        0       2.8         0
  hole 1        0       4.2         0
  hole 1        0       5.6         0
  hole 1        0         7         0
  hole 1        0       8.4         0
  hole 1        0       9.8         0
  hole 1        0      11.2         0
  hole 1        0      12.6         0
  hole 1        0        14         0
  hole 1        0      15.4         0
  hole 1        0      16.8         0
  hole 1        0      18.2         0
  hole 1        0      19.6         0
  hole 1        0        21         0
  hole 1        0      22.4         0
  hole 1        0      23.8         0
  hole 1      1.4         0         0
  hole 1      1.4       1.4         0
  hole 1      1.4       2.8         0
  hole 1      1.4       4.2         0
  hole 1      1.4       5.6         0
  hole 1      1.4         7         0
  hole 1      1.4       8.4         0
  hole 1      1.4       9.8         0
  hole 1      1.4      11.2         0
  hole 1      1.4      12.6         0
  hole 1      1.4        14         0
  hole 1      1.4      15.4         0
  hole 1      1.4      16.8         0
  hole 1      1.4      18.2         0
  hole 1      1.4      19.6         0
```

hole	1	1.4	21	0
hole	1	1.4	22.4	0
hole	1	1.4	23.8	0
hole	1	2.8	0	0
hole	1	2.8	1.4	0
hole	1	2.8	2.8	0
hole	1	2.8	4.2	0
hole	1	2.8	5.6	0
hole	1	2.8	7	0
hole	1	2.8	8.4	0
hole	1	2.8	9.8	0
hole	1	2.8	11.2	0
hole	1	2.8	12.6	0
hole	1	2.8	14	0
hole	1	2.8	15.4	0
hole	1	2.8	16.8	0
hole	1	2.8	18.2	0
hole	1	2.8	19.6	0
hole	1	2.8	21	0
hole	1	2.8	22.4	0
hole	1	2.8	23.8	0
hole	1	4.2	0	0
hole	1	4.2	1.4	0
hole	1	4.2	2.8	0
hole	1	4.2	4.2	0
hole	1	4.2	5.6	0
hole	1	4.2	7	0
hole	1	4.2	8.4	0
hole	1	4.2	9.8	0
hole	1	4.2	11.2	0
hole	1	4.2	12.6	0
hole	1	4.2	14	0
hole	1	4.2	15.4	0
hole	1	4.2	16.8	0
hole	1	4.2	18.2	0
hole	1	4.2	19.6	0
hole	1	4.2	21	0
hole	1	4.2	22.4	0
hole	1	4.2	23.8	0
hole	1	5.6	0	0
hole	1	5.6	1.4	0
hole	1	5.6	2.8	0
hole	1	5.6	4.2	0
hole	1	5.6	5.6	0
hole	1	5.6	7	0
hole	1	5.6	8.4	0
hole	1	5.6	9.8	0
hole	1	5.6	11.2	0
hole	1	5.6	12.6	0
hole	1	5.6	14	0
hole	1	5.6	15.4	0
hole	1	5.6	16.8	0
hole	1	5.6	18.2	0
hole	1	5.6	19.6	0
hole	1	5.6	21	0
hole	1	5.6	22.4	0
hole	1	5.6	23.8	0

hole	1	7	0	0
hole	1	7	1.4	0
hole	1	7	2.8	0
hole	1	7	4.2	0
hole	1	7	5.6	0
hole	1	7	7	0
hole	1	7	8.4	0
hole	1	7	9.8	0
hole	1	7	11.2	0
hole	1	7	12.6	0
hole	1	7	14	0
hole	1	7	15.4	0
hole	1	7	16.8	0
hole	1	7	18.2	0
hole	1	7	19.6	0
hole	1	7	21	0
hole	1	7	22.4	0
hole	1	7	23.8	0
hole	1	8.4	0	0
hole	1	8.4	1.4	0
hole	1	8.4	2.8	0
hole	1	8.4	4.2	0
hole	1	8.4	5.6	0
hole	1	8.4	7	0
hole	1	8.4	8.4	0
hole	1	8.4	9.8	0
hole	1	8.4	11.2	0
hole	1	8.4	12.6	0
hole	1	8.4	14	0
hole	1	8.4	15.4	0
hole	1	8.4	16.8	0
hole	1	8.4	18.2	0
hole	1	8.4	19.6	0
hole	1	8.4	21	0
hole	1	8.4	22.4	0
hole	1	8.4	23.8	0
hole	1	9.8	0	0
hole	1	9.8	1.4	0
hole	1	9.8	2.8	0
hole	1	9.8	4.2	0
hole	1	9.8	5.6	0
hole	1	9.8	7	0
hole	1	9.8	8.4	0
hole	1	9.8	9.8	0
hole	1	9.8	11.2	0
hole	1	9.8	12.6	0
hole	1	9.8	14	0
hole	1	9.8	15.4	0
hole	1	9.8	16.8	0
hole	1	9.8	18.2	0
hole	1	9.8	19.6	0
hole	1	9.8	21	0
hole	1	9.8	22.4	0
hole	1	9.8	23.8	0
hole	1	11.2	0	0
hole	1	11.2	1.4	0
hole	1	11.2	2.8	0

hole 1	11.2	4.2	0
hole 1	11.2	5.6	0
hole 1	11.2	7	0
hole 1	11.2	8.4	0
hole 1	11.2	9.8	0
hole 1	11.2	11.2	0
hole 1	11.2	12.6	0
hole 1	11.2	14	0
hole 1	11.2	15.4	0
hole 1	11.2	16.8	0
hole 1	11.2	18.2	0
hole 1	11.2	19.6	0
hole 1	11.2	21	0
hole 1	11.2	22.4	0
hole 1	11.2	23.8	0
hole 1	12.6	0	0
hole 1	12.6	1.4	0
hole 1	12.6	2.8	0
hole 1	12.6	4.2	0
hole 1	12.6	5.6	0
hole 1	12.6	7	0
hole 1	12.6	8.4	0
hole 1	12.6	9.8	0
hole 1	12.6	11.2	0
hole 1	12.6	12.6	0
hole 1	12.6	14	0
hole 1	12.6	15.4	0
hole 1	12.6	16.8	0
hole 1	12.6	18.2	0
hole 1	12.6	19.6	0
hole 1	12.6	21	0
hole 1	12.6	22.4	0
hole 1	12.6	23.8	0
hole 1	14	0	0
hole 1	14	1.4	0
hole 1	14	2.8	0
hole 1	14	4.2	0
hole 1	14	5.6	0
hole 1	14	7	0
hole 1	14	8.4	0
hole 1	14	9.8	0
hole 1	14	11.2	0
hole 1	14	12.6	0
hole 1	14	14	0
hole 1	14	15.4	0
hole 1	14	16.8	0
hole 1	14	18.2	0
hole 1	14	19.6	0
hole 1	14	21	0
hole 1	14	22.4	0
hole 1	14	23.8	0
hole 1	15.4	0	0
hole 1	15.4	1.4	0
hole 1	15.4	2.8	0
hole 1	15.4	4.2	0
hole 1	15.4	5.6	0
hole 1	15.4	7	0

hole	1	15.4	8.4	0
hole	1	15.4	9.8	0
hole	1	15.4	11.2	0
hole	1	15.4	12.6	0
hole	1	15.4	14	0
hole	1	15.4	15.4	0
hole	1	15.4	16.8	0
hole	1	15.4	18.2	0
hole	1	15.4	19.6	0
hole	1	15.4	21	0
hole	1	15.4	22.4	0
hole	1	15.4	23.8	0
hole	1	16.8	0	0
hole	1	16.8	1.4	0
hole	1	16.8	2.8	0
hole	1	16.8	4.2	0
hole	1	16.8	5.6	0
hole	1	16.8	7	0
hole	1	16.8	8.4	0
hole	1	16.8	9.8	0
hole	1	16.8	11.2	0
hole	1	16.8	12.6	0
hole	1	16.8	14	0
hole	1	16.8	15.4	0
hole	1	16.8	16.8	0
hole	1	16.8	18.2	0
hole	1	16.8	19.6	0
hole	1	16.8	21	0
hole	1	16.8	22.4	0
hole	1	16.8	23.8	0
hole	1	18.2	0	0
hole	1	18.2	1.4	0
hole	1	18.2	2.8	0
hole	1	18.2	4.2	0
hole	1	18.2	5.6	0
hole	1	18.2	7	0
hole	1	18.2	8.4	0
hole	1	18.2	9.8	0
hole	1	18.2	11.2	0
hole	1	18.2	12.6	0
hole	1	18.2	14	0
hole	1	18.2	15.4	0
hole	1	18.2	16.8	0
hole	1	18.2	18.2	0
hole	1	18.2	19.6	0
hole	1	18.2	21	0
hole	1	18.2	22.4	0
hole	1	18.2	23.8	0
hole	1	19.6	0	0
hole	1	19.6	1.4	0
hole	1	19.6	2.8	0
hole	1	19.6	4.2	0
hole	1	19.6	5.6	0
hole	1	19.6	7	0
hole	1	19.6	8.4	0
hole	1	19.6	9.8	0
hole	1	19.6	11.2	0

hole	1	19.6	12.6	0
hole	1	19.6	14	0
hole	1	19.6	15.4	0
hole	1	19.6	16.8	0
hole	1	19.6	18.2	0
hole	1	19.6	19.6	0
hole	1	19.6	21	0
hole	1	19.6	22.4	0
hole	1	19.6	23.8	0
hole	1	21	0	0
hole	1	21	1.4	0
hole	1	21	2.8	0
hole	1	21	4.2	0
hole	1	21	5.6	0
hole	1	21	7	0
hole	1	21	8.4	0
hole	1	21	9.8	0
hole	1	21	11.2	0
hole	1	21	12.6	0
hole	1	21	14	0
hole	1	21	15.4	0
hole	1	21	16.8	0
hole	1	21	18.2	0
hole	1	21	19.6	0
hole	1	21	21	0
hole	1	21	22.4	0
hole	1	21	23.8	0
hole	1	22.4	0	0
hole	1	22.4	1.4	0
hole	1	22.4	2.8	0
hole	1	22.4	4.2	0
hole	1	22.4	5.6	0
hole	1	22.4	7	0
hole	1	22.4	8.4	0
hole	1	22.4	9.8	0
hole	1	22.4	11.2	0
hole	1	22.4	12.6	0
hole	1	22.4	14	0
hole	1	22.4	15.4	0
hole	1	22.4	16.8	0
hole	1	22.4	18.2	0
hole	1	22.4	19.6	0
hole	1	22.4	21	0
hole	1	22.4	22.4	0
hole	1	22.4	23.8	0
hole	1	23.8	0	0
hole	1	23.8	1.4	0
hole	1	23.8	2.8	0
hole	1	23.8	4.2	0
hole	1	23.8	5.6	0
hole	1	23.8	7	0
hole	1	23.8	8.4	0
hole	1	23.8	9.8	0
hole	1	23.8	11.2	0
hole	1	23.8	12.6	0
hole	1	23.8	14	0
hole	1	23.8	15.4	0

```
  hole 1    23.8     16.8        0
  hole 1    23.8     18.2        0
  hole 1    23.8     19.6        0
  hole 1    23.8       21        0
  hole 1    23.8     22.4        0
  hole 1    23.8     23.8        0
global unit 4
com='cask'
 zcylinder 0 1      40      380          0
  hole 3 -26.056    2.256        7
  hole 3 -26.056  -26.056        7
  hole 3   2.256    2.256        7
  hole 3   2.256  -26.056        7
 zcylinder 8 1      43      383         -3
end geometry
read plot
 scr=yes
 ttl='fresh fuel shipping cask 5% enriched lattice'
 pic=mixtures
 xul=-61
 yul=61
 zul=100
 xlr=61
 ylr=-61
 zlr=100
 nax=500
 clr=1 200 200 200
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
     7 145 44 238
     8 150 150 150
 end color
 uax=1 vdn=-1
  end
 scr=yes
 ttl='fresh fuel shipping cask 5% enriched lattice'
 pic=mixtures
 xul=-30
 yul=10
 zul=400
 xlr=30
 ylr=10
 zlr=-16
 nax=500
 clr=1 200 200 200
     2 0 0 205
     3 0 229 238
     4 0 238 0
     5 205 205 0
     6 238 0 0
     7 145 44 238
     8 150 150 150
 end color
 uax=1 wdn=-1
```

```
  end
end plot
end data
read sams
  prtgeom
end sams
end
```

A file comparison with CASE5B.inp returns:

```
Comparing files case5a.inp and CASE5B.INP
***** case5a.inp
=tsunami-3d-k5 parm=(nitawlst)
base case 5a:  17x17 array of 5.0% enriched pwr fuel pins
238groupndf5
***** CASE5B.INP
=tsunami-3d-k5 parm=(nitawlst)
base case 5b:  17x17 array of 6.0% enriched pwr fuel pins
238groupndf5
*****

***** case5a.inp
                                 92234 0.005407837
                                 92235 5
                                 92238 94.99459   end
 helium      2 1.e-10 300   end
***** CASE5B.INP
                                 92234 0.005407837
                                 92235 6
                                 92238 93.99459   end
 helium      2 1.e-10 300   end
*****
```

A file comparison with CASE5C.inp returns:

```
Comparing files case5a.inp and CASE5C.INP
***** case5a.inp
=tsunami-3d-k5 parm=(nitawlst)
base case 5a:  17x17 array of 5.0% enriched pwr fuel pins
238groupndf5
***** CASE5C.INP
=tsunami-3d-k5 parm=(nitawlst)
base case 5c:  17x17 array of 8.0% enriched pwr fuel pins
238groupndf5
*****

***** case5a.inp
                                 92234 0.005407837
                                 92235 5
                                 92238 94.99459   end
 helium      2 1.e-10 300   end
***** CASE5C.INP
                                 92234 0.005407837
                                 92235 8
                                 92238 91.99459   end
```

```
 helium       2 1.e-10 300    end
*****
```

A file comparison with CASE5D.inp returns:

```
Comparing files case5a.inp and CASE5D.INP
***** case5a.inp
=tsunami-3d-k5 parm=(nitawlst)
base case 5a:  17x17 array of 5.0% enriched pwr fuel pins
238groupndf5
***** CASE5D.INP
=tsunami-3d-k5 parm=(nitawlst)
base case 5d:  17x17 array of 10.0% enriched pwr fuel pins
238groupndf5
*****

***** case5a.inp
                                 92234 0.005407837
                                 92235 5
                                 92238 94.99459    end
 helium       2 1.e-10 300    end
***** CASE5D.INP
                                 92234 0.005407837
                                 92235 10
                                 92238 89.99459    end
 helium       2 1.e-10 300    end
*****
```

Normal Base Case 6: Graphite-moderated TRISO fuel pins in hexagonal lattice

The input deck for the normal case (CASE6A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
5% enrich
238groupndf5
read composition
 uo2          1 0.1605 300
                                 92235 5
                                 92238 95   end
 c            1 0.6698 300    end
 si           1 0.0874 300    end
 gd           1 2e-05 300   end
 c-graphite   2 1 300    end
 helium       3 1.e-10 300    end
 ss304        4 1 300    end
end composition
read parameter
 gen=130
 npg=1000
```

```
 nsk=30
 htm=yes
 fdn=yes
 apg=10000
 agn=630
end parameter
read geometry
unit 1
com='hexagon equivalent cylinder'
 zcylinder 1 1    0.75      100         0
global unit 2
com='shipping cask'
 zcylinder 2 1      23      100         0
  hole 1  -19.74          0         0
  hole 1  -16.92          0         0
  hole 1   -14.1          0         0
  hole 1  -11.28          0         0
  hole 1   -8.46          0         0
  hole 1   -5.64          0         0
  hole 1   -2.82          0         0
  hole 1       0          0         0
  hole 1    2.82          0         0
  hole 1   19.74          0         0
  hole 1   16.92          0         0
  hole 1    14.1          0         0
  hole 1   11.28          0         0
  hole 1    8.46          0         0
  hole 1    5.64          0         0
  hole 1    1.41     2.4422         0
  hole 1    4.23     2.4422         0
  hole 1    7.05     2.4422         0
  hole 1    9.87     2.4422         0
  hole 1   12.69     2.4422         0
  hole 1   15.51     2.4422         0
  hole 1   18.33     2.4422         0
  hole 1   -1.41     2.4422         0
  hole 1   -4.23     2.4422         0
  hole 1   -7.05     2.4422         0
  hole 1   -9.87     2.4422         0
  hole 1  -12.69     2.4422         0
  hole 1  -15.51     2.4422         0
  hole 1  -18.33     2.4422         0
  hole 1    1.41    -2.4422         0
  hole 1    4.23    -2.4422         0
  hole 1    7.05    -2.4422         0
  hole 1    9.87    -2.4422         0
  hole 1   12.69    -2.4422         0
  hole 1   15.51    -2.4422         0
  hole 1   18.33    -2.4422         0
  hole 1   -1.41    -2.4422         0
  hole 1   -4.23    -2.4422         0
  hole 1   -7.05    -2.4422         0
  hole 1   -9.87    -2.4422         0
  hole 1  -12.69    -2.4422         0
  hole 1  -15.51    -2.4422         0
  hole 1  -18.33    -2.4422         0
  hole 1  -16.92     4.8844         0
```

hole	1	-14.1	4.8844	0
hole	1	-11.28	4.8844	0
hole	1	-8.46	4.8844	0
hole	1	-5.64	4.8844	0
hole	1	-2.82	4.8844	0
hole	1	0	4.8844	0
hole	1	2.82	4.8844	0
hole	1	5.64	4.8844	0
hole	1	8.46	4.8844	0
hole	1	11.28	4.8844	0
hole	1	14.1	4.8844	0
hole	1	16.92	4.8844	0
hole	1	-16.92	-4.8844	0
hole	1	-14.1	-4.8844	0
hole	1	-11.28	-4.8844	0
hole	1	-8.46	-4.8844	0
hole	1	-5.64	-4.8844	0
hole	1	-2.82	-4.8844	0
hole	1	0	-4.8844	0
hole	1	2.82	-4.8844	0
hole	1	5.64	-4.8844	0
hole	1	8.46	-4.8844	0
hole	1	11.28	-4.8844	0
hole	1	14.1	-4.8844	0
hole	1	16.92	-4.8844	0
hole	1	1.41	7.3266	0
hole	1	4.23	7.3266	0
hole	1	7.05	7.3266	0
hole	1	9.87	7.3266	0
hole	1	12.69	7.3266	0
hole	1	15.51	7.3266	0
hole	1	-1.41	7.3266	0
hole	1	-4.23	7.3266	0
hole	1	-7.05	7.3266	0
hole	1	-9.87	7.3266	0
hole	1	-12.69	7.3266	0
hole	1	-15.51	7.3266	0
hole	1	1.41	-7.3266	0
hole	1	4.23	-7.3266	0
hole	1	7.05	-7.3266	0
hole	1	9.87	-7.3266	0
hole	1	12.69	-7.3266	0
hole	1	15.51	-7.3266	0
hole	1	-1.41	-7.3266	0
hole	1	-4.23	-7.3266	0
hole	1	-7.05	-7.3266	0
hole	1	-9.87	-7.3266	0
hole	1	-12.69	-7.3266	0
hole	1	-15.51	-7.3266	0
hole	1	-14.1	9.7688	0
hole	1	-11.28	9.7688	0
hole	1	-8.46	9.7688	0
hole	1	-5.64	9.7688	0
hole	1	-2.82	9.7688	0
hole	1	0	9.7688	0
hole	1	2.82	9.7688	0
hole	1	5.64	9.7688	0

hole	1	8.46	9.7688	0
hole	1	11.28	9.7688	0
hole	1	14.1	9.7688	0
hole	1	-14.1	-9.7688	0
hole	1	-11.28	-9.7688	0
hole	1	-8.46	-9.7688	0
hole	1	-5.64	-9.7688	0
hole	1	-2.82	-9.7688	0
hole	1	0	-9.7688	0
hole	1	2.82	-9.7688	0
hole	1	5.64	-9.7688	0
hole	1	8.46	-9.7688	0
hole	1	11.28	-9.7688	0
hole	1	14.1	-9.7688	0
hole	1	1.41	12.211	0
hole	1	4.23	12.211	0
hole	1	7.05	12.211	0
hole	1	9.87	12.211	0
hole	1	12.69	12.211	0
hole	1	-1.41	12.211	0
hole	1	-4.23	12.211	0
hole	1	-7.05	12.211	0
hole	1	-9.87	12.211	0
hole	1	-12.69	12.211	0
hole	1	1.41	-12.211	0
hole	1	4.23	-12.211	0
hole	1	7.05	-12.211	0
hole	1	9.87	-12.211	0
hole	1	12.69	-12.211	0
hole	1	-1.41	-12.211	0
hole	1	-4.23	-12.211	0
hole	1	-7.05	-12.211	0
hole	1	-9.87	-12.211	0
hole	1	-12.69	-12.211	0
hole	1	-11.28	14.6532	0
hole	1	-8.46	14.6532	0
hole	1	-5.64	14.6532	0
hole	1	-2.82	14.6532	0
hole	1	0	14.6532	0
hole	1	2.82	14.6532	0
hole	1	5.64	14.6532	0
hole	1	8.46	14.6532	0
hole	1	11.28	14.6532	0
hole	1	-11.28	-14.6532	0
hole	1	-8.46	-14.6532	0
hole	1	-5.64	-14.6532	0
hole	1	-2.82	-14.6532	0
hole	1	0	-14.6532	0
hole	1	2.82	-14.6532	0
hole	1	5.64	-14.6532	0
hole	1	8.46	-14.6532	0
hole	1	11.28	-14.6532	0
hole	1	1.41	17.0954	0
hole	1	4.23	17.0954	0
hole	1	7.05	17.0954	0
hole	1	9.87	17.0954	0
hole	1	-1.41	17.0954	0

```
  hole 1   -4.23  17.0954       0
  hole 1   -7.05  17.0954       0
  hole 1   -9.87  17.0954       0
  hole 1    1.41  -17.0954       0
  hole 1    4.23  -17.0954       0
  hole 1    7.05  -17.0954       0
  hole 1    9.87  -17.0954       0
  hole 1   -1.41  -17.0954       0
  hole 1   -4.23  -17.0954       0
  hole 1   -7.05  -17.0954       0
  hole 1   -9.87  -17.0954       0
 zcylinder 4 1    23.5       103        -3
end geometry
read plot
 scr=yes
 ttl='cross section view'
 pic=mixtures
 xul=-23
 yul=23
 zul=10
 xlr=23
 ylr=-23
 zlr=10
 nax=600
 clr=1 200 200 200
     2 0 0 205
     3 0 229 238
     4 0 238 0
 end color
 uax=1 vdn=-1
  end
end plot
end data
read sams
  prtgeom
end sams
end
```

A file comparison with CASE6B.inp returns:

```
Comparing files case6a.inp and CASE6B.INP
***** case6a.inp
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
5% enrich
238groupndf5
***** CASE6B.INP
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
6% enrich
238groupndf5
*****

***** case6a.inp
 uo2        1 0.1605 300
```

```
                                         92235 5
                                         92238 95   end
 c            1 0.6698 300   end
***** CASE6B.INP
 uo2          1 0.1605 300
                                         92235 6
                                         92238 94   end
 c            1 0.6698 300   end
*****
```

A file comparison with CASE6C.inp returns:

```
Comparing files case6a.inp and CASE6C.INP
***** case6a.inp
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
5% enrich
238groupndf5
***** CASE6C.INP
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
8% enrich
238groupndf5
*****

***** case6a.inp
 uo2          1 0.1605 300
                                         92235 5
                                         92238 95   end
 c            1 0.6698 300   end
***** CASE6C.INP
 uo2          1 0.1605 300
                                         92235 8
                                         92238 92   end
 c            1 0.6698 300   end
*****
```

A file comparison with CASE6D.inp returns:

```
Comparing files case6a.inp and CASE6D.INP
***** case6a.inp
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
5% enrich
238groupndf5
***** CASE6D.INP
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
10% enrich
238groupndf5
*****

***** case6a.inp
 uo2          1 0.1605 300
```

```
                                    92235 5
                                    92238 95    end
 c            1 0.6698 300    end
***** CASE6D.INP
 uo2          1 0.1605 300
                                    92235 10
                                    92238 90    end
 c            1 0.6698 300    end
*****
```

A.3 Contingency Base Case Input Decks

For the contingency base cases, only the 5% case decks are given, since the higher enrichment cases only differ by the material definitions, so are the same (except for variations on the titles) as for the normal cases in the previous section.

Contingency Base Case 1: Stored UF_6 cylinders

The input deck for the contingency case (DCASE1A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
base case 1:  5% enriched uf6 cylinder - model 12b
'238groupndf5
read composition
 uf6          1 den=3.254 0.9 300
                                    92234 0.005407837
                                    92235 5
                                    92238 94.99459    end
 h2o          1 0.1 300 end
 wtptmonel        2   8.33   7
                                    28000 66.5
                                    26000 2
                                    25055 1.5
                                    14000 0.5
                                    13027 2.7
                                    22000 0.5
                                    29000 26.3
                          1 300    end
 orconcrete   3 1 300    end
 h2o          4 0.15 300    end
end composition
read parameter
 gen=130
 npg=1000
 nsk=30
 htm=yes
 fdn=yes
 apg=30000
 agn=630
end parameter
read geometry
unit 1
com='8a monel container bottom'
 hemisphe-x 1 1   15.86 chord       0
```

```
 hemisphe-x 2 1   16.51 chord       0
 xcylinder 2 1   16.61        0  -20.6375
unit 2
com='8a monel container middle'
 xcylinder 1 1   15.86  70.1675        0
 xcylinder 2 1   16.51  70.1675        0
unit 3
com='8a monel container top'
 hemisphe+x 1 1   15.86 chord       0
 hemisphe+x 2 1   16.51 chord       0
 xcylinder 2 1   16.61    21.59        0
global
unit 4
com='8a monel container parts together'
 cuboid 4 1    112.5       0    16.61   -16.61    16.61   -16.61
  hole 2 20.6375        0        0
  hole 1 20.6375        0        0
  hole 3  90.855        0        0
unit 5
end geometry
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=mirror
 -zb=mirror
  end bnds
end data
read sams
  prtgeom
end sams
end
```

Contingency Base Case 2: UO_2 powder in storage rack arrays

The input deck for the contingency case (DCASE2A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 powder in storage rack arrays
238groupndf5
read composition
 uo2         1 0.5 300
                                92234 0.005407837
                                92235 5
                                92238 94.99459   end
 h2o         1 0.5 300 end
 ss316       2 1 300   end
 aluminum    3 1 300   end
 h2o         4 1.00 300   end
 orconcrete  5 1 300   end
 h2o         6 1.0e-20 300   end
end composition
read parameter
 gen=130
```

```
 npg=1000
 nsk=30
 agn=630
 apg=100000
 htm=yes
 fdn=yes
 msh=2
end parameter
read geometry
unit 1
com='single can on shelf'
 zcylinder 1 1      7.5      13.5       0.8
 zcylinder 2 1      7.8      13.8       0.3
 cuboid 6 1         8        -8         8        -8        16       0.3
 cuboid 3 1         8        -8         8        -8        16         0
global
unit 2
com='single rack'
 cuboid 4 1      100       -30       100       -30      100      -30
  hole 1        0         0         0
  hole 1       16         0         0
  hole 1       32         0         0
  hole 1       48         0         0
  hole 1        0        16         0
  hole 1       16        16         0
  hole 1       32        16         0
  hole 1       48        16         0
  hole 1        0        32         0
  hole 1       16        32         0
  hole 1       32        32         0
  hole 1       48        32         0
  hole 1        0        48         0
  hole 1       16        48         0
  hole 1       32        48         0
  hole 1       48        48         0
  hole 1        0         0        16
  hole 1       16         0        16
  hole 1       32         0        16
  hole 1       48         0        16
  hole 1        0        16        16
  hole 1       16        16        16
  hole 1       32        16        16
  hole 1       48        16        16
  hole 1        0        32        16
  hole 1       16        32        16
  hole 1       32        32        16
  hole 1       48        32        16
  hole 1        0        48        16
  hole 1       16        48        16
  hole 1       32        48        16
  hole 1       48        48        16
  hole 1        0         0        32
  hole 1       16         0        32
  hole 1       32         0        32
  hole 1       48         0        32
  hole 1        0        16        32
  hole 1       16        16        32
```

```
  hole 1      32       16       32
  hole 1      48       16       32
  hole 1       0       32       32
  hole 1      16       32       32
  hole 1      32       32       32
  hole 1      48       32       32
  hole 1       0       48       32
  hole 1      16       48       32
  hole 1      32       48       32
  hole 1      48       48       32
  hole 1       0        0       48
  hole 1      16        0       48
  hole 1      32        0       48
  hole 1      48        0       48
  hole 1       0       16       48
  hole 1      16       16       48
  hole 1      32       16       48
  hole 1      48       16       48
  hole 1       0       32       48
  hole 1      16       32       48
  hole 1      32       32       48
  hole 1      48       32       48
  hole 1       0       48       48
  hole 1      16       48       48
  hole 1      32       48       48
  hole 1      48       48       48
end geometry
read bnds
 +xb=vacuum
 -xb=vacuum
 +yb=vacuum
 -yb=vacuum
 +zb=vacuum
 -zb=vacuum
  end bnds
end data
read sams
  prtgeom
end sams
end
```

Contingency Base Case 3: Pressed ceramic UO_2 fuel pellets in boxes

The input deck for the contingency case (DCASE3A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched uo2 pellets in boxes
238groupndf5
read composition
 uo2          1 1.000 300
                                  92234 0.005407837
                                  92235 5
                                  92238 94.99459    end
' gd           1 0.0015 300    end
 ss316        2 1 300    end
```

```
 aluminum     3 1 300    end
 h2o          4 0.06 300    end
 orconcrete   5 1 300    end
 h2o          6 1 300    end
end composition
read parameter
 gen=155
 nsk=30
 npg=1000
 agn=1270
 apg=10000
 htm=yes
 fdn=yes
 msh=2
end parameter
read geometry
unit 1
com='fuel pin'
 zcylinder 1 1    0.55        7        0
unit 2
com='pins in box'
 cuboid 6 1      7.5      -7.5      7.5      -7.5      7.5      0.2
  hole 1      6.9      6.9      0.2
  hole 1      5.7      6.9      0.2
  hole 1      4.5      6.9      0.2
  hole 1      3.3      6.9      0.2
  hole 1      2.1      6.9      0.2
  hole 1      0.9      6.9      0.2
  hole 1     -6.9      6.9      0.2
  hole 1     -5.7      6.9      0.2
  hole 1     -4.5      6.9      0.2
  hole 1     -3.3      6.9      0.2
  hole 1     -2.1      6.9      0.2
  hole 1     -0.9      6.9      0.2
  hole 1      6.9     -6.9      0.2
  hole 1      5.7     -6.9      0.2
  hole 1      4.5     -6.9      0.2
  hole 1      3.3     -6.9      0.2
  hole 1      2.1     -6.9      0.2
  hole 1      0.9     -6.9      0.2
  hole 1     -6.9     -6.9      0.2
  hole 1     -5.7     -6.9      0.2
  hole 1     -4.5     -6.9      0.2
  hole 1     -3.3     -6.9      0.2
  hole 1     -2.1     -6.9      0.2
  hole 1     -0.9     -6.9      0.2
  hole 1      6.9      5.7      0.2
  hole 1      5.7      5.7      0.2
  hole 1      4.5      5.7      0.2
  hole 1      3.3      5.7      0.2
  hole 1      2.1      5.7      0.2
  hole 1      0.9      5.7      0.2
  hole 1     -6.9      5.7      0.2
  hole 1     -5.7      5.7      0.2
  hole 1     -4.5      5.7      0.2
  hole 1     -3.3      5.7      0.2
  hole 1     -2.1      5.7      0.2
```

hole	1	-0.9	5.7	0.2
hole	1	6.9	-5.7	0.2
hole	1	5.7	-5.7	0.2
hole	1	4.5	-5.7	0.2
hole	1	3.3	-5.7	0.2
hole	1	2.1	-5.7	0.2
hole	1	0.9	-5.7	0.2
hole	1	-6.9	-5.7	0.2
hole	1	-5.7	-5.7	0.2
hole	1	-4.5	-5.7	0.2
hole	1	-3.3	-5.7	0.2
hole	1	-2.1	-5.7	0.2
hole	1	-0.9	-5.7	0.2
hole	1	6.9	4.5	0.2
hole	1	5.7	4.5	0.2
hole	1	4.5	4.5	0.2
hole	1	3.3	4.5	0.2
hole	1	2.1	4.5	0.2
hole	1	0.9	4.5	0.2
hole	1	-6.9	4.5	0.2
hole	1	-5.7	4.5	0.2
hole	1	-4.5	4.5	0.2
hole	1	-3.3	4.5	0.2
hole	1	-2.1	4.5	0.2
hole	1	-0.9	4.5	0.2
hole	1	6.9	-4.5	0.2
hole	1	5.7	-4.5	0.2
hole	1	4.5	-4.5	0.2
hole	1	3.3	-4.5	0.2
hole	1	2.1	-4.5	0.2
hole	1	0.9	-4.5	0.2
hole	1	-6.9	-4.5	0.2
hole	1	-5.7	-4.5	0.2
hole	1	-4.5	-4.5	0.2
hole	1	-3.3	-4.5	0.2
hole	1	-2.1	-4.5	0.2
hole	1	-0.9	-4.5	0.2
hole	1	6.9	3.3	0.2
hole	1	5.7	3.3	0.2
hole	1	4.5	3.3	0.2
hole	1	3.3	3.3	0.2
hole	1	2.1	3.3	0.2
hole	1	0.9	3.3	0.2
hole	1	-6.9	3.3	0.2
hole	1	-5.7	3.3	0.2
hole	1	-4.5	3.3	0.2
hole	1	-3.3	3.3	0.2
hole	1	-2.1	3.3	0.2
hole	1	-0.9	3.3	0.2
hole	1	6.9	-3.3	0.2
hole	1	5.7	-3.3	0.2
hole	1	4.5	-3.3	0.2
hole	1	3.3	-3.3	0.2
hole	1	2.1	-3.3	0.2
hole	1	0.9	-3.3	0.2
hole	1	-6.9	-3.3	0.2
hole	1	-5.7	-3.3	0.2

```
   hole 1    -4.5      -3.3      0.2
   hole 1    -3.3      -3.3      0.2
   hole 1    -2.1      -3.3      0.2
   hole 1    -0.9      -3.3      0.2
   hole 1     6.9       2.1      0.2
   hole 1     5.7       2.1      0.2
   hole 1     4.5       2.1      0.2
   hole 1     3.3       2.1      0.2
   hole 1     2.1       2.1      0.2
   hole 1     0.9       2.1      0.2
   hole 1    -6.9       2.1      0.2
   hole 1    -5.7       2.1      0.2
   hole 1    -4.5       2.1      0.2
   hole 1    -3.3       2.1      0.2
   hole 1    -2.1       2.1      0.2
   hole 1    -0.9       2.1      0.2
   hole 1     6.9      -2.1      0.2
   hole 1     5.7      -2.1      0.2
   hole 1     4.5      -2.1      0.2
   hole 1     3.3      -2.1      0.2
   hole 1     2.1      -2.1      0.2
   hole 1     0.9      -2.1      0.2
   hole 1    -6.9      -2.1      0.2
   hole 1    -5.7      -2.1      0.2
   hole 1    -4.5      -2.1      0.2
   hole 1    -3.3      -2.1      0.2
   hole 1    -2.1      -2.1      0.2
   hole 1    -0.9      -2.1      0.2
   hole 1     6.9       0.9      0.2
   hole 1     5.7       0.9      0.2
   hole 1     4.5       0.9      0.2
   hole 1     3.3       0.9      0.2
   hole 1     2.1       0.9      0.2
   hole 1     0.9       0.9      0.2
   hole 1    -6.9       0.9      0.2
   hole 1    -5.7       0.9      0.2
   hole 1    -4.5       0.9      0.2
   hole 1    -3.3       0.9      0.2
   hole 1    -2.1       0.9      0.2
   hole 1    -0.9       0.9      0.2
   hole 1     6.9      -0.9      0.2
   hole 1     5.7      -0.9      0.2
   hole 1     4.5      -0.9      0.2
   hole 1     3.3      -0.9      0.2
   hole 1     2.1      -0.9      0.2
   hole 1     0.9      -0.9      0.2
   hole 1    -6.9      -0.9      0.2
   hole 1    -5.7      -0.9      0.2
   hole 1    -4.5      -0.9      0.2
   hole 1    -3.3      -0.9      0.2
   hole 1    -2.1      -0.9      0.2
   hole 1    -0.9      -0.9      0.2
  cuboid 3 1      7.6      -7.6       7.6      -7.6       7.6        0
 global
 unit 3
 com='single rack of boxes'
  cuboid 4 1      240         0        16         0       150        0
```

hole	2	8	8	0
hole	2	24	8	0
hole	2	40	8	0
hole	2	56	8	0
hole	2	72	8	0
hole	2	88	8	0
hole	2	104	8	0
hole	2	120	8	0
hole	2	136	8	0
hole	2	152	8	0
hole	2	168	8	0
hole	2	184	8	0
hole	2	200	8	0
hole	2	216	8	0
hole	2	232	8	0
hole	2	8	8	16
hole	2	24	8	16
hole	2	40	8	16
hole	2	56	8	16
hole	2	72	8	16
hole	2	88	8	16
hole	2	104	8	16
hole	2	120	8	16
hole	2	136	8	16
hole	2	152	8	16
hole	2	168	8	16
hole	2	184	8	16
hole	2	200	8	16
hole	2	216	8	16
hole	2	232	8	16
hole	2	8	8	32
hole	2	24	8	32
hole	2	40	8	32
hole	2	56	8	32
hole	2	72	8	32
hole	2	88	8	32
hole	2	104	8	32
hole	2	120	8	32
hole	2	136	8	32
hole	2	152	8	32
hole	2	168	8	32
hole	2	184	8	32
hole	2	200	8	32
hole	2	216	8	32
hole	2	232	8	32
hole	2	8	8	48
hole	2	24	8	48
hole	2	40	8	48
hole	2	56	8	48
hole	2	72	8	48
hole	2	88	8	48
hole	2	104	8	48
hole	2	120	8	48
hole	2	136	8	48
hole	2	152	8	48
hole	2	168	8	48
hole	2	184	8	48

hole	2	200	8	48
hole	2	216	8	48
hole	2	232	8	48
hole	2	8	8	64
hole	2	24	8	64
hole	2	40	8	64
hole	2	56	8	64
hole	2	72	8	64
hole	2	88	8	64
hole	2	104	8	64
hole	2	120	8	64
hole	2	136	8	64
hole	2	152	8	64
hole	2	168	8	64
hole	2	184	8	64
hole	2	200	8	64
hole	2	216	8	64
hole	2	232	8	64
hole	2	8	8	80
hole	2	24	8	80
hole	2	40	8	80
hole	2	56	8	80
hole	2	72	8	80
hole	2	88	8	80
hole	2	104	8	80
hole	2	120	8	80
hole	2	136	8	80
hole	2	152	8	80
hole	2	168	8	80
hole	2	184	8	80
hole	2	200	8	80
hole	2	216	8	80
hole	2	232	8	80
hole	2	8	8	96
hole	2	24	8	96
hole	2	40	8	96
hole	2	56	8	96
hole	2	72	8	96
hole	2	88	8	96
hole	2	104	8	96
hole	2	120	8	96
hole	2	136	8	96
hole	2	152	8	96
hole	2	168	8	96
hole	2	184	8	96
hole	2	200	8	96
hole	2	216	8	96
hole	2	232	8	96
hole	2	8	8	112
hole	2	24	8	112
hole	2	40	8	112
hole	2	56	8	112
hole	2	72	8	112
hole	2	88	8	112
hole	2	104	8	112
hole	2	120	8	112
hole	2	136	8	112

```
  hole 2      152         8       112
  hole 2      168         8       112
  hole 2      184         8       112
  hole 2      200         8       112
  hole 2      216         8       112
  hole 2      232         8       112
' cuboid 4 1       240         0        16.1        -0.1        150
0
' cuboid 4 1       240         0        17        -1       150         0
' cuboid 4 1       240         0        18        -2       150         0
' cuboid 4 1       240         0        20        -4       150         0
' cuboid 4 1       240         0        24        -8       150         0
 cuboid 4 1       240         0        28        -12       150         0
end geometry
read bnds
 +xb=vacuum
 -xb=vacuum
 +yb=mirror
 -yb=mirror
 +zb=vacuum
 -zb=vacuum
  end bnds
end data
read sams
  prtgeom
end sams
end
```

Contingency Base Case 4: TRISO pellets in boxes

The input deck for the contingency case (DCASE4A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
storage of 5% enriched TRISO powder in storage rack arrays
238groupndf5
read composition
 uo2          1 0.1605 300
                                92235 5
                                92238 95   end
 c            1 0.6698 300    end
 si           1 0.0874 300    end
 gd           1 2e-05 300    end
 ss316        2 1 300   end
 aluminum     3 1 300   end
 h2o          4 0.06 300   end
 orconcrete   5 1 300   end
 h2o          6 1 300   end
end composition
read parameter
 gen=130
 npg=1000
 nsk=30
 agn=4256
 apg=10000
 htm=yes
```

```
 fdn=yes
 msh=2
end parameter
read geometry
unit 1
com='fuel pin'
 zcylinder 1 1    0.75        7        0
unit 2
com='pins in box'
 cuboid 6 1      7.5      -7.5       7.5      -7.5       7.5       0.2
 hole 1 6.75 6.75 0.2
 hole 1 5.25 6.75 0.2
 hole 1 3.75`6.75 0.2
 hole 1 2.25 6.75 0.2
 hole 1 0.75 6.75 0.2
 hole 1 6.75 -6.75 0.2
 hole 1 5.25 -6.75 0.2
 hole 1 3.75 -6.75 0.2
 hole 1 2.25 -6.75 0.2
 hole 1 0.75 -6.75 0.2
 hole 1 -6.75 6.75 0.2
 hole 1 -5.25 6.75 0.2
 hole 1 -3.75 6.75 0.2
 hole 1 -2.25 6.75 0.2
 hole 1 -0.75 6.75 0.2
 hole 1 -6.75 -6.75 0.2
 hole 1 -5.25 -6.75 0.2
 hole 1 -3.75 -6.75 0.2
 hole 1 -2.25 -6.75 0.2
 hole 1 -0.75 -6.75 0.2
 hole 1 6.75 5.25 0.2
 hole 1 5.25 5.25 0.2
 hole 1 3.75 5.25 0.2
 hole 1 2.25 5.25 0.2
 hole 1 0.75 5.25 0.2
 hole 1 6.75 -5.25 0.2
 hole 1 5.25 -5.25 0.2
 hole 1 3.75 -5.25 0.2
 hole 1 2.25 -5.25 0.2
 hole 1 0.75 -5.25 0.2
 hole 1 -6.75 5.25 0.2
 hole 1 -5.25 5.25 0.2
 hole 1 -3.75 5.25 0.2
 hole 1 -2.25 5.25 0.2
 hole 1 -0.75 5.25 0.2
 hole 1 -6.75 -5.25 0.2
 hole 1 -5.25 -5.25 0.2
 hole 1 -3.75 -5.25 0.2
 hole 1 -2.25 -5.25 0.2
 hole 1 -0.75 -5.25 0.2
 hole 1 6.75 3.75 0.2
 hole 1 5.25 3.75 0.2
 hole 1 3.75 3.75 0.2
 hole 1 2.25 3.75 0.2
 hole 1 0.75 3.75 0.2
 hole 1 6.75 -3.75 0.2
 hole 1 5.25 -3.75 0.2
```

```
 hole 1 3.75 -3.75 0.2
 hole 1 2.25 -3.75 0.2
 hole 1 0.75 -3.75 0.2
 hole 1 -6.75 3.75 0.2
 hole 1 -5.25 3.75 0.2
 hole 1 -3.75 3.75 0.2
 hole 1 -2.25 3.75 0.2
 hole 1 -0.75 3.75 0.2
 hole 1 -6.75 -3.75 0.2
 hole 1 -5.25 -3.75 0.2
 hole 1 -3.75 -3.75 0.2
 hole 1 -2.25 -3.75 0.2
 hole 1 -0.75 -3.75 0.2
 hole 1 6.75 2.25 0.2
 hole 1 5.25 2.25 0.2
 hole 1 3.75 2.25 0.2
 hole 1 2.25 2.25 0.2
 hole 1 0.75 2.25 0.2
 hole 1 6.75 -2.25 0.2
 hole 1 5.25 -2.25 0.2
 hole 1 3.75 -2.25 0.2
 hole 1 2.25 -2.25 0.2
 hole 1 0.75 -2.25 0.2
 hole 1 -6.75 2.25 0.2
 hole 1 -5.25 2.25 0.2
 hole 1 -3.75 2.25 0.2
 hole 1 -2.25 2.25 0.2
 hole 1 -0.75 2.25 0.2
 hole 1 -6.75 -2.25 0.2
 hole 1 -5.25 -2.25 0.2
 hole 1 -3.75 -2.25 0.2
 hole 1 -2.25 -2.25 0.2
 hole 1 -0.75 -2.25 0.2
 hole 1 6.75 0.75 0.2
 hole 1 5.25 0.75 0.2
 hole 1 3.75 0.75 0.2
 hole 1 2.25 0.75 0.2
 hole 1 0.75 0.75 0.2
 hole 1 6.75 -0.75 0.2
 hole 1 5.25 -0.75 0.2
 hole 1 3.75 -0.75 0.2
 hole 1 2.25 -0.75 0.2
 hole 1 0.75 -0.75 0.2
 hole 1 -6.75 0.75 0.2
 hole 1 -5.25 0.75 0.2
 hole 1 -3.75 0.75 0.2
 hole 1 -2.25 0.75 0.2
 hole 1 -0.75 0.75 0.2
 hole 1 -6.75 -0.75 0.2
 hole 1 -5.25 -0.75 0.2
 hole 1 -3.75 -0.75 0.2
 hole 1 -2.25 -0.75 0.2
 hole 1 -0.75 -0.75 0.2
 cuboid 3 1      7.6     -7.6       7.6      -7.6       7.7        0
global
unit 3
com='single rack of boxes'
```

```
cuboid 6 1     240       0       16      0      150      0
 hole 2      8         8        0
 hole 2     24         8        0
 hole 2     40         8        0
 hole 2     56         8        0
 hole 2     72         8        0
 hole 2     88         8        0
 hole 2    104         8        0
 hole 2    120         8        0
 hole 2    136         8        0
 hole 2    152         8        0
 hole 2    168         8        0
 hole 2    184         8        0
 hole 2    200         8        0
 hole 2    216         8        0
 hole 2    232         8        0
 hole 2      8         8       16
 hole 2     24         8       16
 hole 2     40         8       16
 hole 2     56         8       16
 hole 2     72         8       16
 hole 2     88         8       16
 hole 2    104         8       16
 hole 2    120         8       16
 hole 2    136         8       16
 hole 2    152         8       16
 hole 2    168         8       16
 hole 2    184         8       16
 hole 2    200         8       16
 hole 2    216         8       16
 hole 2    232         8       16
 hole 2      8         8       32
 hole 2     24         8       32
 hole 2     40         8       32
 hole 2     56         8       32
 hole 2     72         8       32
 hole 2     88         8       32
 hole 2    104         8       32
 hole 2    120         8       32
 hole 2    136         8       32
 hole 2    152         8       32
 hole 2    168         8       32
 hole 2    184         8       32
 hole 2    200         8       32
 hole 2    216         8       32
 hole 2    232         8       32
 hole 2      8         8       48
 hole 2     24         8       48
 hole 2     40         8       48
 hole 2     56         8       48
 hole 2     72         8       48
 hole 2     88         8       48
 hole 2    104         8       48
 hole 2    120         8       48
 hole 2    136         8       48
 hole 2    152         8       48
 hole 2    168         8       48
```

hole 2	184	8	48
hole 2	200	8	48
hole 2	216	8	48
hole 2	232	8	48
hole 2	8	8	64
hole 2	24	8	64
hole 2	40	8	64
hole 2	56	8	64
hole 2	72	8	64
hole 2	88	8	64
hole 2	104	8	64
hole 2	120	8	64
hole 2	136	8	64
hole 2	152	8	64
hole 2	168	8	64
hole 2	184	8	64
hole 2	200	8	64
hole 2	216	8	64
hole 2	232	8	64
hole 2	8	8	80
hole 2	24	8	80
hole 2	40	8	80
hole 2	56	8	80
hole 2	72	8	80
hole 2	88	8	80
hole 2	104	8	80
hole 2	120	8	80
hole 2	136	8	80
hole 2	152	8	80
hole 2	168	8	80
hole 2	184	8	80
hole 2	200	8	80
hole 2	216	8	80
hole 2	232	8	80
hole 2	8	8	96
hole 2	24	8	96
hole 2	40	8	96
hole 2	56	8	96
hole 2	72	8	96
hole 2	88	8	96
hole 2	104	8	96
hole 2	120	8	96
hole 2	136	8	96
hole 2	152	8	96
hole 2	168	8	96
hole 2	184	8	96
hole 2	200	8	96
hole 2	216	8	96
hole 2	232	8	96
hole 2	8	8	112
hole 2	24	8	112
hole 2	40	8	112
hole 2	56	8	112
hole 2	72	8	112
hole 2	88	8	112
hole 2	104	8	112
hole 2	120	8	112

```
  hole 2     136        8      112
  hole 2     152        8      112
  hole 2     168        8      112
  hole 2     184        8      112
  hole 2     200        8      112
  hole 2     216        8      112
  hole 2     232        8      112
end geometry
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=mirror
 -zb=mirror
  end bnds
end data
read sams
  prtgeom
end sams
end
```

Contingency Base Case 5: UO_2, zircaloy clad fuel pin array in shipping cask

The input deck for the contingency case (DCASE5A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
base case 5:  17x17 array of 5.0% enriched pwr fuel pins
238groupndf5
read composition
 uo2         1 1.0000 300
                                  92234 0.005407837
                                  92235 5
                                  92238 94.99459   end
 h2o      2 0.06 300   end
 wtptzircaloy-4   3   6.501   5
                                  40000 98.24
                                  50000 1.45
                                  24000 0.1
                                  26000 0.2
                                  72000 0.01
                        1 300   end
 h2o         4 1 300   end
 pyrex       5 1 300
                                  5010 18.4309
                                  5011 81.5691   end
 orconcrete  6 1 300   end
 ss304       7 1 300   end
 aluminum    8 1 300   end
end composition
read celldata
  latticecell squarepitch fuelr=0.55 1 gapr=0.62 0 cladr=0.647 3
hpitch=0.7 4 end
```

```
end celldata
read parameter
 gen=164
 nsk=30
 npg=1000
 agn=2636
 apg=10000
 htm=yes
 fdn=yes
 msh=2
end parameter
read geometry
unit 1
com='fuel pin'
 zcylinder 1 1    0.55      366        0
 zcylinder 0 1    0.62      366        0
 zcylinder 3 1   0.647      366        0
global unit 3
com='array of pins'
 cuboid 4 1      24.5      -0.7     24.5      -0.7       366          0
  hole 1       0         0        0
  hole 1       0       1.4        0
  hole 1       0       2.8        0
  hole 1       0       4.2        0
  hole 1       0       5.6        0
  hole 1       0         7        0
  hole 1       0       8.4        0
  hole 1       0       9.8        0
  hole 1       0      11.2        0
  hole 1       0      12.6        0
  hole 1       0        14        0
  hole 1       0      15.4        0
  hole 1       0      16.8        0
  hole 1       0      18.2        0
  hole 1       0      19.6        0
  hole 1       0        21        0
  hole 1       0      22.4        0
  hole 1       0      23.8        0
  hole 1     1.4         0        0
  hole 1     1.4       1.4        0
  hole 1     1.4       2.8        0
  hole 1     1.4       4.2        0
  hole 1     1.4       5.6        0
  hole 1     1.4         7        0
  hole 1     1.4       8.4        0
  hole 1     1.4       9.8        0
  hole 1     1.4      11.2        0
  hole 1     1.4      12.6        0
  hole 1     1.4        14        0
  hole 1     1.4      15.4        0
  hole 1     1.4      16.8        0
  hole 1     1.4      18.2        0
  hole 1     1.4      19.6        0
  hole 1     1.4        21        0
  hole 1     1.4      22.4        0
  hole 1     1.4      23.8        0
  hole 1     2.8         0        0
```

hole	1	2.8	1.4	0
hole	1	2.8	2.8	0
hole	1	2.8	4.2	0
hole	1	2.8	5.6	0
hole	1	2.8	7	0
hole	1	2.8	8.4	0
hole	1	2.8	9.8	0
hole	1	2.8	11.2	0
hole	1	2.8	12.6	0
hole	1	2.8	14	0
hole	1	2.8	15.4	0
hole	1	2.8	16.8	0
hole	1	2.8	18.2	0
hole	1	2.8	19.6	0
hole	1	2.8	21	0
hole	1	2.8	22.4	0
hole	1	2.8	23.8	0
hole	1	4.2	0	0
hole	1	4.2	1.4	0
hole	1	4.2	2.8	0
hole	1	4.2	4.2	0
hole	1	4.2	5.6	0
hole	1	4.2	7	0
hole	1	4.2	8.4	0
hole	1	4.2	9.8	0
hole	1	4.2	11.2	0
hole	1	4.2	12.6	0
hole	1	4.2	14	0
hole	1	4.2	15.4	0
hole	1	4.2	16.8	0
hole	1	4.2	18.2	0
hole	1	4.2	19.6	0
hole	1	4.2	21	0
hole	1	4.2	22.4	0
hole	1	4.2	23.8	0
hole	1	5.6	0	0
hole	1	5.6	1.4	0
hole	1	5.6	2.8	0
hole	1	5.6	4.2	0
hole	1	5.6	5.6	0
hole	1	5.6	7	0
hole	1	5.6	8.4	0
hole	1	5.6	9.8	0
hole	1	5.6	11.2	0
hole	1	5.6	12.6	0
hole	1	5.6	14	0
hole	1	5.6	15.4	0
hole	1	5.6	16.8	0
hole	1	5.6	18.2	0
hole	1	5.6	19.6	0
hole	1	5.6	21	0
hole	1	5.6	22.4	0
hole	1	5.6	23.8	0
hole	1	7	0	0
hole	1	7	1.4	0
hole	1	7	2.8	0
hole	1	7	4.2	0

hole	1	7	5.6	0
hole	1	7	7	0
hole	1	7	8.4	0
hole	1	7	9.8	0
hole	1	7	11.2	0
hole	1	7	12.6	0
hole	1	7	14	0
hole	1	7	15.4	0
hole	1	7	16.8	0
hole	1	7	18.2	0
hole	1	7	19.6	0
hole	1	7	21	0
hole	1	7	22.4	0
hole	1	7	23.8	0
hole	1	8.4	0	0
hole	1	8.4	1.4	0
hole	1	8.4	2.8	0
hole	1	8.4	4.2	0
hole	1	8.4	5.6	0
hole	1	8.4	7	0
hole	1	8.4	8.4	0
hole	1	8.4	9.8	0
hole	1	8.4	11.2	0
hole	1	8.4	12.6	0
hole	1	8.4	14	0
hole	1	8.4	15.4	0
hole	1	8.4	16.8	0
hole	1	8.4	18.2	0
hole	1	8.4	19.6	0
hole	1	8.4	21	0
hole	1	8.4	22.4	0
hole	1	8.4	23.8	0
hole	1	9.8	0	0
hole	1	9.8	1.4	0
hole	1	9.8	2.8	0
hole	1	9.8	4.2	0
hole	1	9.8	5.6	0
hole	1	9.8	7	0
hole	1	9.8	8.4	0
hole	1	9.8	9.8	0
hole	1	9.8	11.2	0
hole	1	9.8	12.6	0
hole	1	9.8	14	0
hole	1	9.8	15.4	0
hole	1	9.8	16.8	0
hole	1	9.8	18.2	0
hole	1	9.8	19.6	0
hole	1	9.8	21	0
hole	1	9.8	22.4	0
hole	1	9.8	23.8	0
hole	1	11.2	0	0
hole	1	11.2	1.4	0
hole	1	11.2	2.8	0
hole	1	11.2	4.2	0
hole	1	11.2	5.6	0
hole	1	11.2	7	0
hole	1	11.2	8.4	0

hole 1	11.2	9.8	0
hole 1	11.2	11.2	0
hole 1	11.2	12.6	0
hole 1	11.2	14	0
hole 1	11.2	15.4	0
hole 1	11.2	16.8	0
hole 1	11.2	18.2	0
hole 1	11.2	19.6	0
hole 1	11.2	21	0
hole 1	11.2	22.4	0
hole 1	11.2	23.8	0
hole 1	12.6	0	0
hole 1	12.6	1.4	0
hole 1	12.6	2.8	0
hole 1	12.6	4.2	0
hole 1	12.6	5.6	0
hole 1	12.6	7	0
hole 1	12.6	8.4	0
hole 1	12.6	9.8	0
hole 1	12.6	11.2	0
hole 1	12.6	12.6	0
hole 1	12.6	14	0
hole 1	12.6	15.4	0
hole 1	12.6	16.8	0
hole 1	12.6	18.2	0
hole 1	12.6	19.6	0
hole 1	12.6	21	0
hole 1	12.6	22.4	0
hole 1	12.6	23.8	0
hole 1	14	0	0
hole 1	14	1.4	0
hole 1	14	2.8	0
hole 1	14	4.2	0
hole 1	14	5.6	0
hole 1	14	7	0
hole 1	14	8.4	0
hole 1	14	9.8	0
hole 1	14	11.2	0
hole 1	14	12.6	0
hole 1	14	14	0
hole 1	14	15.4	0
hole 1	14	16.8	0
hole 1	14	18.2	0
hole 1	14	19.6	0
hole 1	14	21	0
hole 1	14	22.4	0
hole 1	14	23.8	0
hole 1	15.4	0	0
hole 1	15.4	1.4	0
hole 1	15.4	2.8	0
hole 1	15.4	4.2	0
hole 1	15.4	5.6	0
hole 1	15.4	7	0
hole 1	15.4	8.4	0
hole 1	15.4	9.8	0
hole 1	15.4	11.2	0
hole 1	15.4	12.6	0

hole	1	15.4	14	0
hole	1	15.4	15.4	0
hole	1	15.4	16.8	0
hole	1	15.4	18.2	0
hole	1	15.4	19.6	0
hole	1	15.4	21	0
hole	1	15.4	22.4	0
hole	1	15.4	23.8	0
hole	1	16.8	0	0
hole	1	16.8	1.4	0
hole	1	16.8	2.8	0
hole	1	16.8	4.2	0
hole	1	16.8	5.6	0
hole	1	16.8	7	0
hole	1	16.8	8.4	0
hole	1	16.8	9.8	0
hole	1	16.8	11.2	0
hole	1	16.8	12.6	0
hole	1	16.8	14	0
hole	1	16.8	15.4	0
hole	1	16.8	16.8	0
hole	1	16.8	18.2	0
hole	1	16.8	19.6	0
hole	1	16.8	21	0
hole	1	16.8	22.4	0
hole	1	16.8	23.8	0
hole	1	18.2	0	0
hole	1	18.2	1.4	0
hole	1	18.2	2.8	0
hole	1	18.2	4.2	0
hole	1	18.2	5.6	0
hole	1	18.2	7	0
hole	1	18.2	8.4	0
hole	1	18.2	9.8	0
hole	1	18.2	11.2	0
hole	1	18.2	12.6	0
hole	1	18.2	14	0
hole	1	18.2	15.4	0
hole	1	18.2	16.8	0
hole	1	18.2	18.2	0
hole	1	18.2	19.6	0
hole	1	18.2	21	0
hole	1	18.2	22.4	0
hole	1	18.2	23.8	0
hole	1	19.6	0	0
hole	1	19.6	1.4	0
hole	1	19.6	2.8	0
hole	1	19.6	4.2	0
hole	1	19.6	5.6	0
hole	1	19.6	7	0
hole	1	19.6	8.4	0
hole	1	19.6	9.8	0
hole	1	19.6	11.2	0
hole	1	19.6	12.6	0
hole	1	19.6	14	0
hole	1	19.6	15.4	0
hole	1	19.6	16.8	0

hole	1	19.6	18.2	0
hole	1	19.6	19.6	0
hole	1	19.6	21	0
hole	1	19.6	22.4	0
hole	1	19.6	23.8	0
hole	1	21	0	0
hole	1	21	1.4	0
hole	1	21	2.8	0
hole	1	21	4.2	0
hole	1	21	5.6	0
hole	1	21	7	0
hole	1	21	8.4	0
hole	1	21	9.8	0
hole	1	21	11.2	0
hole	1	21	12.6	0
hole	1	21	14	0
hole	1	21	15.4	0
hole	1	21	16.8	0
hole	1	21	18.2	0
hole	1	21	19.6	0
hole	1	21	21	0
hole	1	21	22.4	0
hole	1	21	23.8	0
hole	1	22.4	0	0
hole	1	22.4	1.4	0
hole	1	22.4	2.8	0
hole	1	22.4	4.2	0
hole	1	22.4	5.6	0
hole	1	22.4	7	0
hole	1	22.4	8.4	0
hole	1	22.4	9.8	0
hole	1	22.4	11.2	0
hole	1	22.4	12.6	0
hole	1	22.4	14	0
hole	1	22.4	15.4	0
hole	1	22.4	16.8	0
hole	1	22.4	18.2	0
hole	1	22.4	19.6	0
hole	1	22.4	21	0
hole	1	22.4	22.4	0
hole	1	22.4	23.8	0
hole	1	23.8	0	0
hole	1	23.8	1.4	0
hole	1	23.8	2.8	0
hole	1	23.8	4.2	0
hole	1	23.8	5.6	0
hole	1	23.8	7	0
hole	1	23.8	8.4	0
hole	1	23.8	9.8	0
hole	1	23.8	11.2	0
hole	1	23.8	12.6	0
hole	1	23.8	14	0
hole	1	23.8	15.4	0
hole	1	23.8	16.8	0
hole	1	23.8	18.2	0
hole	1	23.8	19.6	0
hole	1	23.8	21	0

```
  hole 1    23.8      22.4         0
  hole 1    23.8      23.8         0
 cuboid 7 1     24.75     -0.95     24.75     -0.95      366.25      -
.25
 replicate  4 1 6*2. 1
 replicate  4 1 6*2. 1
 replicate  4 1 6*2. 1
end geometry
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=vacuum
 -zb=vacuum
  end bnds
end bnds
end data
read sams
  prtgeom
end sams
end
```

Contingency Base Case 6: Graphite-moderated TRISO fuel pins in hexagonal lattice

The input deck for the contingency case (DCASE6A.INP) is given by:

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=tsunami-3d-k5 parm=(nitawlst)
graphite moderated reactor - hexagonal lattice modeled as cylinder @
5% enrich
238groupndf5
read composition
 uo2          1 0.1605 300
                                  92235 5
                                  92238 95    end
 c            1 0.6698 300   end
 si           1 0.0874 300   end
 gd           1 2e-05 300   end
 c-graphite   2 1 300   end
 helium       3 1 300   end
 ss304        4 1 300   end
 h2o          5 1 300   end
end composition
read parameter
 gen=130
 npg=1000
 nsk=30
 agn=2636
 apg=10000
 htm=yes
 fdn=yes
 msh=2
end parameter
```

```
read geometry
unit 1
com='hexagon equivalent cylinder'
 zcylinder 1 1    0.75      100         0
global unit 2
com='shipping cask'
 zcylinder 2 1      23      100         0
  hole 1  -19.74        0         0
  hole 1  -16.92        0         0
  hole 1   -14.1        0         0
  hole 1  -11.28        0         0
  hole 1   -8.46        0         0
  hole 1   -5.64        0         0
  hole 1   -2.82        0         0
  hole 1       0        0         0
  hole 1    2.82        0         0
  hole 1   19.74        0         0
  hole 1   16.92        0         0
  hole 1    14.1        0         0
  hole 1   11.28        0         0
  hole 1    8.46        0         0
  hole 1    5.64        0         0
  hole 1    1.41   2.4422         0
  hole 1    4.23   2.4422         0
  hole 1    7.05   2.4422         0
  hole 1    9.87   2.4422         0
  hole 1   12.69   2.4422         0
  hole 1   15.51   2.4422         0
  hole 1   18.33   2.4422         0
  hole 1   -1.41   2.4422         0
  hole 1   -4.23   2.4422         0
  hole 1   -7.05   2.4422         0
  hole 1   -9.87   2.4422         0
  hole 1  -12.69   2.4422         0
  hole 1  -15.51   2.4422         0
  hole 1  -18.33   2.4422         0
  hole 1    1.41  -2.4422         0
  hole 1    4.23  -2.4422         0
  hole 1    7.05  -2.4422         0
  hole 1    9.87  -2.4422         0
  hole 1   12.69  -2.4422         0
  hole 1   15.51  -2.4422         0
  hole 1   18.33  -2.4422         0
  hole 1   -1.41  -2.4422         0
  hole 1   -4.23  -2.4422         0
  hole 1   -7.05  -2.4422         0
  hole 1   -9.87  -2.4422         0
  hole 1  -12.69  -2.4422         0
  hole 1  -15.51  -2.4422         0
  hole 1  -18.33  -2.4422         0
  hole 1  -16.92   4.8844         0
  hole 1   -14.1   4.8844         0
  hole 1  -11.28   4.8844         0
  hole 1   -8.46   4.8844         0
  hole 1   -5.64   4.8844         0
  hole 1   -2.82   4.8844         0
  hole 1       0   4.8844         0
```

hole	1	2.82	4.8844	0
hole	1	5.64	4.8844	0
hole	1	8.46	4.8844	0
hole	1	11.28	4.8844	0
hole	1	14.1	4.8844	0
hole	1	16.92	4.8844	0
hole	1	-16.92	-4.8844	0
hole	1	-14.1	-4.8844	0
hole	1	-11.28	-4.8844	0
hole	1	-8.46	-4.8844	0
hole	1	-5.64	-4.8844	0
hole	1	-2.82	-4.8844	0
hole	1	0	-4.8844	0
hole	1	2.82	-4.8844	0
hole	1	5.64	-4.8844	0
hole	1	8.46	-4.8844	0
hole	1	11.28	-4.8844	0
hole	1	14.1	-4.8844	0
hole	1	16.92	-4.8844	0
hole	1	1.41	7.3266	0
hole	1	4.23	7.3266	0
hole	1	7.05	7.3266	0
hole	1	9.87	7.3266	0
hole	1	12.69	7.3266	0
hole	1	15.51	7.3266	0
hole	1	-1.41	7.3266	0
hole	1	-4.23	7.3266	0
hole	1	-7.05	7.3266	0
hole	1	-9.87	7.3266	0
hole	1	-12.69	7.3266	0
hole	1	-15.51	7.3266	0
hole	1	1.41	-7.3266	0
hole	1	4.23	-7.3266	0
hole	1	7.05	-7.3266	0
hole	1	9.87	-7.3266	0
hole	1	12.69	-7.3266	0
hole	1	15.51	-7.3266	0
hole	1	-1.41	-7.3266	0
hole	1	-4.23	-7.3266	0
hole	1	-7.05	-7.3266	0
hole	1	-9.87	-7.3266	0
hole	1	-12.69	-7.3266	0
hole	1	-15.51	-7.3266	0
hole	1	-14.1	9.7688	0
hole	1	-11.28	9.7688	0
hole	1	-8.46	9.7688	0
hole	1	-5.64	9.7688	0
hole	1	-2.82	9.7688	0
hole	1	0	9.7688	0
hole	1	2.82	9.7688	0
hole	1	5.64	9.7688	0
hole	1	8.46	9.7688	0
hole	1	11.28	9.7688	0
hole	1	14.1	9.7688	0
hole	1	-14.1	-9.7688	0
hole	1	-11.28	-9.7688	0
hole	1	-8.46	-9.7688	0

hole	1	-5.64	-9.7688	0
hole	1	-2.82	-9.7688	0
hole	1	0	-9.7688	0
hole	1	2.82	-9.7688	0
hole	1	5.64	-9.7688	0
hole	1	8.46	-9.7688	0
hole	1	11.28	-9.7688	0
hole	1	14.1	-9.7688	0
hole	1	1.41	12.211	0
hole	1	4.23	12.211	0
hole	1	7.05	12.211	0
hole	1	9.87	12.211	0
hole	1	12.69	12.211	0
hole	1	-1.41	12.211	0
hole	1	-4.23	12.211	0
hole	1	-7.05	12.211	0
hole	1	-9.87	12.211	0
hole	1	-12.69	12.211	0
hole	1	1.41	-12.211	0
hole	1	4.23	-12.211	0
hole	1	7.05	-12.211	0
hole	1	9.87	-12.211	0
hole	1	12.69	-12.211	0
hole	1	-1.41	-12.211	0
hole	1	-4.23	-12.211	0
hole	1	-7.05	-12.211	0
hole	1	-9.87	-12.211	0
hole	1	-12.69	-12.211	0
hole	1	-11.28	14.6532	0
hole	1	-8.46	14.6532	0
hole	1	-5.64	14.6532	0
hole	1	-2.82	14.6532	0
hole	1	0	14.6532	0
hole	1	2.82	14.6532	0
hole	1	5.64	14.6532	0
hole	1	8.46	14.6532	0
hole	1	11.28	14.6532	0
hole	1	-11.28	-14.6532	0
hole	1	-8.46	-14.6532	0
hole	1	-5.64	-14.6532	0
hole	1	-2.82	-14.6532	0
hole	1	0	-14.6532	0
hole	1	2.82	-14.6532	0
hole	1	5.64	-14.6532	0
hole	1	8.46	-14.6532	0
hole	1	11.28	-14.6532	0
hole	1	1.41	17.0954	0
hole	1	4.23	17.0954	0
hole	1	7.05	17.0954	0
hole	1	9.87	17.0954	0
hole	1	-1.41	17.0954	0
hole	1	-4.23	17.0954	0
hole	1	-7.05	17.0954	0
hole	1	-9.87	17.0954	0
hole	1	1.41	-17.0954	0
hole	1	4.23	-17.0954	0
hole	1	7.05	-17.0954	0

```
   hole 1     9.87   -17.0954         0
   hole 1    -1.41   -17.0954         0
   hole 1    -4.23   -17.0954         0
   hole 1    -7.05   -17.0954         0
   hole 1    -9.87   -17.0954         0
  cuboid 5 1 4p23.5       101        -1
 end geometry
 read bnds
  +xb=mirror
  -xb=mirror
  +yb=mirror
  -yb=mirror
  +zb=mirror
  -zb=mirror
   end bnds
 end bnds
 end data
 read sams
   prtgeom
 end sams
 end
```

A.4. Sample Powder case input deck

A sample TSUNAMI-1D powder input deck (this one corresponding to 5% enriched) is given by:

```
=tsunami-1d   parm=(nitawlst)
Powder pure
238gr
read composition
 uo2         1 0.2281 293 92235 5 92238 95   end
 h2o         1 0.1818 293 end
end composition
read celldata
multiregion
spherical left_bdy=reflected
right_bdy=vacuum  end
 1            66
 end zone
end celldata
read parameter
isn=32
end parameter
read geometry
spherical vacuum reflected end
 1            66
end geometry
read sams
  prtgeom
end sams
end
```

For the 6% case, the file compare gives:

```
Comparing files dcase7a.inp and DCASE7B.INP
***** dcase7a.inp
read composition
 uo2          1 0.2281 293 92235 5 92238 95   end
 h2o          1 0.1818 293 end
end composition
***** DCASE7B.INP
read composition
 uo2          1 0.2281 293 92235 6 92238 94   end
 h2o          1 0.1723 293 end
end composition
*****
```

For the 8% case, the file compare gives:

```
Comparing files dcase7a.inp and DCASE7C.INP
***** dcase7a.inp
read composition
 uo2          1 0.2281 293 92235 5 92238 95   end
 h2o          1 0.1818 293 end
end composition
***** DCASE7C.INP
read composition
 uo2          1 0.2281 293 92235 8 92238 92   end
 h2o          1 0.1576 293 end
end composition
*****
```

For the 10% case, the file compare gives:

```
Comparing files dcase7a.inp and DCASE7D.INP
***** dcase7a.inp
read composition
 uo2          1 0.2281 293 92235 5 92238 95   end
 h2o          1 0.1818 293 end
end composition
***** DCASE7D.INP
read composition
 uo2          1 0.2281 293 92235 10 92238 90   end
 h2o          1 0.1457 293 end
end composition
*****
```

A.5. Sample TSUNAMI-IP input deck

A sample TSUNAMI-IP input deck (this one corresponding to normal Base Case 1A) is given below. A numbering scheme has been added to the leftmost column to let this list do double duty as the cross reference to the experimental numbers in Appendix B.

There are two sets of duplications that were discovered late in the project, so experiment numbers 382-384 and 422-425 should be disregarded.

The naming convention is mostly decipherable, with the following naming conventions:

- lct = LEU-COMP-THERM
- lst = LEU-SOL-THERM
- hct = HEU-COMP-THERM
- hmt =HEU-MET-THERM
- hst = HEU-SOL-THERM
- imf =IEU-MET-FAST
- car = inherited naming for the LEU-COMP-THERM-045 evaluation

```
Exp#    Input line
        =tsunami-ip
        NRC Task 2 Evaluation
        read parameter
        c
        c_long
        cov_fix
        coverx=44groupv6rec
        cp
        html
        inptcase
        lg
        lgall
        penalty
        penlong
        plot
        prtcomp
        uncert
        uncert_long
        uslstats
        uslsummary
        values
        end parameter
        read applications
        \nrc\normals\case1a.sdf
        end applications
        read experiments
1       \nrc\sdf\ornl\heu\hct010-01.sdf
2       \nrc\sdf\ornl\heu\hct010-02.sdf
3       \nrc\sdf\ornl\heu\hct010-03.sdf
4       \nrc\sdf\ornl\heu\hct010-04.sdf
5       \nrc\sdf\ornl\heu\hct010-05.sdf
6       \nrc\sdf\ornl\heu\hct010-06.sdf
7       \nrc\sdf\ornl\heu\hct010-07.sdf
8       \nrc\sdf\ornl\heu\hct010-08.sdf
```

9	\nrc\sdf\ornl\heu\hct010-09.sdf
10	\nrc\sdf\ornl\heu\hct010-10.sdf
11	\nrc\sdf\ornl\heu\hct010-11.sdf
12	\nrc\sdf\ornl\heu\hct010-12.sdf
13	\nrc\sdf\ornl\heu\hct010-13.sdf
14	\nrc\sdf\ornl\heu\hct010-14.sdf
15	\nrc\sdf\ornl\heu\hct010-15.sdf
16	\nrc\sdf\ornl\heu\hct011-01.sdf
17	\nrc\sdf\ornl\heu\hct011-02.sdf
18	\nrc\sdf\ornl\heu\hct011-03.sdf
19	\nrc\sdf\ornl\heu\hct012-01.sdf
20	\nrc\sdf\ornl\heu\hct012-02.sdf
21	\nrc\sdf\ornl\heu\hct013-01.sdf
22	\nrc\sdf\ornl\heu\hct013-02.sdf
23	\nrc\sdf\ornl\heu\hct014-01.sdf
24	\nrc\sdf\ornl\heu\hct014-02.sdf
25	\nrc\sdf\ornl\heu\hmt006-01.sdf
26	\nrc\sdf\ornl\heu\hmt006-02.sdf
27	\nrc\sdf\ornl\heu\hmt006-03.sdf
28	\nrc\sdf\ornl\heu\hmt006-04.sdf
29	\nrc\sdf\ornl\heu\hmt006-05.sdf
30	\nrc\sdf\ornl\heu\hmt006-06.sdf
31	\nrc\sdf\ornl\heu\hmt006-07.sdf
32	\nrc\sdf\ornl\heu\hmt006-08.sdf
33	\nrc\sdf\ornl\heu\hmt006-09.sdf
34	\nrc\sdf\ornl\heu\hmt006-10.sdf
35	\nrc\sdf\ornl\heu\hmt006-11.sdf
36	\nrc\sdf\ornl\heu\hmt006-12.sdf
37	\nrc\sdf\ornl\heu\hmt006-13.sdf
38	\nrc\sdf\ornl\heu\hmt006-14.sdf
39	\nrc\sdf\ornl\heu\hmt006-15.sdf
40	\nrc\sdf\ornl\heu\hmt006-16.sdf
41	\nrc\sdf\ornl\heu\hmt006-17.sdf
42	\nrc\sdf\ornl\heu\hmt006-18.sdf
43	\nrc\sdf\ornl\heu\hmt006-19.sdf
44	\nrc\sdf\ornl\heu\hmt006-20.sdf
45	\nrc\sdf\ornl\heu\hmt006-21.sdf
46	\nrc\sdf\ornl\heu\hmt006-22.sdf
47	\nrc\sdf\ornl\heu\hmt006-23.sdf
48	\nrc\sdf\ornl\heu\hst001-01.sdf
49	\nrc\sdf\ornl\heu\hst001-02.sdf
50	\nrc\sdf\ornl\heu\hst001-03.sdf
51	\nrc\sdf\ornl\heu\hst001-04.sdf
52	\nrc\sdf\ornl\heu\hst001-05.sdf
53	\nrc\sdf\ornl\heu\hst001-06.sdf
54	\nrc\sdf\ornl\heu\hst001-07.sdf
55	\nrc\sdf\ornl\heu\hst001-08.sdf
56	\nrc\sdf\ornl\heu\hst001-09.sdf
57	\nrc\sdf\ornl\heu\hst001-10.sdf
58	\nrc\sdf\ornl\heu\hst005-11.sdf
59	\nrc\sdf\ornl\heu\hst005-12.sdf
60	\nrc\sdf\ornl\heu\hst005-14.sdf
61	\nrc\sdf\ornl\heu\hst005-15.sdf
62	\nrc\sdf\ornl\heu\hst005-17.sdf
63	\nrc\sdf\ornl\heu\hst006-01.sdf
64	\nrc\sdf\ornl\heu\hst006-08.sdf
65	\nrc\sdf\ornl\heu\hst006-12.sdf

66 \nrc\sdf\ornl\heu\hst006-27.sdf
67 \nrc\sdf\ornl\heu\hst007-01.sdf
68 \nrc\sdf\ornl\heu\hst007-02.sdf
69 \nrc\sdf\ornl\heu\hst007-03.sdf
70 \nrc\sdf\ornl\heu\hst007-04.sdf
71 \nrc\sdf\ornl\heu\hst007-05.sdf
72 \nrc\sdf\ornl\heu\hst007-06.sdf
73 \nrc\sdf\ornl\heu\hst007-07.sdf
74 \nrc\sdf\ornl\heu\hst007-08.sdf
75 \nrc\sdf\ornl\heu\hst007-09.sdf
76 \nrc\sdf\ornl\heu\hst007-10.sdf
77 \nrc\sdf\ornl\heu\hst007-11.sdf
78 \nrc\sdf\ornl\heu\hst007-12.sdf
79 \nrc\sdf\ornl\heu\hst007-13.sdf
80 \nrc\sdf\ornl\heu\hst007-14.sdf
81 \nrc\sdf\ornl\heu\hst007-15.sdf
82 \nrc\sdf\ornl\heu\hst007-16.sdf
83 \nrc\sdf\ornl\heu\hst007-17.sdf
84 \nrc\sdf\ornl\heu\hst009-01.sdf
85 \nrc\sdf\ornl\heu\hst009-02.sdf
86 \nrc\sdf\ornl\heu\hst009-03.sdf
87 \nrc\sdf\ornl\heu\hst009-04.sdf
88 \nrc\sdf\ornl\heu\hst010-01.sdf
89 \nrc\sdf\ornl\heu\hst010-02.sdf
90 \nrc\sdf\ornl\heu\hst010-03.sdf
91 \nrc\sdf\ornl\heu\hst010-04.sdf
92 \nrc\sdf\ornl\heu\hst011-01.sdf
93 \nrc\sdf\ornl\heu\hst011-02.sdf
94 \nrc\sdf\ornl\heu\hst012-01.sdf
95 \nrc\sdf\ornl\heu\hst013-01.sdf
96 \nrc\sdf\ornl\heu\hst014-01.sdf
97 \nrc\sdf\ornl\heu\hst015-01.sdf
98 \nrc\sdf\ornl\heu\hst015-02.sdf
99 \nrc\sdf\ornl\heu\hst016-01.sdf
100 \nrc\sdf\ornl\heu\hst017-01.sdf
101 \nrc\sdf\ornl\heu\hst017-02.sdf
102 \nrc\sdf\ornl\heu\hst017-03.sdf
103 \nrc\sdf\ornl\heu\hst018-01.sdf
104 \nrc\sdf\ornl\heu\hst018-02.sdf
105 \nrc\sdf\ornl\heu\hst018-03.sdf
106 \nrc\sdf\ornl\heu\hst019-01.sdf
107 \nrc\sdf\ornl\heu\hst025-01.sdf
108 \nrc\sdf\ornl\heu\hst025-02.sdf
109 \nrc\sdf\ornl\heu\hst025-04.sdf
110 \nrc\sdf\ornl\heu\hst025-05.sdf
111 \nrc\sdf\ornl\heu\hst027-01.sdf
112 \nrc\sdf\ornl\heu\hst032-01.sdf
113 \nrc\sdf\ornl\heu\hst033-02a.sdf
114 \nrc\sdf\ornl\heu\hst033-02b.sdf
115 \nrc\sdf\ornl\heu\hst033-02c.sdf
116 \nrc\sdf\ornl\heu\hst033-03a.sdf
117 \nrc\sdf\ornl\heu\hst033-03b.sdf
118 \nrc\sdf\ornl\heu\hst033-03c.sdf
119 \nrc\sdf\ornl\heu\hst033-10a.sdf
120 \nrc\sdf\ornl\heu\hst033-10c.sdf
121 \nrc\sdf\ornl\heu\hst033-10d.sdf
122 \nrc\sdf\ornl\ieu\imf003.sdf

123 \nrc\sdf\ornl\ieu\imf004.sdf
124 \nrc\sdf\ornl\ieu\imf005.sdf
125 \nrc\sdf\ornl\ieu\imf006.sdf
126 \nrc\sdf\ornl\leu\car06.sdf
127 \nrc\sdf\ornl\leu\car07.sdf
128 \nrc\sdf\ornl\leu\car08.sdf
129 \nrc\sdf\ornl\leu\car10.sdf
130 \nrc\sdf\ornl\leu\car17.sdf
131 \nrc\sdf\ornl\leu\car18.sdf
132 \nrc\sdf\ornl\leu\car19.sdf
133 \nrc\sdf\ornl\leu\car20.sdf
134 \nrc\sdf\ornl\leu\lct009-01.sdf
135 \nrc\sdf\ornl\leu\lct009-02.sdf
136 \nrc\sdf\ornl\leu\lct009-03.sdf
137 \nrc\sdf\ornl\leu\lct009-04.sdf
138 \nrc\sdf\ornl\leu\lct009-05.sdf
139 \nrc\sdf\ornl\leu\lct009-06.sdf
140 \nrc\sdf\ornl\leu\lct009-07.sdf
141 \nrc\sdf\ornl\leu\lct009-08.sdf
142 \nrc\sdf\ornl\leu\lct009-09.sdf
143 \nrc\sdf\ornl\leu\lct009-10.sdf
144 \nrc\sdf\ornl\leu\lct009-11.sdf
145 \nrc\sdf\ornl\leu\lct009-13.sdf
146 \nrc\sdf\ornl\leu\lct009-14.sdf
147 \nrc\sdf\ornl\leu\lct009-15.sdf
148 \nrc\sdf\ornl\leu\lct009-16.sdf
149 \nrc\sdf\ornl\leu\lct009-17.sdf
150 \nrc\sdf\ornl\leu\lct009-18.sdf
151 \nrc\sdf\ornl\leu\lct009-19.sdf
152 \nrc\sdf\ornl\leu\lct009-20.sdf
153 \nrc\sdf\ornl\leu\lct009-21.sdf
154 \nrc\sdf\ornl\leu\lct009-22.sdf
155 \nrc\sdf\ornl\leu\lct009-23.sdf
156 \nrc\sdf\ornl\leu\lct009-24.sdf
157 \nrc\sdf\ornl\leu\lct009-25.sdf
158 \nrc\sdf\ornl\leu\lct009-26.sdf
159 \nrc\sdf\ornl\leu\lct009-27.sdf
160 \nrc\sdf\ornl\leu\lct010-01.sdf
161 \nrc\sdf\ornl\leu\lct010-02.sdf
162 \nrc\sdf\ornl\leu\lct010-03.sdf
163 \nrc\sdf\ornl\leu\lct010-04.sdf
164 \nrc\sdf\ornl\leu\lct010-05.sdf
165 \nrc\sdf\ornl\leu\lct010-06.sdf
166 \nrc\sdf\ornl\leu\lct010-07.sdf
167 \nrc\sdf\ornl\leu\lct010-08.sdf
168 \nrc\sdf\ornl\leu\lct010-09.sdf
169 \nrc\sdf\ornl\leu\lct010-10.sdf
170 \nrc\sdf\ornl\leu\lct010-11.sdf
171 \nrc\sdf\ornl\leu\lct010-12.sdf
172 \nrc\sdf\ornl\leu\lct010-13.sdf
173 \nrc\sdf\ornl\leu\lct010-14.sdf
174 \nrc\sdf\ornl\leu\lct010-15.sdf
175 \nrc\sdf\ornl\leu\lct010-16.sdf
176 \nrc\sdf\ornl\leu\lct010-17.sdf
177 \nrc\sdf\ornl\leu\lct010-18.sdf
178 \nrc\sdf\ornl\leu\lct010-19.sdf
179 \nrc\sdf\ornl\leu\lct010-20.sdf

180 \nrc\sdf\ornl\leu\lct010-21.sdf
181 \nrc\sdf\ornl\leu\lct010-22.sdf
182 \nrc\sdf\ornl\leu\lct010-23.sdf
183 \nrc\sdf\ornl\leu\lct010-24.sdf
184 \nrc\sdf\ornl\leu\lct010-25.sdf
185 \nrc\sdf\ornl\leu\lct010-26.sdf
186 \nrc\sdf\ornl\leu\lct010-27.sdf
187 \nrc\sdf\ornl\leu\lct010-28.sdf
188 \nrc\sdf\ornl\leu\lct010-29.sdf
189 \nrc\sdf\ornl\leu\lct010-30.sdf
190 \nrc\sdf\ornl\leu\lct012-01.sdf
191 \nrc\sdf\ornl\leu\lct012-02.sdf
192 \nrc\sdf\ornl\leu\lct012-03.sdf
193 \nrc\sdf\ornl\leu\lct012-04.sdf
194 \nrc\sdf\ornl\leu\lct012-05.sdf
195 \nrc\sdf\ornl\leu\lct012-06.sdf
196 \nrc\sdf\ornl\leu\lct012-07.sdf
197 \nrc\sdf\ornl\leu\lct012-08.sdf
198 \nrc\sdf\ornl\leu\lct012-09.sdf
199 \nrc\sdf\ornl\leu\lct012-10.sdf
200 \nrc\sdf\ornl\leu\lct017-01.sdf
201 \nrc\sdf\ornl\leu\lct017-02.sdf
202 \nrc\sdf\ornl\leu\lct017-03.sdf
203 \nrc\sdf\ornl\leu\lct017-04.sdf
204 \nrc\sdf\ornl\leu\lct017-05.sdf
205 \nrc\sdf\ornl\leu\lct017-06.sdf
206 \nrc\sdf\ornl\leu\lct017-07.sdf
207 \nrc\sdf\ornl\leu\lct017-08.sdf
208 \nrc\sdf\ornl\leu\lct017-09.sdf
209 \nrc\sdf\ornl\leu\lct017-10.sdf
210 \nrc\sdf\ornl\leu\lct017-11.sdf
211 \nrc\sdf\ornl\leu\lct017-12.sdf
212 \nrc\sdf\ornl\leu\lct017-13.sdf
213 \nrc\sdf\ornl\leu\lct017-14.sdf
214 \nrc\sdf\ornl\leu\lct017-15.sdf
215 \nrc\sdf\ornl\leu\lct017-16.sdf
216 \nrc\sdf\ornl\leu\lct017-17.sdf
217 \nrc\sdf\ornl\leu\lct017-18.sdf
218 \nrc\sdf\ornl\leu\lct017-19.sdf
219 \nrc\sdf\ornl\leu\lct017-20.sdf
220 \nrc\sdf\ornl\leu\lct017-21.sdf
221 \nrc\sdf\ornl\leu\lct017-22.sdf
222 \nrc\sdf\ornl\leu\lct017-23.sdf
223 \nrc\sdf\ornl\leu\lct017-24.sdf
224 \nrc\sdf\ornl\leu\lct017-25.sdf
225 \nrc\sdf\ornl\leu\lct017-26.sdf
226 \nrc\sdf\ornl\leu\lct017-27.sdf
227 \nrc\sdf\ornl\leu\lct017-28.sdf
228 \nrc\sdf\ornl\leu\lct017-29.sdf
229 \nrc\sdf\ornl\leu\lct040-01.sdf
230 \nrc\sdf\ornl\leu\lct040-02.sdf
231 \nrc\sdf\ornl\leu\lct040-03.sdf
232 \nrc\sdf\ornl\leu\lct042-01.sdf
233 \nrc\sdf\ornl\leu\lct042-02.sdf
234 \nrc\sdf\ornl\leu\lct042-03.sdf
235 \nrc\sdf\ornl\leu\lct042-04.sdf
236 \nrc\sdf\ornl\leu\lct042-05.sdf

237 \nrc\sdf\ornl\leu\lct042-06.sdf
238 \nrc\sdf\ornl\leu\lct042-07.sdf
239 \nrc\sdf\ornl\leu\lct18c1.sdf
240 \nrc\sdf\ornl\leu\lct19c1.sdf
241 \nrc\sdf\ornl\leu\lct19c2.sdf
242 \nrc\sdf\ornl\leu\lct19c3.sdf
243 \nrc\sdf\ornl\leu\lct20c1.sdf
244 \nrc\sdf\ornl\leu\lct20c2.sdf
245 \nrc\sdf\ornl\leu\lct20c3.sdf
246 \nrc\sdf\ornl\leu\lct20c4.sdf
247 \nrc\sdf\ornl\leu\lct20c5.sdf
248 \nrc\sdf\ornl\leu\lct20c6.sdf
249 \nrc\sdf\ornl\leu\lct20c7.sdf
250 \nrc\sdf\ornl\leu\lct21c1.sdf
251 \nrc\sdf\ornl\leu\lct21c2.sdf
252 \nrc\sdf\ornl\leu\lct21c3.sdf
253 \nrc\sdf\ornl\leu\lct21c4.sdf
254 \nrc\sdf\ornl\leu\lct21c5.sdf
255 \nrc\sdf\ornl\leu\lct21c6.sdf
256 \nrc\sdf\ornl\leu\lct22c1.sdf
257 \nrc\sdf\ornl\leu\lct22c2.sdf
258 \nrc\sdf\ornl\leu\lct22c3.sdf
259 \nrc\sdf\ornl\leu\lct22c4.sdf
260 \nrc\sdf\ornl\leu\lct22c5.sdf
261 \nrc\sdf\ornl\leu\lct22c6.sdf
262 \nrc\sdf\ornl\leu\lct22c7.sdf
263 \nrc\sdf\ornl\leu\lct23c1.sdf
264 \nrc\sdf\ornl\leu\lct23c2.sdf
265 \nrc\sdf\ornl\leu\lct23c3.sdf
266 \nrc\sdf\ornl\leu\lct23c4.sdf
267 \nrc\sdf\ornl\leu\lct23c5.sdf
268 \nrc\sdf\ornl\leu\lct23c6.sdf
269 \nrc\sdf\ornl\leu\lct24c1.sdf
270 \nrc\sdf\ornl\leu\lct24c2.sdf
271 \nrc\sdf\ornl\leu\lct25c1.sdf
272 \nrc\sdf\ornl\leu\lct25c2.sdf
273 \nrc\sdf\ornl\leu\lct25c3.sdf
274 \nrc\sdf\ornl\leu\lct25c4.sdf
275 \nrc\sdf\ornl\leu\lct26c1.sdf
276 \nrc\sdf\ornl\leu\lct26c2.sdf
277 \nrc\sdf\ornl\leu\lct26c3.sdf
278 \nrc\sdf\ornl\leu\lct26c4.sdf
279 \nrc\sdf\ornl\leu\lct32a1.sdf
280 \nrc\sdf\ornl\leu\lct32a2.sdf
281 \nrc\sdf\ornl\leu\lct32a3.sdf
282 \nrc\sdf\ornl\leu\lct32a4.sdf
283 \nrc\sdf\ornl\leu\lct32a5.sdf
284 \nrc\sdf\ornl\leu\lct32a6.sdf
285 \nrc\sdf\ornl\leu\lct32a7.sdf
286 \nrc\sdf\ornl\leu\lct32a8.sdf
287 \nrc\sdf\ornl\leu\lct32a9.sdf
288 \nrc\sdf\ornl\leu\lst01c1.sdf
289 \nrc\sdf\ornl\leu\lst03c1.sdf
290 \nrc\sdf\ornl\leu\lst03c2.sdf
291 \nrc\sdf\ornl\leu\lst03c3.sdf
292 \nrc\sdf\ornl\leu\lst03c4.sdf
293 \nrc\sdf\ornl\leu\lst03c5.sdf

294 \nrc\sdf\ornl\leu\lst03c6.sdf
295 \nrc\sdf\ornl\leu\lst03c7.sdf
296 \nrc\sdf\ornl\leu\lst03c8.sdf
297 \nrc\sdf\ornl\leu\lst03c9.sdf
298 \nrc\sdf\ornl\leu\lst04-R1.sdf
299 \nrc\sdf\ornl\leu\lst04-R29.sdf
300 \nrc\sdf\ornl\leu\lst04-R33.sdf
301 \nrc\sdf\ornl\leu\lst04-R34.sdf
302 \nrc\sdf\ornl\leu\lst04-R46.sdf
303 \nrc\sdf\ornl\leu\lst04-R51.sdf
304 \nrc\sdf\ornl\leu\lst04-R54.sdf
305 \nrc\sdf\ornl\leu\lst05c1.sdf
306 \nrc\sdf\ornl\leu\lst05c2.sdf
307 \nrc\sdf\ornl\leu\lst05c3.sdf
308 \nrc\sdf\ornl\leu\lst06c1.sdf
309 \nrc\sdf\ornl\leu\lst06c2.sdf
310 \nrc\sdf\ornl\leu\lst06c3.sdf
311 \nrc\sdf\ornl\leu\lst06c4.sdf
312 \nrc\sdf\ornl\leu\lst06c5.sdf
313 \nrc\sdf\ornl\leu\lst07-R14.sdf
314 \nrc\sdf\ornl\leu\lst07-R30.sdf
315 \nrc\sdf\ornl\leu\lst07-R32.sdf
316 \nrc\sdf\ornl\leu\lst07-R36.sdf
317 \nrc\sdf\ornl\leu\lst07-R49.sdf
318 \nrc\sdf\ornl\leu\lst08-R72.sdf
319 \nrc\sdf\ornl\leu\lst08-R74.sdf
320 \nrc\sdf\ornl\leu\lst08-R76.sdf
321 \nrc\sdf\ornl\leu\lst08-R78.sdf
322 \nrc\sdf\ornl\leu\lst09-R92.sdf
323 \nrc\sdf\ornl\leu\lst09-R93.sdf
324 \nrc\sdf\ornl\leu\lst09-R94.sdf
325 \nrc\sdf\ornl\leu\lst10-R83.sdf
326 \nrc\sdf\ornl\leu\lst10-R85.sdf
237 \nrc\sdf\ornl\leu\lst10-R86.sdf
328 \nrc\sdf\ornl\leu\lst10-R88.sdf
329 \nrc\sdf\ornl\leu\lst16-105.sdf
330 \nrc\sdf\ornl\leu\lst16-R113.sdf
331 \nrc\sdf\ornl\leu\lst16-R125.sdf
332 \nrc\sdf\ornl\leu\lst16-R129.sdf
333 \nrc\sdf\ornl\leu\lst16-R131.sdf
334 \nrc\sdf\ornl\leu\lst16-R140.sdf
335 \nrc\sdf\ornl\leu\lst16-R196.sdf
336 \nrc\sdf\ornl\leu\lst17-R104.sdf
337 \nrc\sdf\ornl\leu\lst17-R122.sdf
338 \nrc\sdf\ornl\leu\lst17-R123.sdf
339 \nrc\sdf\ornl\leu\lst17-R126.sdf
430 \nrc\sdf\ornl\leu\lst17-R130.sdf
341 \nrc\sdf\ornl\leu\lst17-R147.sdf
342 \nrc\sdf\ornl\leu\lst18c1.sdf
343 \nrc\sdf\ornl\leu\lst18c3.sdf
344 \nrc\sdf\ornl\leu\lst18c4.sdf
345 \nrc\sdf\ornl\leu\lst18c5.sdf
346 \nrc\sdf\ornl\leu\lst18c6.sdf
347 \nrc\sdf\ornl\leu\lst19c1.sdf
348 \nrc\sdf\ornl\leu\lst19c2.sdf
349 \nrc\sdf\ornl\leu\lst19c3.sdf
350 \nrc\sdf\ornl\leu\lst19c4.sdf

```
351     \nrc\sdf\ornl\leu\lst19c5.sdf
352     \nrc\sdf\ornl\leu\lst19c6.sdf
353     \nrc\sdf\ornl\leu\lst20c1.sdf
354     \nrc\sdf\ornl\leu\lst20c2.sdf
355     \nrc\sdf\ornl\leu\lst20c3.sdf
356     \nrc\sdf\ornl\leu\lst20c4.sdf
357     \nrc\sdf\ornl\leu\lst21c1.sdf
358     \nrc\sdf\ornl\leu\lst21c2.sdf
359     \nrc\sdf\ornl\leu\lst21c3.sdf
360     \nrc\sdf\ornl\leu\lst21c4.sdf
361     \nrc\sdf\lukus\leu-comp-therm-039-001.sdf
362     \nrc\sdf\lukus\leu-comp-therm-039-002.sdf
363     \nrc\sdf\lukus\leu-comp-therm-039-003.sdf
364     \nrc\sdf\lukus\leu-comp-therm-039-004.sdf
365     \nrc\sdf\lukus\leu-comp-therm-039-005.sdf
366     \nrc\sdf\lukus\leu-comp-therm-039-006.sdf
367     \nrc\sdf\lukus\leu-comp-therm-039-007.sdf
368     \nrc\sdf\lukus\leu-comp-therm-039-008.sdf
369     \nrc\sdf\lukus\leu-comp-therm-039-009.sdf
370     \nrc\sdf\lukus\leu-comp-therm-039-010.sdf
371     \nrc\sdf\lukus\leu-comp-therm-039-011.sdf
372     \nrc\sdf\lukus\leu-comp-therm-039-012.sdf
373     \nrc\sdf\lukus\leu-comp-therm-039-013.sdf
374     \nrc\sdf\lukus\leu-comp-therm-039-014.sdf
375     \nrc\sdf\lukus\leu-comp-therm-039-015.sdf
376     \nrc\sdf\lukus\leu-comp-therm-039-016.sdf
377     \nrc\sdf\lukus\leu-comp-therm-039-017.sdf
378     \nrc\sdf\lukus\leu-sol-therm-022-001.sdf
379     \nrc\sdf\lukus\leu-sol-therm-022-002.sdf
380     \nrc\sdf\lukus\leu-sol-therm-022-003.sdf
381     \nrc\sdf\lukus\leu-sol-therm-022-004.sdf
382     \nrc\sdf\lukus\sol201.sdf
383     \nrc\sdf\lukus\sol202.sdf
384     \nrc\sdf\lukus\sol203.sdf
385     \nrc\sdf\other\lct13_01.sdf
386     \nrc\sdf\other\lct33_01.sdf
387     \nrc\sdf\other\lct33_02.sdf
388     \nrc\sdf\other\lct33_03.sdf
389     \nrc\sdf\other\lct33_04.sdf
390     \nrc\sdf\other\lct33_05.sdf
391     \nrc\sdf\other\lct33_06.sdf
392     \nrc\sdf\other\lct33_07.sdf
393     \nrc\sdf\other\lct33_08.sdf
394     \nrc\sdf\other\lct33_09.sdf
395     \nrc\sdf\other\lct33_10.sdf
396     \nrc\sdf\other\lct33_11.sdf
397     \nrc\sdf\other\lct33_12.sdf
398     \nrc\sdf\other\lct33_13.sdf
399     \nrc\sdf\other\lct33_14.sdf
400     \nrc\sdf\other\lct33_15.sdf
401     \nrc\sdf\other\lct33_16.sdf
402     \nrc\sdf\other\lct33_17.sdf
403     \nrc\sdf\other\lct33_18.sdf
404     \nrc\sdf\other\lct33_19.sdf
405     \nrc\sdf\other\lct33_20.sdf
406     \nrc\sdf\other\lct33_21.sdf
407     \nrc\sdf\other\lct33_22.sdf
```

```
408     \nrc\sdf\other\lct33_23.sdf
409     \nrc\sdf\other\lct33_24.sdf
410     \nrc\sdf\other\lct33_25.sdf
411     \nrc\sdf\other\lct33_26.sdf
412     \nrc\sdf\other\lct33_27.sdf
413     \nrc\sdf\other\lct33_28.sdf
414     \nrc\sdf\other\lct33_29.sdf
415     \nrc\sdf\other\lct33_30.sdf
416     \nrc\sdf\other\lct33_31.sdf
417     \nrc\sdf\other\lct33_32.sdf
418     \nrc\sdf\other\lct33_33.sdf
419     \nrc\sdf\other\lct33_34.sdf
420     \nrc\sdf\other\lct33_35.sdf
421     \nrc\sdf\other\lct33_36.sdf
422     \nrc\sdf\other\lst00801.sdf
423     \nrc\sdf\other\lst00802.sdf
424     \nrc\sdf\other\lst00803.sdf
425     \nrc\sdf\other\lst00804.sdf
        end experiments
        read reactions
        u-233 fission
        u-235 fission
        h-1 scatter
        ca scatter
        o-16 total
        end reactions
        end
```

The other TSUNAMI-IP input decks differ from this one only in line 24 (which follows "read applications"), to designate the base case of interest (normal or contingency).

APPENDIX B: Listing of Best Experiments by Base Case

For use by future investigators, this Appendix contains the list of experiments numbers c_k values for the 6 base cases and the additional bulk damp powder case, in order of decreasing c_k. For each case, only the top 100 experiments are included in the list.

Contingency Base Case 1: Stored UF_6 cylinders

Order	5%		6%		8%		10%	
#	Exp. #	ck	Exp. #	ck	Exp. #	ck	Exp. #	ck
1	132	0.9477	132	0.9403	132	0.9240	132	0.9038
2	133	0.9477	133	0.9397	133	0.9234	133	0.9028
3	278	0.8847	278	0.8776	278	0.8747	278	0.8585
4	277	0.8499	277	0.8416	281	0.8426	281	0.8482
5	130	0.8373	130	0.8232	277	0.8420	269	0.8359
6	281	0.8037	281	0.8150	269	0.8307	277	0.8261
7	269	0.7927	269	0.8029	130	0.8234	130	0.8032
8	402	0.7598	280	0.7603	280	0.7899	280	0.7951
9	405	0.7588	129	0.7528	129	0.7827	129	0.7949
10	403	0.7585	256	0.7377	256	0.7686	256	0.7733
11	404	0.7553	279	0.7363	279	0.7667	279	0.7714
12	406	0.7545	240	0.7325	240	0.7493	271	0.7452
13	280	0.7510	402	0.7261	271	0.7481	240	0.7353
14	240	0.7444	405	0.7254	127	0.7180	127	0.7334
15	410	0.7429	403	0.7248	131	0.7153	16	0.7218
16	408	0.7423	404	0.7220	385	0.7149	131	0.6983
17	386	0.7417	271	0.7212	173	0.7146	173	0.6971
18	409	0.7414	406	0.7211	402	0.7059	385	0.6964
19	387	0.7387	410	0.7016	174	0.7056	174	0.6883
20	388	0.7380	408	0.7010	405	0.7055	175	0.6858
21	389	0.7375	409	0.7002	403	0.7047	17	0.6785
22	129	0.7359	386	0.6989	175	0.7035	179	0.6740
23	256	0.7300	173	0.6985	404	0.7025	19	0.6731
24	279	0.7284	385	0.6978	406	0.7010	176	0.6709
25	271	0.7222	131	0.6974	16	0.6943	177	0.6709
26	385	0.7159	387	0.6963	179	0.6907	402	0.6672
27	173	0.7151	388	0.6956	176	0.6877	405	0.6670
28	131	0.7140	389	0.6952	177	0.6876	18	0.6664
29	234	0.7085	174	0.6887	180	0.6803	403	0.6659
30	235	0.7078	175	0.6870	178	0.6740	180	0.6642
31	174	0.7054	127	0.6816	181	0.6740	404	0.6642
32	175	0.7045	234	0.6737	234	0.6710	60	0.6631
33	236	0.7033	179	0.6736	235	0.6702	406	0.6627
34	411	0.7018	235	0.6729	276	0.6697	128	0.6626

35	233	0.7007	176	0.6697	182	0.6681	21	0.6624
36	414	0.6983	177	0.6690	236	0.6665	181	0.6579
37	214	0.6980	236	0.6686	410	0.6663	276	0.6579
38	238	0.6970	233	0.6660	408	0.6655	178	0.6578
39	412	0.6932	214	0.6638	409	0.6652	20	0.6544
40	413	0.6920	238	0.6625	233	0.6641	182	0.6523
41	179	0.6901	180	0.6623	386	0.6641	187	0.6492
42	237	0.6897	411	0.6590	187	0.6636	189	0.6435
43	215	0.6889	414	0.6558	387	0.6621	186	0.6426
44	392	0.6878	181	0.6556	214	0.6620	188	0.6401
45	391	0.6875	237	0.6553	388	0.6617	22	0.6400
46	232	0.6871	178	0.6548	238	0.6610	61	0.6375
47	176	0.6864	215	0.6548	389	0.6609	62	0.6374
48	177	0.6858	232	0.6529	189	0.6587	126	0.6372
49	390	0.6848	276	0.6520	128	0.6564	234	0.6350
50	216	0.6821	412	0.6513	186	0.6562	235	0.6341
51	222	0.6809	413	0.6502	188	0.6551	236	0.6307
52	180	0.6786	182	0.6486	237	0.6548	233	0.6284
53	196	0.6772	216	0.6481	215	0.6538	214	0.6270
54	217	0.6771	222	0.6470	17	0.6528	238	0.6257
55	193	0.6765	392	0.6451	232	0.6526	2	0.6243
56	195	0.6765	391	0.6449	216	0.6480	257	0.6243
57	194	0.6756	196	0.6442	19	0.6468	1	0.6240
58	218	0.6746	193	0.6436	222	0.6467	121	0.6238
59	223	0.6728	195	0.6435	217	0.6440	237	0.6199
60	197	0.6724	217	0.6431	196	0.6438	215	0.6192
61	181	0.6721	194	0.6427	193	0.6434	410	0.6183
62	178	0.6714	390	0.6424	195	0.6431	232	0.6181
63	192	0.6707	187	0.6406	194	0.6426	408	0.6175
64	191	0.6693	218	0.6406	18	0.6420	409	0.6174
65	199	0.6688	197	0.6396	218	0.6415	386	0.6153
66	415	0.6686	189	0.6394	60	0.6406	216	0.6137
67	219	0.6682	223	0.6391	197	0.6401	387	0.6136
68	182	0.6651	192	0.6379	223	0.6396	388	0.6134
69	220	0.6644	16	0.6375	192	0.6384	222	0.6127
70	416	0.6638	191	0.6365	21	0.6377	389	0.6125
71	127	0.6634	188	0.6358	191	0.6373	196	0.6106
72	276	0.6633	199	0.6358	199	0.6367	193	0.6104
73	224	0.6614	126	0.6356	219	0.6355	217	0.6100
74	419	0.6581	219	0.6345	126	0.6342	195	0.6098
75	418	0.6580	186	0.6324	220	0.6323	194	0.6095
76	417	0.6576	220	0.6308	224	0.6301	218	0.6076
77	187	0.6572	224	0.6278	411	0.6298	197	0.6073
78	198	0.6557	415	0.6253	20	0.6295	223	0.6060

79	221	0.6555	198	0.6229	228	0.6275	192	0.6056
80	189	0.6554	221	0.6223	414	0.6269	118	0.6054
81	228	0.6554	190	0.6218	198	0.6252	191	0.6045
82	190	0.6541	228	0.6218	221	0.6248	199	0.6038
83	188	0.6516	416	0.6212	190	0.6238	219	0.6020
84	420	0.6502	128	0.6170	412	0.6238	183	0.5999
85	394	0.6501	418	0.6161	413	0.6230	272	0.5996
86	393	0.6499	419	0.6161	257	0.6201	220	0.5990
87	186	0.6485	417	0.6154	391	0.6190	224	0.5970
88	421	0.6462	394	0.6077	392	0.6188	275	0.5967
89	395	0.6349	393	0.6076	22	0.6176	120	0.5966
90	397	0.6340	420	0.6070	390	0.6166	228	0.5958
91	227	0.6327	421	0.6034	61	0.6144	241	0.5934
92	396	0.6319	227	0.6008	62	0.6143	198	0.5931
93	407	0.6243	17	0.5944	164	0.6125	221	0.5923
94	126	0.6230	395	0.5923	183	0.6106	190	0.5921
95	398	0.6187	397	0.5915	227	0.6086	164	0.5918
96	128	0.6124	407	0.5909	275	0.6072	184	0.5905
97	203	0.6118	396	0.5896	241	0.6039	371	0.5902
98	164	0.6108	19	0.5888	184	0.6019	58	0.5895
99	16	0.6087	164	0.5860	272	0.6015	361	0.5887
100	399	0.6004	275	0.5857	371	0.6011	115	0.5875

Contingency Base Case 2: UO_2 powder in storage rack arrays

Order #	5% Exp. #	ck	6% Exp. #	ck	8% Exp. #	ck	10% Exp. #	ck
1	130	0.9867	130	0.9772	281	0.9705	281	0.9708
2	277	0.9728	277	0.9699	269	0.9648	269	0.9638
3	278	0.9700	278	0.9694	278	0.9553	280	0.9437
4	133	0.9561	133	0.9571	277	0.9529	129	0.9347
5	240	0.9502	281	0.9558	130	0.9498	278	0.9333
6	132	0.9497	269	0.9519	280	0.9458	256	0.9295
7	281	0.9384	132	0.9512	133	0.9433	279	0.9293
8	269	0.9357	240	0.9412	132	0.9385	277	0.9290
9	173	0.9355	280	0.9351	256	0.9336	133	0.9215
10	131	0.9305	271	0.9281	279	0.9330	130	0.9183
11	174	0.9304	256	0.9257	129	0.9252	132	0.9174
12	385	0.9267	279	0.9247	271	0.9210	271	0.9057
13	271	0.9254	173	0.9206	240	0.9159	127	0.8981
14	175	0.9223	131	0.9158	127	0.8868	240	0.8866
15	179	0.9221	174	0.9153	173	0.8867	16	0.8539
16	280	0.9210	385	0.9111	131	0.8820	173	0.8513
17	176	0.9200	175	0.9072	174	0.8811	131	0.8466
18	177	0.9188	179	0.9071	385	0.8749	174	0.8457
19	180	0.9155	176	0.9046	179	0.8734	179	0.8386
20	256	0.9135	177	0.9033	175	0.8719	276	0.8383
21	279	0.9123	180	0.9005	176	0.8704	385	0.8381
22	181	0.9117	129	0.8999	177	0.8689	175	0.8360
23	178	0.9103	181	0.8963	180	0.8670	176	0.8352
24	182	0.9066	178	0.8947	276	0.8659	128	0.8347
25	189	0.9015	182	0.8911	181	0.8623	177	0.8334
26	276	0.9001	276	0.8905	178	0.8604	180	0.8324
27	188	0.8995	189	0.8864	182	0.8571	181	0.8275
28	234	0.8993	188	0.8846	189	0.8534	17	0.8265
29	235	0.8989	234	0.8649	188	0.8518	19	0.8253
30	214	0.8981	235	0.8644	128	0.8421	178	0.8252
31	236	0.8972	214	0.8641	257	0.8303	182	0.8222
32	233	0.8967	236	0.8628	16	0.8298	257	0.8202
33	238	0.8951	233	0.8622	275	0.8224	189	0.8194
34	215	0.8945	238	0.8608	367	0.8169	188	0.8182
35	196	0.8938	196	0.8606	371	0.8161	60	0.8157
36	193	0.8936	193	0.8605	361	0.8156	18	0.8150
37	195	0.8933	215	0.8603	272	0.8148	21	0.8145
38	194	0.8931	127	0.8602	241	0.8146	1	0.8100
39	232	0.8929	194	0.8600	374	0.8124	2	0.8097
40	237	0.8926	195	0.8600	376	0.8118	20	0.8092

41	216	0.8912	232	0.8586	377	0.8086	61	0.8060
42	197	0.8909	237	0.8582	362	0.8082	62	0.8060
43	192	0.8906	197	0.8578	373	0.8073	121	0.7992
44	222	0.8906	192	0.8575	17	0.8068	272	0.7956
45	191	0.8899	216	0.8570	372	0.8067	275	0.7944
46	199	0.8885	191	0.8567	187	0.8057	22	0.7916
47	223	0.8876	222	0.8566	375	0.8055	371	0.7864
48	218	0.8872	199	0.8552	19	0.8045	361	0.7859
49	217	0.8867	223	0.8536	60	0.8033	118	0.7855
50	219	0.8853	218	0.8530	214	0.8012	241	0.7845
51	190	0.8836	217	0.8524	234	0.8012	367	0.7844
52	220	0.8832	219	0.8512	235	0.8006	374	0.7822
53	198	0.8823	190	0.8507	193	0.7997	376	0.7815
54	224	0.8804	220	0.8491	196	0.7996	120	0.7798
55	221	0.8797	198	0.8489	194	0.7992	362	0.7785
56	129	0.8764	367	0.8487	236	0.7991	377	0.7785
57	402	0.8755	275	0.8486	18	0.7990	373	0.7778
58	406	0.8735	224	0.8462	195	0.7990	372	0.7775
59	405	0.8733	402	0.8462	233	0.7985	115	0.7765
60	403	0.8723	221	0.8458	215	0.7975	375	0.7759
61	404	0.8698	371	0.8447	21	0.7974	58	0.7727
62	367	0.8631	361	0.8443	238	0.7973	187	0.7716
63	275	0.8599	406	0.8442	197	0.7970	114	0.7645
64	371	0.8571	405	0.8440	192	0.7966	59	0.7639
65	361	0.8568	241	0.8433	191	0.7959	368	0.7637
66	241	0.8560	403	0.8429	232	0.7956	369	0.7616
67	187	0.8550	374	0.8418	237	0.7949	363	0.7600
68	374	0.8547	376	0.8413	199	0.7941	117	0.7596
69	376	0.8543	404	0.8405	216	0.7941	364	0.7589
70	377	0.8506	187	0.8397	222	0.7941	119	0.7574
71	362	0.8498	128	0.8396	368	0.7927	113	0.7567
72	164	0.8496	377	0.8378	20	0.7924	116	0.7554
73	373	0.8485	362	0.8371	223	0.7912	230	0.7531
74	372	0.8477	373	0.8359	369	0.7909	370	0.7477
75	375	0.8468	372	0.8352	61	0.7908	231	0.7474
76	228	0.8378	375	0.8342	62	0.7908	186	0.7463
77	230	0.8368	257	0.8326	190	0.7907	193	0.7455
78	127	0.8367	272	0.8292	218	0.7902	196	0.7453
79	203	0.8358	164	0.8244	217	0.7896	214	0.7452
80	386	0.8347	230	0.8210	363	0.7894	194	0.7450
81	388	0.8342	368	0.8209	402	0.7888	195	0.7446
82	209	0.8340	369	0.8194	219	0.7887	234	0.7444
83	368	0.8333	363	0.8182	364	0.7885	235	0.7438
84	389	0.8333	364	0.8176	198	0.7881	197	0.7428

85	272	0.8326	231	0.8156	1	0.7874	192	0.7425
86	387	0.8323	186	0.8124	230	0.7872	236	0.7425
87	369	0.8320	370	0.8082	2	0.7871	233	0.7419
88	231	0.8317	229	0.8065	406	0.7869	191	0.7418
89	128	0.8314	168	0.8054	220	0.7867	215	0.7416
90	363	0.8312	228	0.8040	405	0.7866	238	0.7408
91	210	0.8307	250	0.8033	403	0.7854	250	0.7404
92	364	0.8306	165	0.8011	221	0.7842	199	0.7397
93	204	0.8303	251	0.8009	224	0.7838	232	0.7397
94	257	0.8282	252	0.8001	404	0.7833	239	0.7395
95	205	0.8279	209	0.7998	121	0.7824	229	0.7393
96	211	0.8277	203	0.7990	231	0.7816	222	0.7387
97	200	0.8274	210	0.7965	22	0.7805	237	0.7386
98	186	0.8270	386	0.7954	186	0.7795	216	0.7384
99	206	0.8260	388	0.7952	370	0.7781	251	0.7382
100	165	0.8257	204	0.7941	164	0.7758	190	0.7373

Contingency Base Case 3: Pressed ceramic UO_2 fuel pellets in boxes

Order #	5% Exp. #	ck	6% Exp. #	ck	8% Exp. #	ck	10% Exp. #	ck
1	130	0.9903	130	0.9825	281	0.9785	281	0.9846
2	277	0.9721	277	0.9687	269	0.9728	269	0.9779
3	240	0.9649	240	0.9649	280	0.9724	280	0.9774
4	173	0.9619	281	0.9591	279	0.9668	279	0.9709
5	278	0.9596	173	0.9568	256	0.9658	256	0.9696
6	174	0.9583	271	0.9550	130	0.9611	129	0.9654
7	131	0.9567	278	0.9550	271	0.9604	271	0.9547
8	179	0.9526	269	0.9543	277	0.9551	127	0.9455
9	176	0.9507	174	0.9535	240	0.9518	277	0.9365
10	177	0.9502	280	0.9534	129	0.9500	130	0.9364
11	180	0.9475	131	0.9516	278	0.9410	240	0.9325
12	181	0.9448	179	0.9488	173	0.9359	278	0.9230
13	178	0.9438	279	0.9488	174	0.9328	128	0.9154
14	271	0.9420	256	0.9480	131	0.9306	173	0.9106
15	182	0.9409	176	0.9466	179	0.9293	174	0.9077
16	385	0.9406	177	0.9459	127	0.9272	276	0.9070
17	281	0.9387	180	0.9444	176	0.9267	131	0.9056
18	175	0.9386	181	0.9414	177	0.9257	179	0.9049
19	189	0.9375	178	0.9401	180	0.9256	176	0.9020
20	188	0.9355	182	0.9378	276	0.9243	180	0.9017
21	269	0.9345	189	0.9355	181	0.9224	177	0.9008
22	280	0.9322	276	0.9342	178	0.9205	181	0.8982
23	276	0.9313	188	0.9339	182	0.9188	257	0.8976
24	279	0.9278	385	0.9336	189	0.9180	178	0.8960
25	256	0.9272	175	0.9329	188	0.9171	189	0.8950
26	133	0.9199	129	0.9181	128	0.9113	182	0.8948
27	193	0.9155	133	0.9090	175	0.9113	188	0.8945
28	196	0.9155	275	0.9032	385	0.9104	16	0.8879
29	194	0.9151	132	0.9017	257	0.8968	175	0.8852
30	195	0.9150	367	0.8986	275	0.8946	385	0.8834
31	192	0.9132	371	0.8960	133	0.8895	272	0.8789
32	214	0.9129	361	0.8956	272	0.8859	275	0.8780
33	197	0.9128	241	0.8942	371	0.8859	17	0.8757
34	191	0.9126	376	0.8932	361	0.8854	19	0.8755
35	132	0.9125	374	0.8929	367	0.8853	60	0.8742
36	234	0.9113	128	0.8927	241	0.8845	18	0.8706
37	235	0.9110	127	0.8909	132	0.8824	21	0.8703
38	215	0.9109	193	0.8906	376	0.8823	62	0.8697
39	199	0.9105	196	0.8904	374	0.8820	61	0.8691
40	233	0.9099	194	0.8902	362	0.8793	133	0.8686

41	236	0.9099	195	0.8899	373	0.8789	371	0.8679
42	222	0.9094	362	0.8893	377	0.8789	1	0.8676
43	190	0.9091	377	0.8893	372	0.8779	20	0.8673
44	232	0.9088	373	0.8887	375	0.8764	361	0.8673
45	238	0.9088	192	0.8885	368	0.8651	241	0.8671
46	216	0.9087	191	0.8880	369	0.8640	2	0.8652
47	237	0.9082	197	0.8880	230	0.8639	367	0.8643
48	223	0.9074	372	0.8873	363	0.8628	376	0.8638
49	218	0.9067	375	0.8862	364	0.8614	374	0.8636
50	219	0.9063	190	0.8858	231	0.8600	132	0.8619
51	198	0.9061	199	0.8855	187	0.8581	362	0.8613
52	220	0.9050	214	0.8851	16	0.8575	373	0.8613
53	221	0.9031	215	0.8835	229	0.8552	377	0.8607
54	224	0.9023	222	0.8827	60	0.8524	372	0.8603
55	217	0.8999	234	0.8820	370	0.8512	375	0.8588
56	275	0.8987	198	0.8819	250	0.8489	121	0.8585
57	367	0.8974	257	0.8818	17	0.8483	22	0.8565
58	371	0.8926	216	0.8817	251	0.8476	118	0.8499
59	361	0.8922	235	0.8816	19	0.8473	368	0.8482
60	376	0.8902	232	0.8814	239	0.8471	369	0.8470
61	241	0.8901	223	0.8812	252	0.8470	120	0.8459
62	374	0.8900	272	0.8812	18	0.8461	58	0.8458
63	129	0.8886	233	0.8810	62	0.8455	363	0.8455
64	377	0.8861	236	0.8808	21	0.8448	364	0.8439
65	362	0.8858	238	0.8803	61	0.8448	230	0.8429
66	373	0.8849	219	0.8802	168	0.8433	115	0.8428
67	164	0.8841	237	0.8802	193	0.8426	239	0.8415
68	372	0.8834	218	0.8800	194	0.8421	59	0.8408
69	375	0.8824	220	0.8790	196	0.8421	231	0.8390
70	187	0.8805	230	0.8788	20	0.8420	187	0.8368
71	230	0.8778	221	0.8781	195	0.8415	114	0.8356
72	231	0.8740	187	0.8773	192	0.8407	229	0.8348
73	368	0.8691	224	0.8763	191	0.8402	370	0.8332
74	128	0.8689	231	0.8749	197	0.8401	117	0.8328
75	369	0.8684	368	0.8737	190	0.8397	119	0.8313
76	363	0.8678	217	0.8731	164	0.8396	113	0.8307
77	229	0.8675	369	0.8729	1	0.8384	250	0.8301
78	165	0.8670	164	0.8720	199	0.8374	116	0.8299
79	272	0.8670	363	0.8720	169	0.8361	251	0.8289
80	364	0.8667	364	0.8708	2	0.8360	252	0.8283
81	168	0.8663	229	0.8692	22	0.8357	270	0.8211
82	209	0.8634	168	0.8636	198	0.8346	168	0.8185
83	210	0.8614	370	0.8614	121	0.8337	169	0.8121
84	203	0.8609	250	0.8609	214	0.8335	366	0.8098

85	257	0.8609	251	0.8595	215	0.8323	164	0.8074
86	200	0.8599	252	0.8588	222	0.8322	160	0.8063
87	211	0.8590	165	0.8583	223	0.8314	170	0.8063
88	204	0.8588	169	0.8552	216	0.8308	186	0.8047
89	250	0.8581	170	0.8487	219	0.8304	365	0.8040
90	370	0.8578	166	0.8455	232	0.8301	3	0.8019
91	205	0.8576	160	0.8451	170	0.8300	161	0.8018
92	127	0.8574	186	0.8439	165	0.8299	165	0.8002
93	169	0.8569	171	0.8415	221	0.8297	171	0.7999
94	201	0.8569	209	0.8409	218	0.8295	193	0.7988
95	206	0.8566	239	0.8405	220	0.8295	194	0.7983
96	251	0.8565	161	0.8395	160	0.8286	196	0.7982
97	252	0.8559	210	0.8393	234	0.8286	195	0.7975
98	212	0.8556	200	0.8388	237	0.8282	190	0.7971
99	402	0.8552	167	0.8381	233	0.8281	192	0.7970
100	406	0.8538	211	0.8371	235	0.8281	162	0.7969

Contingency Base Case 4: TRISO pellets in boxes

Order #	5% Exp. #	ck	6% Exp. #	ck	8% Exp. #	ck	10% Exp. #	ck
1	307	0.9483	307	0.9486	307	0.9410	307	0.9257
2	306	0.9229	306	0.9241	306	0.9178	306	0.9036
3	305	0.9201	305	0.9213	305	0.9151	297	0.9019
4	297	0.9143	297	0.9170	297	0.9146	305	0.9010
5	209	0.9134	296	0.9133	296	0.9112	296	0.8988
6	164	0.9103	164	0.9095	164	0.8996	385	0.8867
7	211	0.9103	209	0.9068	356	0.8944	164	0.8860
8	296	0.9103	211	0.9038	385	0.8905	356	0.8835
9	210	0.9099	210	0.9033	168	0.8885	168	0.8801
10	203	0.9097	212	0.9018	295	0.8876	175	0.8778
11	212	0.9083	203	0.9007	209	0.8857	295	0.8773
12	204	0.9061	213	0.8998	211	0.8828	253	0.8750
13	213	0.9061	200	0.8989	165	0.8825	131	0.8732
14	200	0.9052	204	0.8977	253	0.8825	254	0.8721
15	206	0.9037	202	0.8973	210	0.8823	360	0.8718
16	202	0.9035	206	0.8958	360	0.8822	355	0.8716
17	205	0.9035	201	0.8954	355	0.8817	255	0.8695
18	207	0.9022	205	0.8954	175	0.8814	169	0.8692
19	201	0.9016	207	0.8951	212	0.8807	165	0.8689
20	208	0.8969	356	0.8951	254	0.8796	173	0.8661
21	165	0.8916	165	0.8915	213	0.8788	170	0.8645
22	356	0.8911	208	0.8908	200	0.8782	174	0.8643
23	224	0.8907	168	0.8904	169	0.8778	293	0.8631
24	237	0.8897	385	0.8894	255	0.8769	209	0.8629
25	218	0.8889	295	0.8875	202	0.8765	294	0.8628
26	222	0.8886	382	0.8863	131	0.8760	177	0.8627
27	232	0.8883	224	0.8833	382	0.8759	230	0.8612
28	238	0.8879	253	0.8824	203	0.8756	171	0.8608
29	216	0.8876	360	0.8824	201	0.8749	211	0.8598
30	233	0.8876	237	0.8820	204	0.8735	210	0.8594
31	382	0.8875	355	0.8816	170	0.8733	178	0.8588
32	214	0.8874	218	0.8813	207	0.8730	166	0.8587
33	223	0.8872	222	0.8811	293	0.8729	176	0.8587
34	236	0.8871	232	0.8808	294	0.8728	304	0.8582
35	220	0.8868	238	0.8802	206	0.8723	231	0.8579
36	168	0.8865	216	0.8801	205	0.8715	382	0.8579
37	234	0.8863	175	0.8799	166	0.8708	212	0.8576
38	235	0.8863	223	0.8799	208	0.8703	179	0.8574
39	215	0.8862	214	0.8798	171	0.8700	182	0.8563
40	221	0.8858	233	0.8798	173	0.8688	359	0.8561

41	219	0.8854	169	0.8796	174	0.8672	213	0.8558
42	385	0.8850	254	0.8795	304	0.8667	200	0.8556
43	295	0.8830	220	0.8794	177	0.8663	180	0.8540
44	198	0.8800	236	0.8793	384	0.8661	181	0.8537
45	217	0.8786	221	0.8787	359	0.8656	202	0.8537
46	199	0.8783	215	0.8786	230	0.8654	201	0.8524
47	360	0.8781	234	0.8784	178	0.8629	318	0.8524
48	253	0.8777	235	0.8784	231	0.8625	112	0.8518
49	355	0.8771	219	0.8780	167	0.8621	354	0.8514
50	197	0.8768	166	0.8772	176	0.8621	167	0.8507
51	384	0.8761	255	0.8768	224	0.8617	160	0.8505
52	192	0.8759	384	0.8755	179	0.8605	203	0.8503
53	191	0.8758	170	0.8754	318	0.8605	242	0.8498
54	169	0.8757	131	0.8742	182	0.8603	207	0.8492
55	166	0.8756	198	0.8731	237	0.8603	384	0.8490
56	175	0.8751	293	0.8724	354	0.8602	321	0.8489
57	254	0.8748	294	0.8724	222	0.8599	204	0.8488
58	193	0.8742	171	0.8723	218	0.8598	324	0.8486
59	195	0.8740	199	0.8714	232	0.8593	303	0.8485
60	194	0.8738	217	0.8712	242	0.8591	320	0.8479
61	196	0.8738	197	0.8698	160	0.8587	206	0.8478
62	190	0.8725	192	0.8690	216	0.8587	208	0.8476
63	255	0.8721	191	0.8689	214	0.8586	323	0.8473
64	170	0.8714	193	0.8673	223	0.8586	205	0.8470
65	131	0.8700	167	0.8672	238	0.8585	229	0.8462
66	171	0.8684	173	0.8670	112	0.8581	172	0.8454
67	294	0.8678	195	0.8669	233	0.8581	319	0.8452
68	293	0.8676	194	0.8668	220	0.8579	161	0.8450
69	167	0.8649	196	0.8668	221	0.8576	162	0.8449
70	173	0.8626	190	0.8658	236	0.8576	189	0.8448
71	228	0.8624	174	0.8656	181	0.8573	312	0.8444
72	383	0.8614	304	0.8652	215	0.8573	322	0.8442
73	174	0.8613	177	0.8651	180	0.8571	328	0.8437
74	177	0.8609	359	0.8649	321	0.8569	326	0.8432
75	359	0.8601	230	0.8633	234	0.8568	240	0.8430
76	304	0.8598	178	0.8618	235	0.8567	325	0.8430
77	230	0.8577	176	0.8607	303	0.8567	327	0.8429
78	178	0.8576	231	0.8607	219	0.8565	163	0.8421
79	176	0.8563	383	0.8607	324	0.8564	188	0.8413
80	160	0.8558	160	0.8600	320	0.8559	317	0.8403
81	231	0.8552	242	0.8596	323	0.8551	224	0.8398
82	242	0.8551	182	0.8592	172	0.8546	358	0.8398
83	182	0.8548	354	0.8589	161	0.8533	237	0.8388
84	179	0.8543	179	0.8588	162	0.8533	222	0.8385

85	354	0.8537	318	0.8587	319	0.8531	218	0.8382
86	318	0.8532	172	0.8566	198	0.8528	232	0.8380
87	172	0.8526	181	0.8559	322	0.8519	214	0.8376
88	181	0.8515	180	0.8553	328	0.8514	216	0.8373
89	180	0.8508	321	0.8549	199	0.8512	238	0.8373
90	162	0.8504	303	0.8548	383	0.8512	223	0.8372
91	161	0.8503	162	0.8547	163	0.8511	233	0.8368
92	321	0.8493	161	0.8546	326	0.8509	302	0.8368
93	303	0.8492	324	0.8543	229	0.8508	236	0.8365
94	163	0.8489	320	0.8539	325	0.8507	220	0.8362
95	324	0.8486	228	0.8532	327	0.8507	215	0.8361
96	320	0.8483	163	0.8529	197	0.8499	221	0.8360
97	323	0.8472	323	0.8529	217	0.8498	234	0.8358
98	319	0.8454	112	0.8514	192	0.8489	235	0.8356
99	112	0.8444	319	0.8511	191	0.8488	381	0.8353
100	322	0.8439	322	0.8497	312	0.8485	219	0.8349

Contingency Base Case 5: UO_2, zircaloy clad fuel pin array in shipping cask

Order #	5% Exp. #	ck	6% Exp. #	ck	8% Exp. #	ck	10% Exp. #	ck
1	133	0.9733	278	0.9728	278	0.9573	281	0.9462
2	132	0.9707	133	0.9660	133	0.9512	269	0.9377
3	278	0.9621	277	0.9625	132	0.9484	278	0.9344
4	277	0.9453	132	0.9623	281	0.9455	133	0.9292
5	130	0.9439	130	0.9558	277	0.9449	132	0.9270
6	385	0.8790	281	0.9298	269	0.9377	277	0.9206
7	240	0.8768	269	0.9233	130	0.9289	280	0.9113
8	173	0.8757	240	0.9046	280	0.9128	129	0.9016
9	281	0.8754	280	0.9003	256	0.8985	130	0.8984
10	234	0.8742	173	0.8946	279	0.8969	256	0.8955
11	235	0.8738	385	0.8925	129	0.8925	279	0.8941
12	131	0.8735	131	0.8919	271	0.8841	271	0.8706
13	236	0.8708	271	0.8886	240	0.8815	127	0.8597
14	233	0.8693	256	0.8884	173	0.8619	240	0.8542
15	269	0.8689	174	0.8880	131	0.8589	16	0.8303
16	175	0.8685	279	0.8866	385	0.8581	173	0.8283
17	174	0.8681	175	0.8855	174	0.8552	131	0.8254
18	214	0.8680	179	0.8777	175	0.8523	385	0.8242
19	238	0.8667	177	0.8751	127	0.8482	174	0.8216
20	237	0.8626	176	0.8747	179	0.8456	175	0.8193
21	215	0.8612	180	0.8692	176	0.8420	179	0.8126
22	232	0.8602	129	0.8657	177	0.8420	176	0.8086
23	216	0.8568	178	0.8653	180	0.8374	177	0.8084
24	222	0.8568	181	0.8650	276	0.8338	276	0.8074
25	179	0.8550	182	0.8609	181	0.8326	180	0.8047
26	177	0.8539	276	0.8565	178	0.8323	128	0.8014
27	176	0.8526	189	0.8526	182	0.8283	17	0.7998
28	218	0.8521	234	0.8501	189	0.8212	181	0.7997
29	223	0.8506	235	0.8497	188	0.8183	178	0.7990
30	217	0.8491	188	0.8492	128	0.8071	19	0.7970
31	196	0.8487	214	0.8476	16	0.8056	182	0.7954
32	193	0.8483	236	0.8475	234	0.7868	18	0.7916
33	195	0.8482	233	0.8465	235	0.7863	189	0.7891
34	194	0.8475	238	0.8446	257	0.7853	21	0.7877
35	219	0.8468	215	0.8422	187	0.7851	60	0.7867
36	197	0.8457	237	0.8418	214	0.7851	188	0.7866
37	180	0.8449	232	0.8408	236	0.7843	20	0.7833
38	192	0.8448	222	0.8392	275	0.7837	257	0.7773
39	220	0.8446	216	0.8385	233	0.7833	22	0.7703
40	199	0.8440	193	0.8359	238	0.7817	61	0.7671
41	191	0.8436	196	0.8359	215	0.7799	62	0.7670
42	224	0.8435	195	0.8354	17	0.7791	1	0.7659
43	178	0.8425	194	0.8351	237	0.7788	2	0.7659

44	280	0.8409	218	0.8345	232	0.7783	121	0.7624
45	181	0.8408	223	0.8345	222	0.7771	275	0.7575
46	271	0.8397	197	0.8334	216	0.7762	187	0.7535
47	221	0.8377	192	0.8328	193	0.7759	272	0.7530
48	182	0.8368	191	0.8318	196	0.7758	118	0.7479
49	402	0.8356	199	0.8313	19	0.7754	371	0.7459
50	198	0.8353	219	0.8310	195	0.7752	361	0.7454
51	405	0.8351	217	0.8309	194	0.7751	241	0.7432
52	403	0.8337	220	0.8291	18	0.7744	374	0.7422
53	406	0.8322	224	0.8277	197	0.7733	376	0.7419
54	190	0.8321	221	0.8245	192	0.7728	367	0.7410
55	404	0.8311	198	0.8244	223	0.7727	120	0.7407
56	256	0.8284	190	0.8237	371	0.7726	377	0.7386
57	279	0.8261	127	0.8194	60	0.7723	362	0.7369
58	189	0.8254	187	0.8183	218	0.7722	373	0.7364
59	188	0.8207	164	0.8167	361	0.7721	375	0.7356
60	276	0.8194	402	0.8132	191	0.7718	372	0.7352
61	228	0.8145	405	0.8119	199	0.7709	115	0.7351
62	164	0.8140	403	0.8105	241	0.7705	186	0.7327
63	386	0.8127	406	0.8105	367	0.7703	234	0.7322
64	203	0.8119	404	0.8082	272	0.7695	235	0.7316
65	388	0.8105	275	0.8073	374	0.7694	58	0.7314
66	387	0.8101	128	0.8025	21	0.7693	214	0.7314
67	389	0.8100	367	0.7984	376	0.7693	236	0.7298
68	410	0.8047	371	0.7978	219	0.7691	233	0.7288
69	408	0.8039	361	0.7973	217	0.7689	238	0.7275
70	409	0.8035	241	0.7959	164	0.7681	215	0.7263
71	187	0.7984	186	0.7955	220	0.7672	164	0.7255
72	204	0.7984	374	0.7954	224	0.7656	237	0.7248
73	129	0.7941	376	0.7953	377	0.7656	232	0.7247
74	209	0.7941	228	0.7947	20	0.7652	193	0.7239
75	205	0.7922	377	0.7914	190	0.7645	222	0.7239
76	411	0.7909	203	0.7907	198	0.7643	230	0.7237
77	206	0.7886	362	0.7890	362	0.7637	196	0.7236
78	414	0.7884	373	0.7881	221	0.7633	194	0.7231
79	210	0.7880	375	0.7873	186	0.7631	195	0.7229
80	392	0.7877	230	0.7861	373	0.7629	59	0.7227
81	391	0.7866	372	0.7861	375	0.7621	216	0.7227
82	211	0.7851	165	0.7843	372	0.7614	197	0.7214
83	390	0.7845	257	0.7840	402	0.7585	368	0.7210
84	412	0.7833	209	0.7830	22	0.7574	192	0.7208
85	413	0.7823	204	0.7818	405	0.7570	114	0.7205
86	200	0.7813	168	0.7807	406	0.7558	191	0.7199
87	212	0.7793	272	0.7801	403	0.7555	223	0.7198
88	186	0.7783	231	0.7799	230	0.7547	369	0.7198
89	415	0.7760	210	0.7782	404	0.7535	199	0.7188
90	207	0.7750	205	0.7776	62	0.7503	218	0.7188
91	201	0.7748	211	0.7755	61	0.7502	364	0.7181
92	213	0.7744	206	0.7750	231	0.7483	363	0.7178

93	227	0.7743	200	0.7739	368	0.7466	231	0.7171
94	165	0.7731	368	0.7710	369	0.7457	219	0.7160
95	416	0.7719	369	0.7706	121	0.7445	217	0.7157
96	202	0.7717	212	0.7705	364	0.7444	117	0.7147
97	420	0.7665	364	0.7698	363	0.7439	220	0.7142
98	417	0.7664	250	0.7695	1	0.7433	190	0.7134
99	419	0.7663	363	0.7690	2	0.7431	198	0.7126
100	418	0.7661	201	0.7689	168	0.7428	224	0.7126

Contingency Base Case 6: Graphite-moderated TRISO fuel pins in hexagonal lattice

Order	5%		6%		8%		10%	
#	Exp. #	ck	Exp. #	ck	Exp. #	ck	Exp. #	ck
1	385	0.9293	385	0.9336	385	0.9302	385	0.9162
2	175	0.9227	175	0.9275	175	0.9244	175	0.9109
3	209	0.9129	131	0.9127	131	0.9111	131	0.8991
4	164	0.9118	173	0.9091	173	0.9076	269	0.8990
5	210	0.9099	164	0.9089	174	0.9051	240	0.8965
6	211	0.9095	174	0.9071	177	0.9010	173	0.8955
7	131	0.9086	177	0.9039	240	0.9009	271	0.8946
8	222	0.9083	209	0.9026	179	0.9003	174	0.8927
9	212	0.9074	179	0.9025	176	0.8994	281	0.8923
10	214	0.9074	176	0.9021	178	0.8973	130	0.8881
11	223	0.9074	178	0.9007	180	0.8965	177	0.8879
12	237	0.9074	307	0.9004	182	0.8952	179	0.8877
13	200	0.9073	210	0.8998	181	0.8950	176	0.8865
14	224	0.9073	168	0.8996	130	0.8932	256	0.8863
15	232	0.9073	211	0.8994	164	0.8912	180	0.8839
16	216	0.9067	180	0.8989	168	0.8885	178	0.8838
17	218	0.9065	182	0.8986	189	0.8865	280	0.8834
18	203	0.9064	181	0.8980	271	0.8862	181	0.8819
19	238	0.9064	200	0.8975	188	0.8843	182	0.8819
20	215	0.9062	212	0.8974	230	0.8799	279	0.8796
21	233	0.9060	222	0.8964	169	0.8791	189	0.8738
22	213	0.9059	213	0.8961	307	0.8791	188	0.8719
23	236	0.9055	223	0.8957	165	0.8771	168	0.8697
24	173	0.9049	224	0.8956	269	0.8759	164	0.8665
25	220	0.9049	201	0.8952	231	0.8757	230	0.8661
26	201	0.9047	214	0.8952	170	0.8746	277	0.8645
27	221	0.9047	232	0.8952	209	0.8731	231	0.8614
28	234	0.9047	237	0.8950	166	0.8715	169	0.8603
29	235	0.9047	165	0.8949	210	0.8702	276	0.8589
30	202	0.9044	202	0.8948	211	0.8697	374	0.8578
31	219	0.9041	216	0.8947	222	0.8696	376	0.8575
32	204	0.9038	218	0.8945	171	0.8694	377	0.8571
33	206	0.9029	215	0.8940	214	0.8689	371	0.8568
34	207	0.9029	240	0.8940	223	0.8688	170	0.8556
35	174	0.9028	238	0.8939	374	0.8688	375	0.8553
36	205	0.9027	221	0.8934	376	0.8685	361	0.8552
37	198	0.9020	233	0.8933	232	0.8683	241	0.8540
38	307	0.9013	220	0.8932	200	0.8682	165	0.8528
39	199	0.9010	236	0.8927	224	0.8681	362	0.8524

40	197	0.8998	203	0.8926	237	0.8680	367	0.8523
41	177	0.8997	219	0.8924	377	0.8680	307	0.8520
42	208	0.8991	207	0.8922	216	0.8678	278	0.8515
43	192	0.8990	234	0.8919	281	0.8678	373	0.8515
44	191	0.8987	235	0.8919	256	0.8677	229	0.8504
45	193	0.8981	198	0.8911	306	0.8676	171	0.8501
46	179	0.8978	204	0.8910	212	0.8675	272	0.8496
47	195	0.8978	206	0.8908	215	0.8674	166	0.8490
48	176	0.8977	169	0.8904	218	0.8674	372	0.8488
49	194	0.8977	205	0.8903	238	0.8671	370	0.8485
50	196	0.8977	199	0.8899	371	0.8670	364	0.8484
51	217	0.8973	208	0.8899	233	0.8665	257	0.8481
52	165	0.8965	189	0.8894	213	0.8663	253	0.8472
53	190	0.8964	197	0.8888	221	0.8663	369	0.8472
54	178	0.8963	192	0.8879	236	0.8661	160	0.8465
55	168	0.8958	191	0.8877	201	0.8659	368	0.8454
56	180	0.8941	306	0.8877	220	0.8659	254	0.8450
57	182	0.8940	166	0.8874	375	0.8658	363	0.8448
58	181	0.8934	188	0.8871	361	0.8657	128	0.8432
59	306	0.8871	193	0.8871	234	0.8654	255	0.8425
60	166	0.8864	194	0.8866	305	0.8654	306	0.8421
61	169	0.8864	195	0.8866	235	0.8653	161	0.8414
62	240	0.8859	196	0.8865	253	0.8653	162	0.8414
63	305	0.8848	170	0.8863	276	0.8653	167	0.8407
64	189	0.8844	190	0.8859	202	0.8652	366	0.8402
65	170	0.8823	230	0.8858	219	0.8652	305	0.8400
66	188	0.8819	130	0.8857	198	0.8649	250	0.8390
67	130	0.8812	305	0.8854	160	0.8646	275	0.8384
68	230	0.8794	217	0.8853	229	0.8646	187	0.8380
69	382	0.8786	231	0.8820	367	0.8644	209	0.8379
70	171	0.8774	171	0.8815	199	0.8640	172	0.8372
71	231	0.8758	167	0.8770	241	0.8635	251	0.8362
72	167	0.8750	253	0.8770	197	0.8633	222	0.8358
73	384	0.8739	382	0.8764	254	0.8631	252	0.8356
74	228	0.8734	160	0.8755	362	0.8631	214	0.8353
75	253	0.8721	254	0.8748	280	0.8626	210	0.8350
76	160	0.8708	384	0.8725	192	0.8624	223	0.8349
77	254	0.8699	255	0.8723	167	0.8622	211	0.8344
78	255	0.8673	162	0.8710	277	0.8622	232	0.8344
79	162	0.8661	229	0.8710	191	0.8621	60	0.8342
80	161	0.8657	374	0.8708	373	0.8621	163	0.8342
81	229	0.8647	161	0.8705	193	0.8618	216	0.8338
82	172	0.8635	376	0.8705	207	0.8614	237	0.8338
83	374	0.8628	377	0.8701	194	0.8613	224	0.8337

84	376	0.8626	371	0.8683	196	0.8612	215	0.8336
85	377	0.8620	172	0.8681	195	0.8611	200	0.8333
86	383	0.8609	375	0.8676	279	0.8608	218	0.8332
87	367	0.8602	367	0.8674	370	0.8608	238	0.8331
88	371	0.8601	361	0.8671	255	0.8606	365	0.8327
89	163	0.8600	271	0.8656	208	0.8605	233	0.8325
90	375	0.8593	362	0.8650	190	0.8603	221	0.8324
91	361	0.8589	370	0.8650	203	0.8600	212	0.8321
92	370	0.8569	163	0.8647	364	0.8598	236	0.8321
93	362	0.8568	241	0.8643	162	0.8597	198	0.8319
94	241	0.8561	373	0.8639	161	0.8595	220	0.8317
95	373	0.8556	364	0.8628	372	0.8593	234	0.8316
96	364	0.8544	276	0.8612	206	0.8591	235	0.8314
97	276	0.8529	372	0.8610	204	0.8590	199	0.8313
98	372	0.8526	369	0.8604	217	0.8585	201	0.8311
99	369	0.8519	228	0.8595	205	0.8584	213	0.8311
100	187	0.8508	383	0.8592	369	0.8580	219	0.8311

Bulk Damp Powder Case

Order #	5% Exp. #	ck	6% Exp. #	ck	8% Exp. #	ck	10% Exp. #	ck
1	278	0.9668	278	0.9557	281	0.9334	281	0.9155
2	130	0.9642	277	0.9491	278	0.9208	129	0.9013
3	277	0.9639	133	0.9415	269	0.9196	269	0.8999
4	133	0.9499	130	0.9407	133	0.9115	278	0.8839
5	132	0.9449	281	0.9401	129	0.9102	133	0.8783
6	281	0.9319	132	0.9376	132	0.9092	280	0.8773
7	269	0.9228	269	0.9291	277	0.9087	132	0.8771
8	240	0.9090	280	0.9119	280	0.8991	277	0.8682
9	280	0.9080	129	0.9046	130	0.8878	279	0.8577
10	279	0.8958	279	0.8975	279	0.8814	256	0.8532
11	256	0.8928	256	0.8940	256	0.8773	127	0.8517
12	271	0.8919	240	0.8852	127	0.8603	130	0.8390
13	129	0.8882	271	0.8817	271	0.8484	271	0.8133
14	173	0.8879	173	0.8569	240	0.8321	16	0.7922
15	131	0.8843	127	0.8550	173	0.7939	240	0.7838
16	174	0.8825	131	0.8535	131	0.7912	128	0.7571
17	179	0.8743	174	0.8511	174	0.7878	1	0.7536
18	176	0.8718	179	0.8429	276	0.7863	19	0.7529
19	177	0.8707	276	0.8403	16	0.7858	2	0.7517
20	180	0.8677	176	0.8400	128	0.7831	17	0.7514
21	276	0.8652	177	0.8388	179	0.7795	173	0.7393
22	181	0.8636	180	0.8363	176	0.7761	276	0.7380
23	178	0.8626	181	0.8317	177	0.7749	131	0.7372
24	182	0.8588	178	0.8305	180	0.7730	174	0.7331
25	189	0.8560	182	0.8268	181	0.7678	21	0.7328
26	385	0.8560	189	0.8246	178	0.7664	60	0.7301
27	175	0.8532	385	0.8226	182	0.7630	18	0.7297
28	188	0.8532	188	0.8219	189	0.7616	62	0.7283
29	127	0.8394	175	0.8203	188	0.7592	61	0.7281
30	196	0.8357	128	0.8046	385	0.7568	20	0.7264
31	193	0.8354	275	0.7910	175	0.7551	179	0.7249
32	194	0.8351	196	0.7845	1	0.7518	176	0.7212
33	195	0.8351	193	0.7843	19	0.7509	177	0.7199
34	234	0.8347	194	0.7840	17	0.7501	180	0.7185
35	235	0.8340	195	0.7839	2	0.7500	257	0.7143
36	214	0.8334	234	0.7823	257	0.7461	181	0.7130
37	236	0.8318	235	0.7815	60	0.7362	178	0.7115
38	197	0.8316	214	0.7813	275	0.7345	121	0.7109
39	192	0.8315	187	0.7809	21	0.7343	182	0.7083
40	233	0.8312	197	0.7804	62	0.7326	189	0.7075

41	191	0.8307	192	0.7802	61	0.7323	188	0.7053
42	215	0.8297	191	0.7795	18	0.7322	385	0.7006
43	238	0.8292	236	0.7793	20	0.7284	175	0.6993
44	199	0.8278	233	0.7786	187	0.7246	118	0.6946
45	232	0.8270	215	0.7774	272	0.7173	22	0.6945
46	237	0.8269	238	0.7766	121	0.7151	115	0.6887
47	222	0.8259	199	0.7763	371	0.7109	120	0.6881
48	216	0.8258	257	0.7762	241	0.7103	58	0.6853
49	190	0.8245	232	0.7745	361	0.7098	275	0.6852
50	218	0.8225	237	0.7743	367	0.7097	114	0.6780
51	223	0.8223	222	0.7736	374	0.7049	187	0.6772
52	219	0.8212	190	0.7735	376	0.7042	272	0.6769
53	198	0.8204	216	0.7734	186	0.7022	59	0.6739
54	220	0.8192	367	0.7732	22	0.7017	117	0.6727
55	275	0.8182	371	0.7705	362	0.7016	119	0.6712
56	217	0.8175	218	0.7700	373	0.7011	113	0.6710
57	221	0.8163	223	0.7699	377	0.7004	116	0.6694
58	402	0.8156	361	0.7696	118	0.7003	241	0.6596
59	224	0.8153	241	0.7691	372	0.6997	371	0.6596
60	405	0.8141	198	0.7688	375	0.6972	361	0.6583
61	406	0.8140	219	0.7687	193	0.6946	186	0.6578
62	403	0.8131	402	0.7681	196	0.6946	367	0.6555
63	404	0.8109	220	0.7667	194	0.6941	374	0.6530
64	187	0.8095	405	0.7667	120	0.6939	376	0.6523
65	128	0.8075	406	0.7664	195	0.6939	362	0.6501
66	367	0.8052	403	0.7656	58	0.6930	373	0.6499
67	371	0.8001	217	0.7654	115	0.6926	377	0.6487
68	361	0.7993	374	0.7654	234	0.6907	372	0.6485
69	241	0.7981	376	0.7648	197	0.6906	375	0.6460
70	374	0.7957	221	0.7641	192	0.6903	368	0.6317
71	376	0.7951	404	0.7636	214	0.6901	369	0.6292
72	362	0.7916	224	0.7627	235	0.6898	363	0.6271
73	377	0.7909	362	0.7616	191	0.6896	3	0.6254
74	373	0.7907	373	0.7609	236	0.6877	239	0.6239
75	372	0.7892	377	0.7607	233	0.6868	364	0.6239
76	375	0.7868	272	0.7606	199	0.6860	193	0.6238
77	257	0.7853	16	0.7600	215	0.6860	196	0.6237
78	186	0.7819	372	0.7595	238	0.6849	194	0.6233
79	272	0.7788	375	0.7570	190	0.6840	195	0.6230
80	164	0.7785	186	0.7550	232	0.6830	68	0.6222
81	386	0.7764	368	0.7421	402	0.6829	77	0.6206
82	388	0.7760	369	0.7400	368	0.6826	197	0.6197
83	389	0.7752	363	0.7387	237	0.6825	192	0.6194
84	228	0.7751	164	0.7360	114	0.6824	191	0.6188

85	387	0.7745	364	0.7359	59	0.6823	234	0.6187
86	368	0.7719	230	0.7342	222	0.6823	214	0.6183
87	369	0.7700	1	0.7334	216	0.6818	235	0.6177
88	408	0.7699	17	0.7322	405	0.6817	230	0.6159
89	410	0.7694	19	0.7321	406	0.6812	236	0.6156
90	363	0.7691	2	0.7317	403	0.6805	199	0.6150
91	409	0.7691	231	0.7296	369	0.6802	126	0.6146
92	230	0.7674	60	0.7293	404	0.6787	233	0.6146
93	364	0.7665	228	0.7256	223	0.6785	402	0.6142
94	231	0.7631	250	0.7239	198	0.6784	215	0.6141
95	203	0.7610	229	0.7235	218	0.6784	190	0.6135
96	229	0.7568	62	0.7232	363	0.6784	82	0.6134
97	250	0.7553	61	0.7227	117	0.6783	405	0.6131
98	204	0.7549	251	0.7223	219	0.6772	238	0.6128
99	209	0.7539	370	0.7221	119	0.6765	406	0.6124
100	251	0.7537	252	0.7213	113	0.6759	403	0.6118